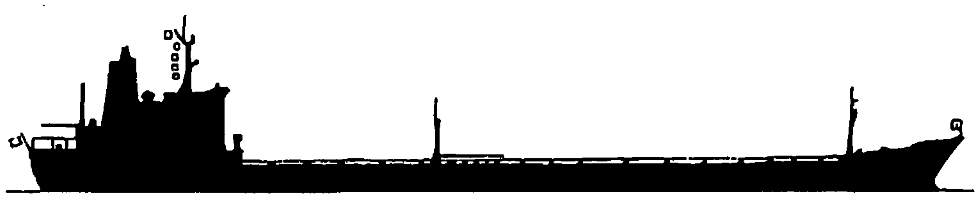
DOT-CG-N-01-91-1.4
DOT-VNTSC-CG-91-2.III

Port Needs Study
(Vessel Traffic Services Benefits)
Volume III

Research and Special Programs
Administration
John A. Volpe National
Transportation Systems Center
Cambridge MA 02142-1093

August 1991



This document is available to the public
through the National Technical Information
Service, Springfield, VA 22161

U.S. Department
of Transportation
United States
Coast Guard
Office of Navigation Safety and Waterway Services
Washington DC 20593

Tai K. Liu
494-2456

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-CG-N-01-91-1.4		

4. Title and Subtitle	5. Report Date
PORT NEEDS STUDY (Vessel Traffic Services Benefits) Vol. III - Technical Supplement	August 1991
	6. Performing Organization Code DTS-41
7. Author(s) D. Maio, et al	8. Performing Organization Report No. DOT-VNTSC-CG-91-2.III
9. Performing Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration John A. Volpe National Transportation Systems Center Cambridge, MA 02142-1093	10. Work Unit No. (TRAIS) CG1A1/B1039
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Office of Navigation Safety and Waterway Services Washington, DC 20593	13. Type of Report and Period Covered Final Report February 1990-July 1991
	14. Sponsoring Agency Code GNSP

15. Supplementary Notes

16. Abstract

This study documents the benefits and costs of potential U.S. Coast Guard Vessel Traffic Services (VTS) in selected U.S. deep water ports on the Atlantic, Gulf and Pacific Coasts. The U.S. Department of Transportation's Research and Special Programs Administration's Volpe National Transportation Systems Center (VNTSC) conducted the study for the U.S. Coast Guard, Office of Navigation Safety and Waterway Service, Special Projects Staff. The entire study is documented in three separately bound volumes plus a separate Study Overview. Volume I is the main document covering all aspects of the input data, analysis methods, and results. The focus of Volume I is presentation of information across all 23 study zones concurrently. Volume II focuses on organization and presentation of information for each individual study zone. It contains the appendix tables of input data, output statistics and the documentation of the candidate Vessel Traffic Services (VTS) Design by NavCom Systems. Volume III is a compendium of technical papers on data sources, analytical methods, and models supplementing material in Volume I.

17. Key Words	18. Distribution Statement
Vessel Traffic Service, Navigational Risk, Benefit-Cost Analysis, Risk Model, Vessel Casualties, Oil Spill Impacts, Vessel Casualty Consequences	DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VA 22161

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	714	

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)
1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)
1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)
1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)
1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)
$[(x - 32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)
1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)
1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)
1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)
1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)
$[(9/5)\,y + 32]$ °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

TABLE OF CONTENTS

OVERVIEW

The U.S. Coast Guard Port Needs Study - Vessel Traffic Services Benefits Study of 1991, is documented in three volumes. Volume I is the principal report. Volume II is the Appendix containing tables of input data and output statistics of the integrated model as well as the details of the Candidate VTS Design development and cost estimates, by NavCom Systems, Inc. for each of the 23 study zones.

This Volume III is a compendium of technical papers documenting separate elements of the study conducted by VNTSC analysts Judith C. Schwenk and Tai-Kuo Liu, Phillip Howells and Philip Pitha, Unisys and off-site contractors Jack Faucett Associates, A.T. Kearney, Inc., Eastern Research Group, Inc., and NavCom Systems, Inc. These technical papers presented as sections of Volume III, provide detailed explanations of the analytical procedures, input data sources, models and assumptions that produced the results presented in Volumes I and II.

Section 1 - COMMODITY AND VESSEL TRAFFIC FORECASTS (prepared by Jack Faucett Associates) describes the procedures used to develop vessel transits and commodity tonnage estimates for the base period 1979-1989 and for the forecast period 1995-2010. Distributions of commodities carried by vessel type and size are detailed.

Section 2 - EFFECTIVENESS OF VESSEL TRAFFIC SERVICE SYSTEMS IN REDUCING VESSEL ACCIDENTS (prepared by A.T. Kearney, Inc.) describes the literature review, and development of estimates of VTS effectiveness in reducing vessel casualties. VTS Effectiveness Factors are integrated into the process of projecting vessel casualties avoided by VTS.

Section 3 - NAVIGATIONAL RISK MODEL DEVELOPMENT (prepared by Tai-Kuo Liu, DTS 42) describes the analysis of historical vessel casualties and their causes and the development of a navigational risk model used to project future vessel casualties in each of 99 study subzones.

Section 4 - VTS DESIGN FINAL REPORT (prepared by NavCom Systems, Inc.) describes the field surveys, engineering judgement of local needs, selection of surveillance modules and cost estimating procedures applied consistently across all 23 study zone candidate VTS Designs.

OVERVIEW (Cont.)

Section 5 - VTS TECHNOLOGY SURVEY (prepared by NavCom Systems, Inc.) describes the review of international developments in the state-of-the-art VTS technologies and their applications. This section documents the technical descriptions and costs of the 18 surveillance modules from which selections were made to postulate an integrated Candidate VTS Design for each study zone.

Section 6 - UNIT COSTS OF VESSEL CASUALTY CONSEQUENCES (prepared by Judith C. Schwenk, DTS 49) describes methods and sources used to develop the unit cost factors for each human, environmental and material loss that is a consequence of vessel casualties and spills of hazardous commodities.

Section 7 - ESTIMATES OF COSTS ASSOCIATED WITH OIL AND HAZARDOUS CHEMICAL SPILLS AND COSTS OF IDLE RESOURCES DURING VESSEL REPAIR (prepared by Eastern Research Group, Inc.) describes the input data sources, analytical methods and assumptions used to estimate costs associated with both spill clean-up costs and the opportunity cost of idle damaged vessels.

Section 8 - THE CONSEQUENCES OF CASUALTIES AFFECTING LNG AND LPG TANKERS (prepared by Jack Faucett Associates) describes the sources and methods of estimating the probability of spills of LNG and LPG from specialized tankers and the expected losses from fire and/or explosion that accompany such gas spills.

Section 9 - INTEGRATED MODEL FOR PROJECTING VTS AVOIDED VESSEL CASUALTIES, CONSEQUENCES, LOSSES, BENEFITS AND VTS COSTS (prepared by Philip Howells and Philip Pitha [UNISYS]) describes the model which stores all the historical traffic, casualty and consequence input data, calculates all the projected avoided vessel casualties, consequences, the benefits and costs of the candidate VTS design and the existing VTS systems. The integrated model pulls together the data and algorithms by all the project analysis areas into a single analytical tool.

SECTION 1.

COMMODITY AND VESSEL TRAFFIC FORECASTS

Prepared For:

The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Prepared By:

Jack Faucett Associates
4550 Montgomery Avenue
Suite 300 North
Bethesda, MD 20814
March 1991

1. COMMODITY AND VESSEL TRAFFIC FORECASTS

NOTE: This section documents the Jack Faucett Associates effort performed in support of Sections 3 and 5 (Volume I) of the Port Needs Study under Contract DTRS-57-89-D-00089, OMNI Task Number RA0012.

SECTION 1. TABLE OF CONTENTS

Page

LIST OF EXHIBITS

INTRODUCTION

This section describes the procedures used for developing commodity and freight-vessel traffic estimates for nine historic years (1979-1986 and 1988) and for four forecast years (1995, 2000, 2005 and 2010) from 1987 base year data. These estimates and forecasts were developed, by vessel type, for each of 23 study "zones" for which new or upgraded VTS capabilities are being considered. Corresponding estimates and forecasts for passenger vessels are developed separately and documented elsewhere.

This section contains six subsections. Following this introduction is a chapter describing the development of a 1987 base-year commodity-traffic file from: U.S. Army Corps of Engineers (COE) commodity data; study base-year vessel-traffic file (also derived from COE data); and other sources. Chapter 3 describes the development of commodity and freight-vessel traffic estimates required for other historic years. The next two chapters describe the development of corresponding commodity and vessel traffic forecasts for 1995, 2000, 2005 and 2010. The final chapter presents related data and procedural information required for estimating cargo losses that result from vessel casualties.

BASE-YEAR COMMODITY DATA

Base-year (1987) commodity data were obtained primarily from the U.S. Army Corps of Engineers (COE) commodity file for 1987. This file contains tons of traffic by COE commodity code (Comcode), waterway code, "direction", and type of movement (foreign, coastwise, or internal/local).

All commodity analyses described in this report were performed at the COE Comcode level. At the end of these analyses, base-year, historic-year, and forecast-year commodity traffic data were aggregated to the VTS Comcode level for subsequent processing in the integrated model. The COE commodity codes are listed in Exhibit 2.1. They can be seen to correspond generally to the four-digit Standard Transportation Commodity Classification (STCC) codes.

The waterway codes generally designate a section of a waterway that usually contains a port, a portion of a major port, or several minor ports. There are one or more waterway codes corresponding to every study zone except the Santa Barbara Channel (Zone 4).

The "directional" information contained on each record distinguishes shipments, receipts, local traffic (i.e., traffic that is local to the waterway section), cross-river traffic, and through traffic. Through traffic is further distinguished by direction: upbound and downbound (for rivers); inbound and outbound (for harbor entrances and other waterways where this meaning is unambiguous); or north or eastbound and south or westbound (for other waterways).

To use the COE commodity file in our analyses, several steps were required:

- The two digits of directional information were collapsed to correspond to the single digit contained in the corresponding vessel file;

- Commodity movements were assigned to (or allocated among) shipment types, vessel types, and vessel sizes; and

- Estimates of commodity movements through the Santa Barbara Channel were developed.

EXHIBIT 2.1

CORPS OF ENGINEERS' COMMODITY CODES

Code No.	Item Name
	Group 01-Farm Products
0101	Cotton, raw
0102	Barley and rye
0103	Corn
0104	Oats
0105	Rice
0106	Sorghum Grains
0107	Wheat
0111	Soybeans
0112	Flaxseed
0119	Oilseeds, not elsewhere classified
0121	Tobacco, leaf
0122	Hay and Fodder
0129	Field crops, not elsewhere classified
0131	Fresh fruits
0132	Bananas and plantains
0133	Coffee, green and roasted (including instant)
0134	Cocoa beans
0141	Fresh and frozen vegetables
0151	Live animals (livestock) except zoo animals, cats, dogs, etc.
0161	Animals and animal products, not elsewhere classified
0191	Miscellaneous farm products
	Group 08-Forest Products
0841	Crude rubber and allied gums
0861	Forest products, not elsewhere classified
	Group 09-Fresh Fish and Other Marine Products
0911	Fresh fish, except shellfish
0912	Shellfish, except prepared or preserved
0913	Menhaden
0931	Marine shells, unmanufactured
	Group 10-Metallic Ores
1011	Iron ore and concentrates
1021	Copper ore and concentrates
1051	Bauxite and other aluminum ores and concentrates
1061	Manganese ores and concentrates
1091	Nonferrous metal ores and concentrates, not elsewhere classified
	Group 11-Coal
1121	Coal and lignite
	Group 13-Crude Petroleum
1311	Crude petroleum

EXHIBIT 2.1

CORPS OF ENGINEERS' COMMODITY CODES – (Continued)

Code No.	Item Name
	Group 14-Nonmetallic Minerals, Except Fuels
1411	Limestone flux and calcareous stone
1412	Building stone, unworked
1442	Sand, gravel and crushed rock
1451	Clay, ceramic and refractory materials
1471	Phosphate rock
1479	Natural fertilizer materials, not elsewhere classified
1491	Salt
1492	Sulphur, dry
1493	Sulphur, liquid
1494	Gypsum, crude and plasters
1499	Nonmetallic minerals, except fuels, not elsewhere classified
	Group 19-Ordnance and Accessories
1911	Ordnance and accessories
	Group 20-Food and Kindred Products
2011	Meat, fresh, chilled, or frozen
2012	Meat and meat products prepared or preserved, including canned meat products
2014	Tallow, animal fats and oils
2015	Animal by-products, not elsewhere classified
2021	Dairy products, except dried milk and cream
2022	Dried milk and cream
2031	Fish and fish products, including shellfish, prepared or preserved
	Group 20-Food and Kindred Products
2034	Vegetables and preparations, canned and otherwise prepared and preserved
2039	Fruits, and fruit and vegetable juices, canned and otherwise prepared or preserved
2041	Wheat flour and semolina
2042	Animal feeds
2049	Grain mill products, not elsewhere classified
2061	Sugar
2062	Molasses
2081	Alcoholic beverages
2091	Vegetable oils, all grades; margarine and shortening
2092	Animal oils and fats, not elsewhere classified, including marine
2094	Groceries
2095	Ice
2099	Miscellaneous food products
	Group 21-Tobacco Products
2111	Tobacco manufactures
	Group 22-Basic Textiles
2211	Basic textile products, except textile fibers
2212	Textile fibers not elsewhere classified
	Group 23-Apparel and Other Finished Textile Products Including Knit
2311	Apparel and other finished textile products, including knit

EXHIBIT 2.1

CORPS OF ENGINEERS' COMMODITY CODES – (Continued)

Code No.	Item Name
	Group 24-Lumber and Wood Products Except Furniture
2411	Logs
2412	Rafted logs
2413	Fuel wood, charcoal, and wastes
2414	Timber, posts, poles, piling, and other wood in the rough
2415	Pulpwood, log
2416	Wood chips, staves, moldings, and excelsior
2421	Lumber
2431	Veneer, plywood, and other worked wood
2491	Wood manufactures, not elsewhere classified
	Group 25-Furniture and Fixtures
2511	Furniture and fixtures
	Group 26-Pulp, Paper and Allied Products
2611	Pulp
2621	Standard newsprint paper
2631	Paper and paperboard
2691	Pulp, paper and paperboard products, not elsewhere classified
	Group 27-Printed Matter
2711	Printed matter
	Group 28-Chemicals and Allied Products
2810	Sodium hydroxide (caustic soda)
2811	Crude products from coal tar, petroleum, and natural gas, except benzene and toluene
2812	Dyes, organic pigment, dyeing and tanning materials
2813	Alcohols
2816	Radioactive and associated materials, including wastes
2817	Benzene and toluene, crude and commercially pure
2818	Sulphuric acid
2819	Basic chemicals and basic chemical products, not elsewhere classified
2821	Plastic materials, regenerated cellulose and synthetic resins, including film, sheeting, and laminates
2822	Synthetic rubber
2823	Synthetic (man-made) fiber
2831	Drugs (biological products, medicinal chemicals, botanical products and pharmaceutical preparations)
2841	Soap, detergents, and cleaning preparations; perfumes, cosmetics, and other toilet preparations
2851	Paints, varnishes, lacquers, enamels, and allied products
2861	Gum and wood chemicals
2871	Nitrogenous chemical fertilizers, except mixtures
2872	Potassic chemical fertilizers, except mixtures
2873	Phosphatic chemical fertilizers, except mixtures
2876	Insecticides, fungicides, pesticides, and disinfectants
2879	Fertilizers and fertilizer materials, not elsewhere classified
2891	Miscellaneous chemical products

Code No.	Item Name
	Group 29-Petroleum and Coal Products
2911	Gasoline, including natural gasoline
2912	Jet fuel
2913	Kerosene
2914	Distillate fuel oil
2915	Residual fuel oil
2916	Lubricating oils and greases
2917	Naphtha, mineral spirits, solvents, not elsewhere classified
2918	Asphalt, tar, and pitches
2920	Coke, including petroleum coke
2921	Liquefied petroleum gases, coal gases, natural gas, and natural gas liquids
2951	Asphalt building materials
2991	Petroleum and coal products, not elsewhere classified
	Group 30-Rubber and Miscellaneous Plastic Products
3011	Rubber and miscellaneous plastic products
	Group 31-Leather and Leather Products
3111	Leather and leather products
	Group 32-Stone, Clay, Glass and Concrete Products
3211	Glass and glass products
3241	Building cement
3251	Structural clay products, including refractories
3271	Lime
3281	Cut stone and stone products
3291	Miscellaneous nonmetallic mineral products
	Group 33-Primary Metal Products
3311	Pig iron
3312	Slag
3313	Coke (coal and petroleum), petroleum pitches and asphalts, and naphtha and solvents
3314	Iron and steel ingots, and other primary forms, including blanks for tube and pipe, and sponge iron
3315	Iron and steel bars, rods, angles, shapes and sections, including sheet piling
3316	Iron and steel plates and sheets
3317	Iron and steel pipe and tube
3318	Ferroalloys
3319	Primary iron and steel products, not elsewhere classified including castings in the rough
3321	Nonferrous metals primary smelter product, basic shapes, wire castings and forgings, except copper, lead, zinc and aluminum
3322	Copper and copper alloys, whether or not refined, unworked
3323	Lead and zinc including alloys, unworked
3324	Aluminum and aluminum alloys, unworked

EXHIBIT 2.1

CORPS OF ENGINEERS' COMMODITY CODES – (Continued)

Code No.	Item Name
	Group 34-Fabricated Metal Products, Except Ordnance, Machinery and Transportation Equipment
3411	Fabricated metal products, except ordnance, machinery, and transportation equipment
	Group 35-Machinery, Except Electrical
3511	Machinery, except electrical
	Group 36-Electrical Machinery, Equipment and Supplies
3611	Electrical machinery equipment and supplies
	Group 37-Transportation Equipment
3711	Motor vehicles, parts and equipment
3721	Aircraft and parts
3731	Ships and boats
3791	Miscellaneous transportation equipment
	Group 38-Instruments, Photographic and Optical Goods, Watches and Clocks
3811	Instruments, photographic and optical goods, watches and clocks
	Group 39-Miscellaneous Products of Manufacturing
3911	Miscellaneous products of manufacturing
	Group 40-Waste and Scrap Materials
4011	Iron and steel scrap
4012	Nonferrous metal scrap
4022	Textile waste, scrap, and sweepings
4024	Paper waste and scrap
4029	Waste and scrap, not elsewhere classified
	Group 41-Special Items
4111	Water
4112	Miscellaneous shipments not identifiable by commodity
4113	LCL freight
4118	Materials used in waterway improvement, Government materials
4119	Empty containers
9999*	Department of Defense controlled cargo and special category items

*Cargoes exported on Department of Defense controlled vessels (other than goods for the use of U.S. Armed Forces abroad) and non-Department of Defense shipments of military component items (abbreviated SCI) for which commodity detail is not furnished to the Corps of Engineers.

In addition, data for four Comcodes were dropped, and data for transport of liquefied natural gas (LNG) was extracted from its COE Comcode and placed in a separate Comcode. The initial processing of the base-year commodity file is described below.

Commodities

With two exceptions, all commodity movements in the COE file were incorporated into our commodity file. The exceptions were:

- Domestic movements of fresh fish, fresh shellfish, and menhaden (Comcodes 0911, 0912 and 0913). Nearly all of these movements represent receipts of fish in fishing boats.
- Water (Comcode 4111). A small amount of water (8,000 tons in 1987) is shipped on coastal vessels, and a modest amount (890,000 tons) on inland barges. These movements were excluded from the analysis because their loss would have no environmental impact and they have only a negligible value.

Direction

Each commodity record was assigned a direction:

"1" for receipts and for through traffic coded (by the COE) as inbound, upbound, or traveling northward or eastward; and

"2" for shipments and for through traffic coded as outbound, downbound, or traveling southward or westward.

"Local" movements were split in two, with half assigned a code of "1" and half assigned a code of "2".[1,2]

---

[1]The COE coding system also distinguishes a category of "cross river flows". No movements in this category were encountered, but they would have been treated in the same way as local movements.

[2]The COE file contained some records for through movements for which direction was not coded. For each waterway, we assigned any such records a direction code consistent with the primary direction used for all other movements at the waterway. When there were equal volumes (tons) of other movements in both directions, these through movements were assigned a direction code of "1".

<u>Assignment to Shipment Type</u>

Commodity movements were assigned to shipment type in a two-step process.

The first step involved distinguishing commodities by their most common form of transport. Five forms of transport were distinguished:

- rafted logs (RL);
- tanker (T) or "liquid bulk";
- dry bulk (DB);
- containerized (C); and
- general cargo (G).

Commodity groupings that are frequently transported in different forms were assigned to the most commonly used transport form.

The second step involved a more detailed analysis of the form of transport used for several commodity groups that were considered to raise possibly significant environmental concerns. All coastwise and foreign shipments of these commodity groups that could be potentially made in dry or liquid bulk form were classified as:

- occupying an entire vessel;

- being shipped in bulk on a multi-commodity vessel (<u>e.g.</u>, a "parcel tanker" carrying shipments of several different chemicals); or

- being shipped in nonbulk form.

This classification was made on the basis of inherent commodity characteristics and an analysis of the total annual volume of each commodity group at individual COE waterways. The analysis is described in the appendix. Exhibit 2.2 lists all commodity groups that were treated as hazardous commodies in the environmental impact analysis (including several that are shipped only in nonbulk form) and shows the resulting percentage of each of these commodity groups assigned to full vessel, other bulk, and nonbulk shipments. At the end of this step, the transport-form codes were modified, where necessary, to be consistent with the results of this last analysis; i.e., low-volume movements of some dry or liquid bulk commodities were reclassified as being nonbulk.

Assignment to Vessel Type and Size

For each COE waterway, shipments in each direction were assigned to vessel types and sizes on the basis of their shipment type, their vessel counts by direction at each waterway, and their vessel-size characteristics:

- All movements of rafted logs were assigned to towboats.
- Internal movements of tanker shipments were assigned to small tanker barges (or small self-propelled tankers in a few waterways where there were no movements of tanker barges).
- Internal movements of dry bulk and nonbulk shipments were assigned to small dry barges (or small dry-cargo vessels in a few waterways).
- Foreign and coastwise movements of tanker shipments were distributed among self-propelled tankers and large tanker barges using a procedure described below (or assigned to small tanker barges in a few waterways where there were no movements of the other vessel types).
- Foreign and coastwise movements of dry bulk and nonbulk shipments were distributed among dry cargo vessels and large dry barges using a procedure described below (or assigned to small dry barges in a few waterways).

For each waterway, the distribution of foreign and coastwise movements of tanker shipments across large tanker barges and small, medium and large self-propelled tankers was based on the numbers of each of the four vessel categories moving through the waterway in the appropriate direction and the

EXHIBIT 2.2 CLASSIFICATION OF SPECIFIED COMMODITIES

		Shipment Type for Foreign and Coastwise Movements (Percent of Tons)			Vessels Used for Bulk Shipments	
COE Code	Commodity Class	Full Vessel	Other Bulk	Nonbulk	Tanker	Dry Bulk
1311	Crude Petroleum	100%	---	---	X	
1479	Natural Fert. Mtrl. NEC	---	---	100%		
1491	Salt	68	25%	7		X
1492	Sulfur, Dry	---	---	100		
1493	Sulfur, Liquid	100	---	---	X	
2810	Sodium Hydroxide	---	64	36		X
2811	Crude Prod-Coal Tar-Pet	---	31	69		X
2813	Alcohols	---	100	---	X	
2816	Radioactive Materials	---	---	100		
2817	Benzene and Toluene	---	100	---	X	
2818	Sulfuric Acid	---	0	100	X	
2819	Basic Chem and Prod NEC	---	---	100		
2851	Paints and Allied Product	---	---	100		
2861	Gum and Wood Chemicals	---	---	100		
2871	Nitrogen Chem. Fert.	56	36	8	X	
2872	Potassic Chem. Fert.	---	97	3		X
2873	Phosphate Chem. Fert.	---	98	2		X
2876	Pesticides-Disinfectants	---	---	100		
2879	Fertilizers & Materials NEC	---	95	5		X
2891	Misc. Chem. Products	---	---	100		
2911	Gasoline	---	100	---	X	
2912	Jet Fuel	---	100	---	X	
2913	Kerosene	---	100	---	X	
2914	Distillate Fuel Oil	---	100	---	X	
2915	Residual Fuel Oil	---	100	---	X	
2916	Lubric Oils-Greases	---	100	---	X	
2917	Naphtha. Petlm Solvents	---	100	---	X	
2921	LPG	98	---	2	X	
2922	LNG	100	---	---	X	
3271	Lime	---	0	100		X

relative carrying capacities of the four vessel categories. The relative carrying capacities of the three sizes of self-propelled tankers were developed from data on the relationship between deadweight tons and vessel draft for self-propelled tankers[3], subjectively adjusted for the effect of size-classification procedure for the study.[4] Typical carrying capacities for coastal barges were obtained from Corps of Engineers data.[5]

The result of the above procedure was a set of weights indicating the relative amounts of cargo typically carried by coastal tanker barges and the three sizes of self-propelled tankers. For each waterway, the total tonnage of each liquid-bulk commodity group moving in a given direction was distributed across the four vessel categories so that, for each category, the average amount of the commodity carried per vessel was proportional to the corresponding numerical weights. The weights used for tankers are shown in the first column of Exhibit 2.3. Distributional weights for dry bulk and nonbulk shipments were developed in the same way and are shown in the second and third columns of the exhibit.

The distributional weights for small self-propelled vessels are very small: 0.01 for tanker and dry-bulk shipments and 0.04 for nonbulk shipments. The small values result in assigning very little cargo to vessels classified as "small"; i.e., those operating with a draft of less than 19 feet. In the case of tankers and dry-bulk carriers, such vessels are nearly always deeper-draft vessels that are operating empty; however, nonzero entries are needed (at least for tankers) because there are some shallow-draft waterways that are served only by vessels operating at such shallow drafts.

The distributional weights shown in Exhibit 2.3 were used for all coastwise and foreign movements of all commodities to and from all waterways. Within the scope of our effort, it was not practical to vary them to reflect differences in waterway depth or type of movement.

---

[3]DRI/McGraw-Hill, et.al., Fleet Forecasts for the United States to 2020, Draft, prepared for U.S. Army Corps of Engineers, Fort Belvoir, Virginia, March 21, 1990, Draft Tables.

[4]The vessel counts classify vessels by size according to their operating draft (as recorded in the COE data base). This procedure has the effect of classifying many vessels as "large" when they are fully loaded and "medium" when they are empty.

[5]U.S. Army Corps of Engineers, Waterborne Commerce Statistics Center, Waterborne Transportation Lines of the United States: 1988, New Orleans, LA, 1989.

EXHIBIT 2.3

RELATIVE TONNAGES CARRIED BY SELF-PROPELLED VESSELS AND COASTAL BARGES BY SIZE OF VESSEL

Vessel Category	Shipment Type		
	Tanker	Dry Bulk	Nonbulk
Self Propelled			
Small	0.01	0.01	0.04
Medium	1	1	1
Large	24	7	4
Coastal Barge	2	1	0

The Santa Barbara Channel

The COE files contain no data for the Santa Barbara Channel (Study Zone 4). Our estimates of commodity movements through this channel were developed from our data for Los Angeles/Long Beach (LA/LB) (Study Zone 3) and estimates of the numbers of vessels passing through the channel, by type and size obtained from private industry sources in the area. Our estimates were developed using the following procedure:

1. All coastwise receipts of crude oil at LA/LB were assumed to represent Alaskan crude passing through the channel. The estimated number of tankers involved in this movement was derived from the LA/LB data and subtracted from the vessel counts.

2. The ratio of the resulting number of non-Alaskan tankers passing through the channel to the corresponding number at LA/LB was applied uniformly to all other liquid-bulk commodity movements at LA/LB to obtain an estimate of the volume of these commodities passing through the channel.

3. For all other vessel types, the ratio of the estimated number of vessels passing through the channel to the number observed at LA/LB was applied to the corresponding commodity records to obtain estimates of the volume of these commodities passing through the channel.

Liquefied Natural Gas

One final step in the analysis of the development of our base-year data file involved the creation of a separate commodity code (2922) for liquefied natural gas (LNG). In 1987, receipts at the Everett (Mass.) LNG terminal (waterway code 0153) accounted for all waterborne movements of LNG, and LNG accounted for all or virtually all of the receipts of liquefied gases (Comcode 2921) at this terminal. Accordingly, all receipts of Comcode 2921 at Waterway 0153 were recoded as Comcode 2922.

The creation of a separate commodity code for LNG permits separate analysis of the effects of casualties involving LNG tankers and those involving tankers carrying liquefied petroleum gas (LPG) (the primary constituent of the residual Comcode 2921).

HISTORIC-YEAR COMMODITY AND VESSEL TRAFFIC

For purposes of analysis, estimates were required of commodity and vessel traffic by vessel type and size, waterway, and (for commodity traffic) by commodity group for the 1979-1988 period.

Estimates of commodity traffic for each of the historic years were developed inexpensively by obtaining a set of ratios between total tons of freight in each year by study zone and corresponding tonnage in 1987, and applying these ratios to the 1987 commodity-traffic file. The tonnage ratios were derived from Corps of Engineers data on annual tonnage for 1979-1988 published for all major ports[1]. The ratios used are shown in Exhibit 3.1. For each study zone and year, a single ratio was used for all commodities and waterways.

Estimates of vessel traffic for the historic years were developed by multiplying 1987 vessel traffic by the commodity-traffic ratios shown in Exhibit 3.1, and adjusting for changes in average capacity of self-propelled vessels over the period. Between 1978 and 1988, the average capacity of dry-bulk carriers grew by an average of 1.5 percent per year, and that of freighters by 1.2 percent per year[2]. Accordingly, our estimates of the number of movements of all three sizes of self-propelled dry-cargo vessels were adjusted to reflect an average annual capacity increase of 1.4 percent.

Although the average capacity of dry-cargo vessels increased over the 1978-1988 period, the average capacity of tankers declined (by an average of 3.0 percent annually). This decline was primarily due to retirements of the very largest tankers. Since these vessels never served any of the study zones, their retirement did not affect the average capacity of tankers serving these zones. Accordingly, our estimates of the number of movements of self-propelled tankers in the historic years do not reflect any change in the average capacity of these vessels.

---

[1]U.S. Army Corps of Engineers, Waterborne Commerce Statistics Center, Waterborne Commerce of the United States, Calendar Year 1988, U.S. Army Engineer District, New Orleans, LA, 1990, Parts 1-4.

[2]U.S. Department of Transportation, Maritime Administration, Merchant Fleets of the World as of December 31, 1987 and December 31, 1988, Washington, D.C., 1988 and 1989.

EXHIBIT 3.1

RATIOS USED FOR ESTIMATING ANNUAL COMMODITY TRAFFIC
FOR 1979-1986 AND 1988

	Study Zone	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	BOSTON	1.3284	1.1111	1.0240	0.8872	0.8591	1.0030	0.8708	1.0608	1.0000	1.0409
2	PUGET SOUND, WA	0.9873	1.0776	1.0001	0.8702	0.8980	1.0569	0.8975	0.9324	1.0000	1.1017
3	LOS ANGELES/LONG BEACH, CA	0.7538	0.7982	0.8692	0.8697	0.8007	0.8579	0.9304	0.9562	1.0000	1.0666
4	SANTA BARBARA, CA	0.7538	0.7982	0.8692	0.8697	0.8007	0.8579	0.9304	0.9562	1.0000	1.0666
5	PORT ARTHUR, TX	1.4926	1.3559	1.1846	0.9973	1.0129	0.9791	0.8808	0.9524	1.0000	1.1172
6	NEW ORLEANS, LA	1.1580	1.1990	1.2333	1.2367	0.9691	0.9373	0.8855	0.9132	1.0000	1.0488
7	HOUSTON/GALVESTON, TX	1.0445	0.9679	0.8971	0.8410	0.7882	0.8599	0.8056	0.9033	1.0000	1.1097
8	CHESAPEAKE SOUTH	1.0084	1.2579	1.1968	1.2802	0.9528	1.0195	1.1198	1.0546	1.0000	1.1526
9	CHESAPEAKE NORTH	1.3723	1.3348	1.3285	1.0892	0.8422	0.9951	0.9716	0.9452	1.0000	1.1184
10	CORPUS CHRISTI, TX	1.0384	0.8405	0.7841	0.7093	0.7309	0.8233	0.7972	0.9358	1.0000	1.0820
11	NEW YORK, NY	1.0588	1.0806	1.0130	0.9658	0.9532	1.0462	0.9839	1.0211	1.0000	1.0034
12	LONG ISLAND SOUND	1.1120	0.9773	0.9511	0.8307	0.8654	1.1122	0.9786	1.0536	1.0000	1.0110
13	PHILADELPHIA, PA	1.2890	1.0634	0.9964	0.8838	0.8067	0.8643	0.9062	0.9890	1.0000	1.0632
14	SAN FRANCISCO, CA	0.9628	1.0072	0.9667	0.8397	0.8304	0.8572	0.8764	0.9519	1.0000	1.0574
15	PORTLAND, OR	0.9122	0.9285	0.8792	0.7985	0.9162	1.0273	0.8782	0.8634	1.0000	1.2048
16	COOK INLET, AK	0.6125	0.8045	0.7939	0.8435	0.8753	0.8613	0.9322	0.9462	1.0000	1.0026
17	PORTLAND, ME	1.4493	1.4039	1.6122	1.1426	0.8638	0.6861	0.8334	0.7640	1.0000	0.8795
18	PORTSMOUTH, NH	1.0052	0.7950	0.8774	0.6474	0.6396	0.7619	0.7939	0.9959	1.0000	0.9949
19	PROVIDENCE, RI	1.1516	1.0079	0.9454	0.8808	0.7614	0.8305	0.9049	1.0061	1.0000	1.0519
20	WILMINGTON, NC	1.2449	1.0174	1.0235	0.7359	0.7451	0.7195	0.7014	0.8562	1.0000	1.0436
21	JACKSONVILLE, FL	1.1331	1.1602	1.1750	0.9424	0.8722	0.8788	0.8404	0.9227	1.0000	1.1722
22	TAMPA, FL	1.0808	1.0975	1.0152	0.8595	0.9352	1.0500	1.0587	0.9008	1.0000	1.1343
23	MOBILE, AL	1.0889	1.1600	1.1613	0.9979	0.9167	1.1029	1.1656	1.1602	1.0000	1.1263

COMMODITY FORECASTS

Forecasts of commodity traffic for 1995, 2000, 2005 and 2010 were developed primarily from forecasts for the 1986-2000 time period developed by the Bureau of Labor Statistics (BLS) in 1988[1]. The forecasts used were the moderate-growth forecasts of real domestic output, exports and imports, by industrial sector.

The Basic Procedure

In order to develop the commodity forecasts, a correspondence was developed between 127 sectors of BLS' 226-sector input-output table and the COE commodity codes. (The BLS sectors used were the 126 goods-producing sectors plus the scrap sector.) For each comcode, the average annual growth rate in real output of the corresponding BLS sector or sectors was determined, as were the corresponding growth rates in real exports and real imports. The resulting annual growth rates by COE commodity code, with one adjustment explained subsequently, are shown in ratio form in Exhibit 4.1.

An initial set of forecasts were developed by assuming that, for all commodity groups, traffic volumes would grow uniformly at the indicated growth rates. The export and import growth rates were used for export and import movements, and the output growth rates were used for all other movements.

---

[1]U.S. Department of Labor, Bureau of Labor Statistics, Projections 2000, U.S. Government Printing Office, Washington, D.C., March 1988.

To provide some feel for the growth rates incorporated in this initial set of forecasts, the third column of Exhibit 4.2 shows the overall annual growth rate for gross national product (GNP) reflected in the BLS forecasts, as well as the overall annual growth rates for exports, imports, and the real domestic output of goods-producing industries. This exhibit also shows the corresponding growth rates for two historic periods (1972-1986 and 1976-1988) and for the 1990 BLS moderate-growth forecasts for 1988-2000[2]. (The 1988 forecasts were used in our analysis because the 1990 forecasts by industrial sector are not currently available on disk.) It can be seen that the 1988 forecast annual growth rate of 2.0 percent for real domestic output of goods-producing industries is slightly lower than the more recent 1990 forecast and between the corresponding rates for the two historic periods shown. The 1988 forecast annual growth rates for real exports and imports are somewhat lower than both the more recent forecast and the corresponding rates for the two historic periods.

---

[2] Monthly Labor Review, November 1989, U.S. Department of Labor, Bureau of Labor Statistics, pp. 17 and 28.

EXHIBIT 4.1

ANNUAL GROWTH RATIOS BY COE COMMODITY CODE

COE Commodity Code	Production	Exports	Imports
101	1.0107	1.0406	1.0301
102	1.0107	1.0406	1.0301
103	1.0107	1.0406	1.0301
104	1.0107	1.0406	1.0301
105	1.0107	1.0406	1.0301
106	1.0107	1.0406	1.0301
107	1.0107	1.0406	1.0301
111	1.0107	1.0406	1.0301
112	1.0107	1.0406	1.0301
119	1.0107	1.0406	1.0301
121	1.0107	1.0406	1.0301
122	1.0107	1.0406	1.0301
129	1.0107	1.0406	1.0301
131	1.0107	1.0406	1.0301
132	1.0107	1.0406	1.0301
133	1.0107	1.0406	1.0301
134	1.0107	1.0406	1.0301
141	1.0107	1.0406	1.0301
151	1.0062	1.0614	1.0240
161	1.0062	1.0614	1.0240
191	1.0107	1.0406	1.0301
841	1.0227	1.0564	1.0111
861	1.0227	1.0564	1.0111
911	1.0227	1.0564	1.0111
912	1.0227	1.0564	1.0111
913	1.0227	1.0564	1.0111
931	1.0227	1.0564	1.0111
1011	1.0196	1.0526	1.0421
1021	1.0196	1.0526	1.0421
1051	1.0196	1.0526	1.0421
1061	1.0196	1.0526	1.0421
1091	1.0196	1.0526	1.0421
1121	1.0211	1.0213	1.0585
1311	0.9961	1.0036	1.0459
1411	1.0200	1.0142	1.0150
1412	1.0200	1.0142	1.0150
1442	1.0200	1.0142	1.0150
1451	1.0200	1.0142	1.0150
1471	1.0200	1.0142	1.0150
1479	1.0200	1.0142	1.0150
1491	1.0200	1.0142	1.0150
1492	1.0200	1.0142	1.0150
1493	1.0200	1.0142	1.0150
1494	1.0200	1.0142	1.0150
1499	1.0200	1.0142	1.0150
1911	0.9915	1.0436	1.0362

EXHIBIT 4.1

ANNUAL GROWTH RATIOS BY COE COMMODITY CODE – (continued)

COE Commodity Code	Production	Exports	Imports
2011	1.0113	1.0511	1.0161
2012	1.0113	1.0511	1.0161
2014	1.0113	1.0511	1.0161
2015	1.0113	1.0511	1.0161
2021	1.0061	1.0592	1.0180
2022	1.0061	1.0592	1.0180
2031	1.0292	1.0585	1.0290
2034	1.0292	1.0585	1.0290
2039	1.0292	1.0585	1.0290
2041	1.0202	1.0564	1.0316
2042	1.0202	1.0564	1.0316
2049	1.0202	1.0564	1.0316
2061	1.0055	1.0640	1.0213
2062	1.0055	1.0640	1.0213
2081	1.0160	1.0547	1.0234
2091	1.0202	1.0564	1.0316
2092	1.0202	1.0564	1.0316
2094	1.0196	1.0596	1.0329
2095	1.0196	1.0596	1.0329
2099	1.0196	1.0596	1.0329
2111	0.9883	1.0229	1.0249
2211	1.0104	1.0435	1.0190
2212	1.0104	1.0435	1.0190
2311	1.0119	1.0409	1.0366
2411	1.0207	1.0408	0.9830
2412	1.0207	1.0408	0.9830
2413	1.0207	1.0408	0.9830
2414	1.0207	1.0408	0.9830
2415	1.0207	1.0408	0.9830
2416	1.0207	1.0408	0.9830
2421	1.0179	1.0487	1.0330
2431	1.0176	1.0516	1.0237
2491	1.0168	1.0450	1.0328
2511	1.0277	1.0465	1.0278
2611	1.0301	1.0570	1.0273
2621	1.0301	1.0570	1.0273
2631	1.0301	1.0570	1.0273
2691	1.0259	1.0463	1.0364
2711	1.0301	1.0339	1.0213
2810	1.0195	1.0433	1.0372
2811	1.0195	1.0433	1.0372
2812	1.0195	1.0433	1.0372
2813	1.0195	1.0433	1.0372
2816	1.0195	1.0433	1.0372
2817	1.0195	1.0433	1.0372

EXHIBIT 4.1

ANNUAL GROWTH RATIOS BY COE COMMODITY CODE – (continued)

COE Commodity Code	Production	Exports	Imports
2818	1.0195	1.0433	1.0372
2819	1.0195	1.0433	1.0372
2821	1.0365	1.0612	1.0472
2822	1.0365	1.0612	1.0472
2823	1.0365	1.0612	1.0472
2831	1.0344	1.0552	1.0221
2841	1.0268	1.0463	1.0275
2851	1.0135	1.0479	1.0716
2861	1.0195	1.0433	1.0372
2871	1.0114	1.0591	1.0260
2872	1.0114	1.0591	1.0260
2873	1.0114	1.0591	1.0260
2876	1.0114	1.0591	1.0260
2879	1.0114	1.0591	1.0260
2891	1.0198	1.0602	1.0326
2911	1.0143	1.0221	1.0158
2912	1.0143	1.0221	1.0158
2913	1.0143	1.0221	1.0158
2914	1.0143	1.0221	1.0158
2915	1.0143	1.0221	1.0158
2916	1.0143	1.0221	1.0158
2917	1.0143	1.0221	1.0158
2918	1.0143	1.0221	1.0158
2920	1.0200	1.0280	1.0189
2921	1.0143	1.0221	1.0158
2951	1.0200	1.0280	1.0189
2991	1.0200	1.0280	1.0189
3011	1.0365	1.0491	1.0245
3111	0.9942	1.0427	1.0243
3211	1.0098	1.0090	1.0214
3241	1.0155	0.9907	1.0193
3251	1.0140	1.0148	1.0272
3271	1.0184	1.0031	1.0334
3281	1.0140	1.0148	1.0272
3291	1.0140	1.0148	1.0272
3311	1.0170	1.0295	1.0133
3312	1.0170	1.0295	1.0133
3313	1.0170	1.0295	1.0133
3314	1.0170	1.0295	1.0133
3315	1.0170	1.0295	1.0133
3316	1.0170	1.0295	1.0133
3317	1.0170	1.0295	1.0133
3318	1.0170	1.0295	1.0133
3319	1.0179	1.0098	1.0321
3321	1.0207	1.0319	1.0131

EXHIBIT 4.1

ANNUAL GROWTH RATIOS BY COE COMMODITY CODE -- (continued)

COE Commodity Code	Production	Exports	Imports
3322	1.0171	1.0238	1.0201
3323	1.0166	1.0469	1.0084
3324	1.0182	1.0374	1.0236
3411	1.0119	1.0335	1.0209
3511	1.0256	1.0514	1.0236
3611	1.0254	1.0746	1.0432
3711	1.0124	1.0306	1.0119
3721	1.0197	1.0647	1.0154
3731	1.0060	1.0315	1.0309
3791	1.0181	1.1015	0.9882
3811	1.0322	1.0584	1.0294
3911	1.0081	1.0409	1.0347
4011	1.0194	1.0770	1.0186
4012	1.0194	1.0770	1.0186
4022	1.0194	1.0770	1.0186
4024	1.0194	1.0770	1.0186
4029	1.0194	1.0770	1.0186
4111	1.0211	1.0470	1.0404
4112	1.0254	1.0553	1.0324
4118	1.0200	1.0142	1.0150
4119	1.0254	1.0553	1.0324
9999	0.9915	1.0436	1.0362

EXHIBIT 4.2

HISTORIC AND FORECAST AVERAGE ANNUAL RATES OF GROWTH

	1972-1986[1]	1976-1988[2]	1986-2000[3]	1988-2000[4]
Gross National Product	2.5%	2.9%	2.4%	2.3%
Real Domestic Output of Goods Producing Industries	1.4	2.2	2.0	2.2
Exports	4.7	5.2	3.9	4.7
Imports	5.5	6.5	2.5	2.7

Sources:

[1]U.S. Department of Commerce, Bureau of Economic Analysis, as quoted in Source No. 3.

[2]U.S. Department of Commerce, Bureau of Economic Analysis, as quoted in Source No. 4.

[3]U.S. Department of Labor, Bureau of Labor Statistics, *Projections 2000*, U.S. Government Printing Office, Washington, D.C., March 1988, pp. 11 and 31.

[4]U.S. Department of Labor, Bureau of Labor Statistics, *Monthly Labor Review*, November 1989, pp. 17 and 28.

It may be observed that the BLS growth rates represent growth in value of product, while we have used these rates to represent growth in volume (tons) of product. The growth rates were not adjusted for potential changes in real value per ton. This ratio has been growing steadily for many high-value manufactured products. However, changes in value per ton of the low-value commodities of greatest interest in our analysis are less predictable. Accordingly, we have used the BLS growth rates without adjustment to represent growth in tonnage transported.

It should also be observed that the BLS growth rates are national growth rates. With some important exceptions, discussed below, these national growth rates were applied to traffic growth at all ports.

Adjustments

Liquefied Natural Gas

Forecasts of LNG imports were developed separately from the above procedure. The only LNG terminal operating in the base year, 1987, was the one in Everett, MA. However, a second terminal (at Lake Charles, LA) resumed operation in 1990, and a third (at Cove Point, MD) is expected to resume operations in 1992.

Exhibit 4.3 shows 1987 LNG receipts at Everett, estimated 1990 receipts at Everett and Lake Charles, and the maximum capacity at all three terminals. Also shown in this exhibit are the LNG volumes we assumed for the three terminals for each of the four forecast years. The volumes indicated are highly conjectural. Increases in the price of natural gas from overseas sources (relative the cost of competing energy products from other sources) could cause the Lake Charles and Cove Point terminals to close again (as they have in the past). On the other hand, any further decline in the cost of LNG relative to that of alternative energy sources could cause greater use of these three terminals and, perhaps, the opening of additional terminals.

Our 2010 forecast of LNG imports represents about 6.4 percent of forecast waterborne imports of all petroleum products on a tonnage basis, and a smaller percentage on a BTU basis. To adjust for our forecasts of increased LNG imports, the annual growth rates for all other petroleum products (Comcodes 2911-2918 and 2921) were reduced from the value of 2.01 percent/year implied by the BLS forecast to the value of 1.58 percent/year shown in Exhibit 4.1.

EXHIBIT 4.3

FORECAST RECEIPTS AT LNG TERMINALS
(millions of short tons)

Terminal	COE Waterway Code	1987[1]	1990 Estimate[2]	Forecasts				Capacity[3]
				1995	2000	2005	2010	
Everett, MA	0153	0.04	1.78	2.0	2.2	2.4	2.6	3.5
Cove Point, MD	0479	---	1.5	2.0	2.5	3.0	3.5	4.6
Lake Charles, LA	2254	---	---	0.5	1.5	2.5	3.5	8.5

[1]U.S. Army Corps of Engineers commodity file for 1987.

[2]Derived from company data for January-July.

[3]Company representatives.

Coastwise Petroleum Shipments

There are two sets of shipments for which forecasts by region and industrial sector were available at a reasonable level of aggregation for our use. These are shipments of Alaskan crude to West Coast refineries, and shipments of petroleum products from refineries in Texas and Louisiana to other Gulf and East Coast ports. For the first set of shipments, forecast-year volumes were estimated by multiplying base-year volumes by the ratio of forecast-year/base-year employment in oil and gas extraction in Alaska, using the Bureau of Economic Analysis' "OBERS" forecasts of employment by 56 industrial sectors by state and region[3]. For the second set of shipments, forecast-year volumes were estimated by multiplying base-year volumes by corresponding ratios for petroleum-refinery employment in the production of petroleum and coal products. The forecast ratios used for these two sets of shipments are shown in Exhibit 4.4.

Crude-Oil Imports

Forecasts of crude-oil imports entering the three Texas study zones were adjusted for the effect of the planned Texport offshore petroleum terminal[4]. This terminal would be located in international waters 27 miles from shore in the vicinity of Galveston. Crude oil received at this terminal would be transported by pipeline to Freeport, Texas, about 45 miles southwest of the Galveston Bay inlet. A five million dollar feasibility study is now nearing completion. Construction of the terminal and pipeline is expected to take five years, with completion currently expected in 1997. Alternative plans being considered would allow maximum throughput of either one or two million barrels per day. The project is a joint venture between the Texas Railroad Commission, Phillips 66, and eleven additional oil companies.

---

[3]U.S. Department of Commerce, Bureau of Economic Analysis, BEA Regional Projections to 2040, U.S. Government Printing Office, Washington, D.C., June 1990.

[4]Tod Morgan, Texas State Controller's Office, Austin, Texas, personal communication, January 1991. (Mr. Morgan was formerly with the Texas Railroad Commission.)

EXHIBIT 4.4

GROWTH RATIOS USED FOR ALASKAN CRUDE OIL AND GULF-COAST PETROLEUM PRODUCTS

	Ratio Relative to 1987 Volume			
	1995	2000	2005	2010
Alaskan Crude Oil	1.0	1.011	1.011	0.989
Gulf-Coast Petroleum Products	0.965	0.958	0.934	0.910

Completion of Texport would result in a substantial reduction in crude oil received at existing Texas ports and significant changes in the pipeline movements of crude in the area, but the actual effects are not known.

For this analysis, it was presumed that the less ambitious version of Texport would be built and would be fully operational by the year 2000. Annual throughput in 2000-2010 was assumed to be about 240 million barrels (or 36 million tons) representing 65 percent of capacity. (The 65 percent utilization rate is the same as that experienced by the existing Louisiana Offshore Oil Port.) The annual throughput represents 90 percent of COE estimates of 1987 crude imports at Freeport and Houston/Galveston/Texas City and 52 percent of 1987 crude imports at all Texas ports. Although the greatest effect of Texport would be a reduction of imports received at Freeport and Houston/Galveston/Texas City, it is clear that some reduction would also occur in receipts at other Texas ports. On this basis, our 2000-2010 forecasts of crude oil imports at Houston/Galveston were reduced by 50 percent, and the corresponding forecasts for the Corpus Christi and Beaumont/Port Arthur study zones by ten percent. It was assumed that Texport would lie outside the Houston/Galveston study zone, though it is possible that it will actually lie just inside the Houston/Galveston approach subzone.

VESSEL FORECASTS

Estimates of vessel traffic, by vessel type and size, and waterway, were developed for the four forecast years (1995, 2000, 2005, and 2010) using: the estimates of commodity traffic for the corresponding years; base-year ratios of average tons carried per vessel; and adjustments for forecast changes in the size of vessels used for international trade. The development of these estimates is described below.

Self-Propelled Vessels

For self-propelled vessels, initial forecasts of the number of vessels, by size, type, waterway and direction, were developed by scaling the 1987 vessel counts (exclusive of LNG tankers) using a corresponding set of tonnage ratios. For medium and large vessels, these ratios were developed by obtaining total forecast-year tons carried by vessels (exclusive of LNG tankers) of a given size and type operating in the appropriate direction to or from a given waterway, and dividing by corresponding base-year tons. For small vessels, the tonnage ratios were obtained in the same way, except that, for each of the two types of small self-propelled vessel, a single set of ratios was developed based on total tonnage of appropriate commodities being carried in either direction. (A broader set of tonnages is used for "small" self-propelled vessels because this category of vessels includes a number of larger vessels that carry commodities only in one direction and that are classified as "small" (on the basis of operating draft) when operating in the opposite direction.)

For a few minor waterways, the COE data for 1987 indicated some operation of self-propelled vessels of a particular type and direction without any corresponding foreign or coastwise commodity movements. For these waterways, forecasts for dry-cargo or tanker vessels of these types were developed using ratios for: (a) dry or liquid (respectively) foreign and coastwise commodity movements in the opposite direction; (b) dry or liquid internal commodity movements in either direction; or (c) (if the two previous rules fail) population forecasts[1].

---

[1]Forecast population growth rates were obtained by study zone from Coastal Population Change: 1990-2010, U.S. Coast Guard Memorandum, G-CCS-3, Nov. 1, 1990.

Estimates of the number of LNG tanker deliveries at the three LNG ports (Everett, Lake Charles and Cove Point) were obtained by dividing the forecast tons of LNG by 63,887 (the capacity of a 125,000 cubic meter LNG tanker). Each LNG tanker delivery was treated as accounting for the arrival of one tanker with an operating draft of at least 30 feet (i.e., a "large" tanker) and the departure of one empty tanker with an operating draft of less than 18 feet (classified as a "small" tanker). These estimates were added to the initial forecast of large and small tankers for the three corresponding waterways.

For foreign traffic (but not for coastwise traffic), the initial estimates were adjusted to reflect the effects of forecast growth in the sizes of vessels. These adjustments were derived by combining data on recent trends (presented in Chapter 3) with ton/ship-year ratios derived from DRI estimates and forecasts[2] of two quantities: annual capacity tons of ships in international trade serving United States ports; and annual number of ship-years of service available.

For dry-cargo vessels, for 1995 and 2000, we assumed a continuation of the recent average 1.4 percent annual rate of growth in capacity per vessel; for 2005 and 2010, on the basis of DRI forecasts, we assumed average capacity would exceed the 1987 level by 24.3 percent (for large vessels) and 19.8 percent (for medium and small vessels). For large tankers, on the basis of DRI forecasts, we assumed average capacity would exceed the 1987 level by 2.4 percent in 2005 and 6.0 percent in 2010; and we assumed average 1995 and 2000 capacity would be the same as in 1987 (DRI forecasts indicate a decrease). For medium and small tankers, we assumed no change in capacity from the 1987 levels. (Again, DRI forecasts indicate a decrease.)

The final step in developing the forecasts of the number of self-propelled vessel movements by size, type and waterway was to sum the above forecasts over the two directions and to combine the separate forecasts for foreign and coastwise (and local, if any) movements.

---

[2]DRI/McGraw-Hill, Temple, Barker and Sloane, and Lloyd's Maritime Information Services, Fleet Forecasts for the United States to 2020, Draft, prepared for the U.S. Army Corps of Engineers, Fort Belvoir, VA, March 1990. This source also contains forecasts for five separate coastal regions, but ton/ship-year ratios calculated at the region level did not appear to be sufficiently reliable to use.

Barges

Barge forecasts were developed by first dividing the base-year barge counts into numbers of coastal and inland barges and scaling on the basis of the forecast changes in corresponding commodity traffic. For each waterway and barge type (dry or tanker), the number of coastal barge movements were estimated by taking all movements of "large" barges (i.e., those with a draft exceeding 18 feet) and adding an equal number of other barge movements in the opposite direction (limited, if necessary, by the total number of movements in that direction); the latter figure represents estimated empty movements of coastal barges. All remaining barge movements were assumed to represent inland barges.

Forecasts of the numbers of coastal and inland dry and tank barges operating at each waterway were obtained by multiplying the base-year counts by the corresponding tonnage ratios for traffic carried by each of the four types of barge. In this process, the numbers of coastal barges operating with deep drafts (over 18 feet) and with shallow drafts were kept separate. The forecasts of shallow-draft coastal-barge operations were then combined with the forecasts of inland barge operations to produce forecasts of numbers of "small" barges (by type, waterway and direction), while the forecasts of deep-draft coastal-barge operations were used as the forecasts of "large" barges (by type, waterway and direction). Finally, all forecast barge counts (by size and type) were summed over both directions to produce forecasts of total number of barge operations, by size, type and waterway, for each forecast year.

In order to develop forecasts of tugboat and towboat operations, it was first necessary to distribute the base-year counts across the three types of operation: towing of coastal barges; towing of inland barges; and accompanying self-propelled vessels. For each waterway, the number of towboats towing coastal barges in the base year was set to the number of coastal barge movements in that year. Similarly, for each waterway, the number of towboats towing inland barges in the base year was estimated by dividing the number of inland dry and tank barges operating in that waterway by the estimated average numbers of barges per tow. (For inland barges, barge/tow ratios of one were used except as indicated in Exhibit 5.1.) Finally, any remaining tugboat and towboat movements were assumed to represent tugboats accompanying large self-propelled vessels.

Estimates of the numbers of tugboat and towboat operations, by waterway, in each of the forecast years were obtained by scaling the base-year estimates of the three types of operation by corresponding ratios of forecast-year to base-year operations of coastal barges, inland barges, and medium and large self-propelled vessels, and summing the results across the three types of operation.

EXHIBIT 5.1

INLAND BARGE/TOW RATIOS FOR WATERWAYS WITH RATIOS EXCEEDING ONE

Study Zone	Ratio for		Waterways
	Dry Barges	Tank Barges	
5. Port Arthur, TX	3	3	All
6. New Orleans, LA	25	4	2252 Port of Baton Rouge
	25	4	6033 Mississippi River, New Orleans to Baton Rouge
	10	4	2251 Port of New Orleans
	10	4	2052 Inner Harbor Navigation Canal
	10	4	6032 Mississippi River, New Orleans to Mouth of Passes
	10	4	6904 Passes of the Mississippi River
	10	4	2060 Mississippi River - Gulf Outlet
	3	3	All others
7. Houston/Galveston, TX	3	3	All
8. Hampton Roads, VA	2	2	All
10. Corpus Christi, TX	3	3	All
16. Anchorage, AK	4	4	All
20. Wilmington, NC	2	2	All
22. Tampa, FL	2	1	All
23. Mobile, AL	3	3	All

CARGO LOSSES

The vessel data base developed in this study distinguishes four types of cargo-carrying vessel:

- self-propelled dry-cargo vessels;
- self-propelled tankers;
- dry cargo barges; and
- tanker barges.

For a casualty involving a vessel of one of these types, it is necessary to estimate the expected cargo loss by commodity type. This analysis requires information about: the probabilities that one or more of the vessel's compartments (i.e., a task or a hold) will rupture; for each of the commodity groups distinguished by TSC, the probability that a ruptured compartment will contain cargo belonging to that commodity group; and, for each such commodity group, the expected cargo loss.

Our commodity forecasts, developed from COE data on shipments and receipts by commodity, can provide only imperfect information about the commodities carried by a particular vessel. For most COE waterway codes, the COE commodity file contains no information about cargo that is not loaded or unloaded at some pier in the corresponding waterway[1]. This data limitation leads us to make the simplifying assumption that any compartments that rupture are those that contain cargo about which information is known; i.e., the cargo (with some exceptions[2]) originates or terminates at the waterway to or from which the vessel is traveling. This assumption has some effect on the identification of commodities that might be spilled in particular waterways and in the corresponding study zones. However, it need not have any effect on the estimates of the amount of cargo lost. Hence, this assumption does not lead to any significant biases in the study results. The procedures for estimating expected cargo loss for the four types of cargo-carrying vessels are quite similar to each other but differ slightly in some particulars. These procedures are described below.

---

[1]The principal exceptions are waterway codes that correspond to sections of a river or an inland waterway. For vessels using rivers and inland waterways, the COE has reasonably complete route information that allows the derivation of information about most or all cargo carried. For such waterway sections, the COE files (and, hence, our forecasts) contain information about cargo that is neither shipped nor received in the waterway section.

[2]See the preceding footnote.

Tankers

Exhibit 6.1 shows estimated average capacities (in tons) of compartments for several different vessel types and sizes; and Exhibit 6.2 shows estimates of the average number of compartments that are likely to be loaded or unloaded at any waterway. The number of tanks or holds loaded or unloaded at a given waterway may be less than the total number of such compartments on the vessel. For tankers (such as product tankers and parcel tankers) that commonly carry commodities from a single origin to multiple destinations, the number of tanks loaded at an origin is likely to be greater than the number unloaded at any single destination.

Exhibits 6.1 and 6.2 distinguish several categories of self-propelled tankers. Three of these represent tankers designed for a single product: crude petroleum, liquid sulfur, or molasses. LNG and LPG tankers are also specialized vessels designed for a single product, but the two types are similar enough in terms of numbers of tanks and tons of gas per tank to be combined into a single category[3]. The remaining categories consist of product tankers and parcel tankers. Product tankers typically transport several shipments of various petroleum products from a refinery to one or more destinations. Parcel tankers usually provide scheduled common-carrier service on a fixed route, carrying several shipments of chemicals and some other liquids shipped in relatively small quantities. Gas and parcel tankers are double-hulled, and parcel tankers frequently have cofferdam bulkheads between tanks.

For a tanker or tank barge of a given type and size, the expected amount of cargo loaded or unloaded at any waterway can be obtained by multiplying the average number of tanks loaded or unloaded (from Exhibit 6.2) by the average size of the tanks. For any waterway served by tankers or tank barges of different types, for any vessel size, the relative numbers of vessels of each of the six tanker types distinguished in the exhibits can be taken to be proportional to the total amount (in tons) of shipments and receipts of commodities carried by tankers of that type and size divided by the expected amount of such cargo per vessel loaded or unloaded at any waterway (derived from Exhibits

---

[3]A third type of gas tanker is designed to carry anhydrous ammonia. However, since the COE commodity group data do not distinguish anhydrous ammonia from other nitrogen fertilizers (STCC 2871), this type of tanker is not distinguished in our analysis.

EXHIBIT 6.1

AVERAGE SIZE OF TANKS AND HOLDS

(tons)

Vessel Type and Commodities	Self-Propelled Vessels			Barges	
	Small	Medium	Large	Inland	Coastal
Tankers					
1311 - Crude Petroleum	2,000	4,000	10,000	600	2,500
1493 - Liquid Sulfur	1,900	3,800	4,800	1,500	3,000
2062 - Molasses	2,000	4,000	5,000	750	2,000
291x - Petroleum Products	700	1,000	3,000	600	2,000
2921/2922 - LPG/LNG	1,700	3,300	12,800	500	2,100
Other Liquids (includes 2813, 2817, 2818, 2871)	250	300	400	400	1,200
Dry Bulk	500	1,500	10,000	1,400	15,000
General Cargo	500	1,000	2,500	---	---

EXHIBIT 6.2

EXPECTED NUMBER OF TANKS OR HOLDS PER VESSEL THAT ARE LOADED OR UNLOADED AT A GIVEN WATERWAY

Vessel Type and Commodities	Self-Propelled Vessels			Barges	
	Small	Medium	Large	Inland	Coastal
Tankers					
1311 - Crude Petroleum	1	1	12	5	5
1493 - Liquid Sulfur	1	1	5	1.5	4
2062 - Molasses	1	1	5	3	6
291x - Petroleum Products	2	4/3	18/6	5	6/3
2921/2922 - LPG/LNG	1	1	4	5	5
Other Liquids (includes 2813, 2817, 2818, 2871)	5/2	10/2	15/3	4/3	10/3
Dry Bulk	1	1	2	1	1
General Cargo	1	1	2	---	---

N.B. Where two numbers are shown, the first is for shipments, the second for receipts.

6.1 and 6.2).[4] These numbers can then be used to distribute the estimated numbers of tankers and tank barges serving the waterway across the six tanker types, and thus to derive the probability that a tanker or tank barge casualty in a specific study subzone involves a tanker or tank barge of a particular type serving a given waterway.

The probability that a particular tank contains cargo may be taken to be fifty percent. For a tanker or tank barge of a given type and size, the probability that a ruptured cargo-carrying tank contains a specific commodity may be taken to be proportional to the ratio of the volume (in tons) of that commodity carried to or from a particular waterway in such vessels to the volume of all such commodities, and the volume of the tank may be taken as the average volume shown in Exhibit 6.1.[5]

---

[4]It should be noted that, for some tanker types, the number of tanks loaded at a waterway is higher than the number unloaded. (See Exhibit 6.2.) Shipments and receipts are distinguished in the commodity file by the direction code (a "2" or a "1", respectively). Unfortunately, our processing of the commodity file (see Chapter 2) resulted in dropping special designation of through movements, so that all movements must be analyzed as being either shipments or receipts.

[5]The assumption that the lost cargo is being shipped or received at the waterway from or to which the vessel is traveling is made necessary by limitations in the COE commodity data. The effects of this assumption are discussed above.

The simplifying assumption that the size of a ruptured tank of a parcel tanker is independent of the type of commodity carried affects the probability of a particular commodity being involved and the size of a spill of that commodity inversely. Accordingly, the effects on the expected amount of the commodity spilled tend to cancel. (They do not cancel completely because we are also ignoring the effect of tank size on the probability that a particular tank will rupture.)

Dry-Cargo Barges

Virtually all dry-cargo barges carry dry bulk commodities in a single hold, and they are almost always either empty or fully loaded. The usual capacity of inland dry-bulk barges is 1,400 tons and, as shown in Exhibit 6.1, the average capacity of coastal dry-bulk barges is 15,000 tons.

The probability that any barge is loaded is close to 50 percent. If the barge is loaded, it is almost certainly carrying one of the commodities identified as being transported in a barge of that type to, from or through the waterway to, from or through which the barge is traveling. The probability that the barge is carrying a given commodity is obtained by taking the amount of the commodity transported by such barges to, from or through the waterway and dividing by the corresponding amounts of all such commodities.

Self-Propelled Dry-Cargo Vessels

The procedure for estimating cargo losses for self-propelled dry-cargo vessels is slightly more complicated than the one for dry-cargo barges.

About 62 percent of self-propelled dry-cargo vessels are bulk carriers[6]. However, since liners make more stops, the probability that a self-propelled dry-cargo vessel entering or leaving a particular study zone is a bulk carrier is appreciably lower. A procedure for estimating this probability is presented subsequently.

As shown in Exhibit 6.2, most small and medium-sized dry-bulk carriers have a single hold, and the average number of holds for larger dry-bulk vessels is two. Usually, all holds contain the same commodity and are either loaded or unloaded at a given stop. The average load per hold is shown in Exhibit 6.1. The probability that a loaded dry-bulk carrier traveling to or from a given waterway carries a given commodity can be obtained by taking the amount of the commodity being transported by self-propelled dry-cargo vessels to or from that waterway and dividing by the corresponding amounts for all such dry-bulk commodities.

General-cargo vessels may carry either containers or unprotected cargo in their holds. About 35 percent of these vessels are containerships or roll-on/roll-off (RoRo) vessels[7], but even these vessels may carry unprotected cargo in their holds. General-cargo vessels may be either liners (i.e., vessels operating on a regular route) or tramps. Tramp general-cargo vessels traveling to and from a given waterway are likely to have their holds full in one direction and empty in the other. Liner holds are relatively unlikely to be either empty or completely full. It is reasonable to presume that the expected amount of cargo carried in a liner hold is somewhat greater than half the capacity of the hold, perhaps 60 to 70 percent of this capacity.

---

[6]DRI/McGraw-Hill, Temple, Barker and Sloane, and Lloyd's Maritime Information Services, Fleet Forecasts for the United States to 2020, prepared for the U.S. Army Corps of Engineers, Fort Belvoir, VA, Draft, March 1990.

[7]Ibid.

The probability that cargo carried by general-cargo vessels is unprotected is no greater than 50 percent. Unprotected cargo is likely to consist of steel, machinery, logs, over-dimensioned items, etc.; though some general-cargo vessels may carry small shipments of a dry-bulk commodity. All high-volume commodities are normally containerized.

For analytic purposes, it is appropriate to treat all dry-bulk shipments as being carried in dry-bulk vessels, and all other dry cargo as being carried in general cargo vessels. The expected amount of cargo loaded or unloaded at any waterway by a dry-bulk carrier (which normally carries cargo in only one direction) can be obtained by multiplying the average number of holds loaded or unloaded at a waterway (from Exhibit 6.2) by the average size of the holds (from Exhibit 6.1). For analytic purposes, the corresponding quantity for a general-cargo vessel may be assumed to be estimated similarly; though, for these vessels, this quantity is likely to vary from port to port.

Using the same procedure as was used for tankers, the above quantities can be used to divide the number of dry-cargo vessels of a given size traveling to or from a given waterway between dry-bulk carriers and general-cargo vessels. The probability that a ruptured hold of a dry-bulk carrier will contain a given dry-bulk commodity can then be obtained in the same way as the corresponding probability for tankers, and the expected volume carried can be obtained from Exhibit 6.1.

Since general-cargo vessels normally carry an extensive mix of shipments, a slightly different procedure is required for these vessels. For these vessels, the total contents of a ruptured hold can be estimated as 60 percent of the capacity of the hold. The expected amount of any nonbulk commodity in a ruptured hold is then estimated by multiplying the total contents affected by the ratio of the shipments and receipts of the commodity at the waterway to shipments and receipts of all nonbulk commodities at this waterway.

SHIPMENT SIZE CHARACTERISTICS OF SPECIFIED BULK COMMODITIES

In the event of a casualty, the expected size and characteristics of a release of bulk commodities depend in a significant way on the way they are being transported. In particular, significant differences exist between shipments that:

- occupy a whole vessel;
- are stored in bulk in part of the vessel (e.g., in a "parcel tanker" carrying shipments of several different chemicals);
- or are shipped in smaller quantities (e.g., in steel drums on a general cargo vessel).

This memorandum presents: the procedure we are using in Task 2 for allocating shipments of bulk commodities among these three types of shipment size; and recommended Task 6 procedures for using this information when estimating the expected volumes of various commodities released as a result of a casualty. The Task 2 procedure addresses only bulk commodities that present relatively non- routine costs in the case of a release; i.e., bulk commodities distinguished at the four-digit STCC-code level. Other bulk commodities (all of which are dry bulk) are treated as being always carried as the sole cargo of a dry-bulk carrier.

Classification of Specified Commodities

Exhibit 7.1 lists the 30 classes of commodities whose release is treated as presenting nonroutine costs. The last two columns of this exhibit identify those of these commodities that are frequently transported in liquid form by tankers[8] and another seven commodities that have the potential to be transported in dry-bulk form. The eight remaining commodity classes have been assumed to be always transported in nonbulk form. Most of these last commodity classes contain a relatively large number of different products, few if any of which are likely to be transported in large enough volumes to warrant bulk shipment. Also, some of these commodities (e.g., radioactive materials) require special packaging that precludes bulk shipment. Although dry sulfur is exported in large volumes, we understand that all shipments of sulfur in dry form are nonbulk shipments.

Of the 15 liquids, three are rarely if ever transported in anything less than a full tankerload lot. These are crude petroleum, liquid sulfur, and liquefied natural gas (LNG). We assumed that these three commodities are always transported in a full tanker.

A fourth liquid, liquefied petroleum gas (LPG) is transported only in special LPG tankers or as general cargo in individual cylinders. We used the allocation procedure presented in a subsequent section to distinguish between these two forms of transport for LPG, excluding the option of "other bulk" transport.

Coastwise movements of most major petroleum products are usually made in tankers that contain multiple products and that are destined for more than one port. Such shipments are appropriately classified as "other bulk." We assumed that all foreign and coastwise shipments of petroleum products fall into the "other bulk" category.

Most liquid chemicals are generally carried in bulk form by parcel tankers or in nonbulk form in steel drums or cylinders. An exception is anhydrous ammonia, a gas that is frequently transported in liquefied form in specially designed tankers. Several dry chemicals can be carried in less-than-full-

---

[8] The category of nitrogen chemical fertilizers has been arbitrarily included among the "tanker" commodities. Anhydrous ammonia is transported in liquefied from by specialized tankers, while other nitrogen fertilizers are transported in liquid, dry-bulk and packaged forms by a variety of tanker and dry-cargo vessels.

EXHIBIT 7.1 CLASSIFICATION OF SPECIFIED COMMODITIES

COE Code	Commodity Class	Shipment Type for Foreign and Coastwise Movements (Percent of Tons)			Vessels Used for Bulk Shipments	
		Full Vessel	Other Bulk	Nonbulk	Tanker	Dry Bulk
1311	Crude Petroleum	100%	---	---	X	
1479	Natural Fert. Mtrl. NEC	---	---	100%		
1491	Salt	68	25%	7		X
1492	Sulfur, Dry	---	---	100		
1493	Sulfur, Liquid	100	---	---	X	
2810	Sodium Hydroxide	---	64	36		X
2811	Crude Prod-Coal Tar-Pet	---	31	69		X
2813	Alcohols	---	100	---	X	
2816	Radioactive Materials	---	---	100		
2817	Benzene and Toluene	---	100	---	X	
2818	Sulfuric Acid	---	0	100	X	
2819	Basic Chem and Prod NEC	---	---	100		
2851	Paints and Allied Product	---	---	100		
2861	Gum and Wood Chemicals	---	---	100		
2871	Nitrogen Chem. Fert.	56	36	8	X	
2872	Potassic Chem. Fert.	---	97	3		X
2873	Phosphate Chem. Fert.	---	98	2		X
2876	Pesticides-Disinfectants	---	---	100		
2879	Fertilizers & Materials NEC	---	95	5		X
2891	Misc. Chem. Products	---	---	100		
2911	Gasoline	---	100	---	X	
2912	Jet Fuel	---	100	---	X	
2913	Kerosene	---	100	---	X	
2914	Distillate Fuel Oil	---	100	---	X	
2915	Residual Fuel Oil	---	100	---	X	
2916	Lubric Oils-Greases	---	100	---	X	
2917	Naphtha. Petlm Solvents	---	100	---	X	
2921	LPG	98	---	2	X	
2922	LNG	100	---	---	X	
3271	Lime	---	0	100		X

vesselload quantities in either bulk or nonbulk form. Salt can be transported in full vesselload, other bulk, or nonbulk form. Foreign and coastwise shipments of all these commodities were assigned to the nonbulk, "other bulk", or (where appropriate) full-vessel shipment types using the allocation procedure presented subsequently. The resulting distributions across shipment types are shown in Exhibit 7.1.

Two of the commodities allocated by this procedure (sulfuric acid and lime) were estimated to be shipped entirely in nonbulk form, while shipments of the remaining commodities were distributed across two or, in some cases, all three of the shipment types. (In the exhibit, a zero indicates a percentage obtained by the procedure, while a dash indicates an option that was excluded from consideration.)

We assumed that all internal movements of all commodities are transported by inland barges in bargeload quantities (since there is little reason to use barge transport for smaller quantities).

Multi-Shipment Bulk Vessels

There are several types of bulk vessels that commonly carry more than one commodity and/or serve more than one destination.

"Parcel tankers" are used for carrying intermediate-sized shipments of a variety of liquid commodities. Stolt-Neilsen operates a large fleet of such vessels. Their vessels contain between 12 and 57 tanks (or "parcels") each. The tanks range in size from 7,000 to 40,000 tons, but we understand that some compartmentalized domestic tankers have tanks as small as 5,000 tons. The vessels are double-hulled with cofferdam bulkheads between some tanks. The tanks are self-contained vertical units, so that some tanks are better insulated from the exterior of the vessel than others. The larger vessels are deep-draft vessels operated in transoceanic service, while the smaller ones are used for coastwise movements and to provide a link between the larger vessels and ports that they do not normally serve. Commodity transfers between coastwise and transoceanic vessels are made both in port and at sea.[9]

---

[9] Betty Jane Duval, Stolt-Nielsen, Inc., personal communication, November 1990.

"Product tankers," used for transporting petroleum products, also usually carry multiple products and serve more than one destination, though their tanks are fewer and larger. Product tankers typically have 15 to 20 tanks and serve two to four destinations. Until recently, all product tankers were single-hulled. However, the Oil Pollution Act of 1990 requires the gradual replacement or conversion of these vessels by or to double-hulled vessels.

Finally, at least some use is made of dry-bulk vessels that carry multiple products and serve multiple destinations.

The Corps of Engineers Commodity Files

The Corps of Engineers (COE) commodity files contain annual data on the volume (tons) of receipts and shipments by waterway section and COE commodity code. The waterway sections may vary in width or length and may contain various types and quantities of port facilities. The file provides data on the volume of each commodity shipped or received at a specific "waterway," but it apparently does not contain data on the volume of freight carried by vessels stopping at the waterway.

For waterway sections on which through traffic is significant (including all sections of the Gulf Intercoastal Waterway), the commodity files also contain annual data on the volume of through movements of commodities. The data on through movements is apparently intended to represent all shipments carried by vessels transiting the waterway section.

Assignment of Shipment Type to Commodity Movements

Except as indicated in the first section of this memorandum, foreign and coastwise receipts at each waterway of the bulk commodities listed in Exhibit 1 were assigned one of three shipment types (full vessel, other bulk, or nonbulk) on the basis of the tons of each commodity received in 1987.

Foreign and coastwise receipts of salt (Commodity Code 1491) were classified as:

- "nonbulk" if their 1987 volume was less than 60,000 tons;
- "other bulk" if their volume was between 60,000 tons and 200,000 tons (equivalent to approximately one 15,000-ton full vessel shipment per month); and
- "full vessel" otherwise.

The same breakpoint between "full vessel" and "other bulk" was used for both foreign and coastwise shipments despite differences in the typical capacities of coastwise and transoceanic vessels (and the availability of coastal barges, with capacities as low as 10,000 tons, for some coastwise movements.)

Foreign and coastwise receipts of three dry-bulk chemicals (2810, 2811 and 2879) were split between nonbulk and other bulk on the same basis, but were assumed never to be transported in a full vessel. Receipts of potassium and phosphate fertilizer (2872 and 2873) were split between nonbulk and other bulk using a breakpoint of 20,000 tons per year. The lower breakpoint reflects the assumption that these seasonal commodities would require a minimum of only four shipments per year. Receipts of nitrogen fertilizer, which can be shipped in dry, liquid or gaseous forms, were split between all three shipment types using breakpoints of 20,000 and 120,000 tons per year. (The 120,000-ton breakpoint represents four tankerload shipments pr year in a 30,000-ton tanker.) The resulting estimate that 56 percent of nitrogen fertilizer is received in full vesselload quantities may be high, since full vessels are likely to be used primarily for anhydrous ammonia.

A common size for a small LPG tanker is 24,000 cubic meters. Since LPG weighs 0.685 short tons per cubic meter, a vessel of this size has a capacity of about 16,400 tons. An LPG terminal receiving one such tankerload shipment per month would receive 197,000 tons of LPG annually. However, a review of COE data indicates that most ports receiving significant volumes of LPG received less than 197,000 tons in 1987. Since it is unlikely that these ports received LPG in cylinders, we have used 16,000 tons as the breakpoint between tankerload and nonbulk shipment of LPG. Since the hazards of LPG transport make it appear unlikely that multiple shipments would be made in a single vessel, we presume that the observed annual volumes are the result of tankerload-shipment delivery frequencies of less than twelve per year. With the 16,000-ton breakpoint, our procedure classifies only 1.7 percent of LPG coastwise and foreign receipts as being nonbulk. This percentage includes 13,752 tons of LPG received at Bellingham Harbor (in the Seattle study zone).

As stated in the first section of this memorandum, all transport of crude oil, liquid sulfur, and LNG was presumed to be tankerload, and all transport of petroleum products was automatically classified as other bulk.

For the commodities discussed above, applying the above classification rules to all foreign and coastwise receipts in the 1987 COE commodity file produced the percentage distributions of the tonnages of these commodities across shipment types shown in Exhibit 1.

Originating and through movements of a given commodity generally represent shipments being made to multiple destinations. Shipment sizes for such movements normally are determined not by the total annual volume of traffic at the waterway in question, but by the annual volumes at the several destinations being served by these shipments. For this reason, our procedure allocates foreign and coastwise shipments and foreign and coastwise through traffic at any waterway across shipment types using the percentages (shown in Exhibit 1) derived from the corresponding analysis of receipts at all waterways in the COE commodity file.

SECTION 2.

EFFECTIVENESS OF VESSEL TRAFFIC SERVICE SYSTEMS IN REDUCING VESSEL ACCIDENTS

Prepared For:

The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Prepared By:

A.T. Kearney, Inc.
225 Reinekers Lane
Alexandria, VA
March 1991

2. EFFECTIVENESS OF VESSEL TRAFFIC SERVICE SYSTEMS IN REDUCING VESSEL ACCIDENTS

NOTE: This section documents the A.T. Kearney effort performed in support of Sections 4 and 5 of the Port Needs Study (Volume I) under Contract DTRS-57-89-D-00089, OMNI Task No. RA0012. Navigation Systems Specialists, Inc., assisted A.T. Kearney in arranging the Focus Group sessions.

SECTION 2. TABLE OF CONTENTS

SECTION 2. TABLE OF CONTENTS (Cont')

SECTION 2 EXHIBITS

SECTION 2 EXHIBITS (Cont')

1.0 INTRODUCTION AND SUMMARY

Vessel Traffic Service (VTS) systems have been variously defined and exist in a number of configurations, but their basic objective is to provide information and advice on other traffic and navigational hazards to ships and other vessels. In some instances the VTS control center has its own radar coverage of the waterway under its cognizance and directly maintains surveillance of vessel movements. Radio contact is maintained with vessels participating in the system. However in other instances the VTS system will function without its own radar coverage, and will maintain estimated tracks of vessels based on vessel reports of passing waypoints and dead reckoning. This latter method is typically termed a vessel movement reporting system (VMRS).

In order to accomplish the VTS Benefit-Cost Assessment, a detailed risk model was constructed which links the relationship among vessel traffic, the occurrence of vessel casualties, the damages and other consequences associated with the casualties, and the expected effectiveness that VTS systems could have in reducing vessel casualties and the associated damages.

One of the major components of the risk assessment process was an analysis of the historical vessel casualty statistics in ports. The term "casualty" used throughout this report refers to a vessel casualty which is essentially synonymous with a vessel involved in an accident. Based on future expected volumes of vessel traffic, and vessel casualty propabilities future numbers of vessel casualties were projected to represent the situation before the introduction of any VTS system. Casualty rate reduction factors were then defined which reflected the estimated reduction in vessel casualties that could be expected to occur with the introduction of VTS systems.

The development of the casualty rate reduction factors was the subject of the VTS effectiveness analysis portion of the study. This was undertaken by A. T. Kearney and the results of that work is summarized in this report.

Exhibit 1-1 provides an overview of the VTS effectiveness analysis. In simplified form, the risk analysis determines VTS benefits by multiplying the casualty rate reduction factors times the projected number of vessel casualties times the dollar damage per casualty. This is done for a series of combinations of casualty types, waterbody types and vessel types. The casualty types are broken down into three types consisting of:

- Collisions
- Rammings
- Groundings

In the overall risk model the waters of the 23 ports under study were broken down into six subzone types reflecting differences in the character of each waterbody. These six waterbody or subzone types consisted of waters having the character of an:

- Open Approach
- Convergence Area
- Open Harbor or Bay
- Enclosed Harbor
- Constricted Waterway
- River

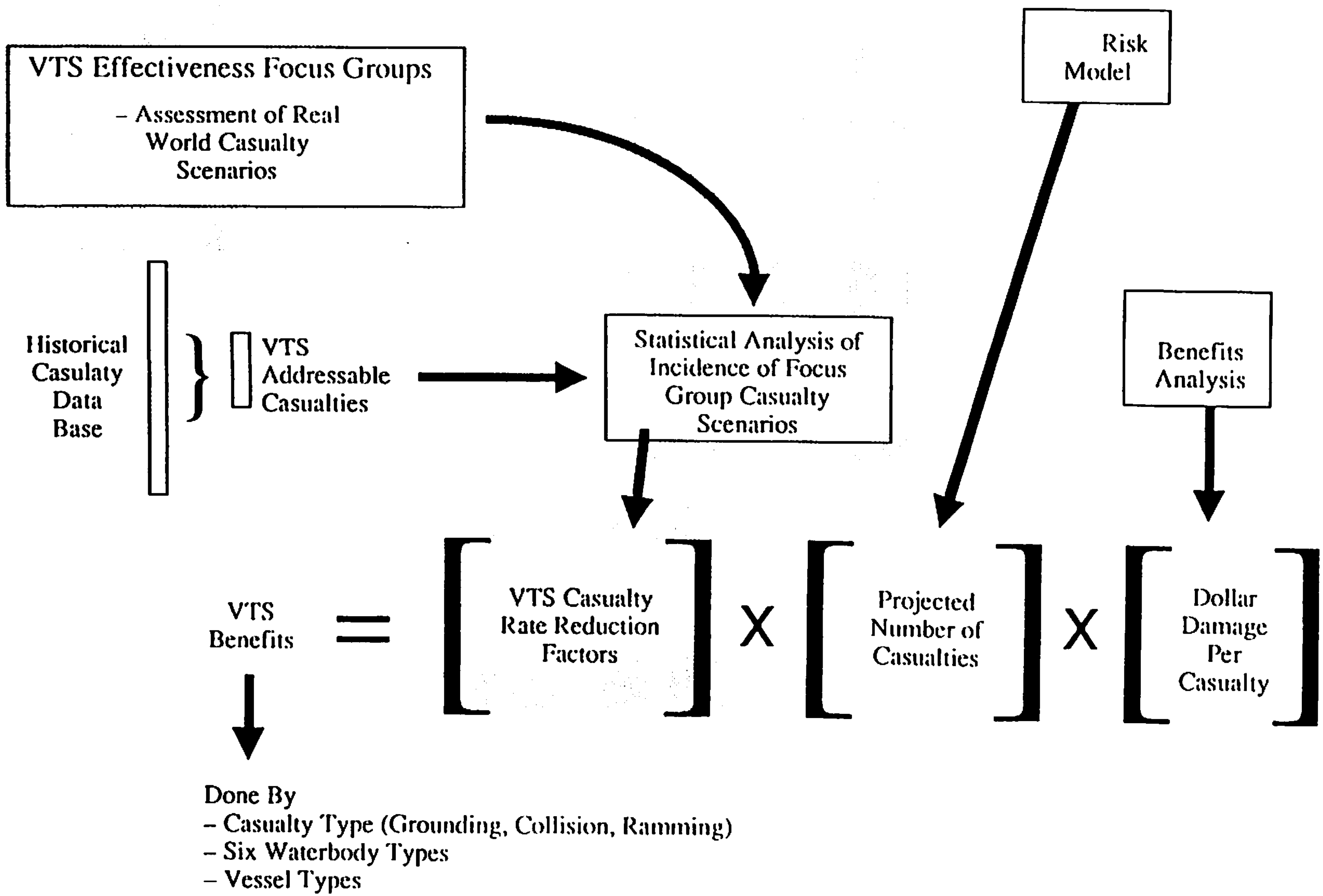
The ports that were studied included:

- Boston
- Puget Sound
- Los Angeles / Long Beach
- Santa Barbara
- Port Arthur, TX
- New Orleans
- Houston / Galveston
- Chesapeake Bay (Norfolk / Hampton Roads)
- Baltimore
- Corpus Christi, TX
- New York
- Philadelphia
- Long Island Sound
- San Francisco
- Portland, OR
- Cook Inlet, AK
- Portland, ME
- Portsmouth, NH
- Providence, RI
- Wilmington, NC
- Jacksonville, FL
- Tampa, FL
- Mobile, AL

A number of vessel types were defined based on their size and characteristics.

The projected number of casualties were based on the Coast Guard CASMAIN commercial vessel casualty data base. From this a subset of "VTS addressable" casualties were determined based on a detailed review of the Coast Guard accident report narratives.

Overview Of VTS Effectiveness Analysis



ATK1/1304/4ks

The "addressable" casualties consisted of those where it was initially felt that a VTS system had at least some potential to prevent the accident from occurring. That a casualty was "addressable" did not mean that a VTS could prevent it with 100 percent probability.

The key objective of the VTS effectiveness analysis was to determine the expected percentage (represented by the casualty rate reduction factors) of the "addressable" casualties that could be prevented with the introduction of some form of VTS. A second objective of the effectiveness analysis was to provide historical adjustment factors to the casualty data base being used in the risk model to account for those ports that had a VTS system in place in the past.

A number of alternative VTS performance levels were defined initially to help define the various technologies that could be employed. Ultimately three levels of VTS system performance were defined consisting of:

- Level I - Vessel Movement Reporting System
- Level II - Basic Radar Surveillance
- Level III - Advanced Radar Surveillance
- Level IV - Automatic Dependent Surveillance

For each study zone a Candidate VTS Design was developed consisting of various combinations of the above technology for each port. The appropriate casualty rate reduction factors were then selected and assigned to each waterbody/subzone in these zones. The Candidate VTS Design tended to be dominated by the Level III technology.

As shown in Exhibit 1-1 the development of the casualty rate reduction factors were based on a synthesis of expert opinion. This involved a two-step process. First, a series of Focus Groups were conducted using participants having expertise and previous experience with VTS systems and vessel operation. The Focus Groups developed a series of VTS effectiveness estimates for a number of real world vessel accident scenarios. These scenarios were developed to correspond to real world casualty situations to which the panel participants could respond. The panels were carefully structured to focus on specific causal factors and those linkages where VTS could successfully intervene to prevent the accident.

Next, it was necessary to convert the results from the Focus Groups into casualty rate reduction factors which correspond to the data base of VTS addressable casualties. This entailed a detailed statistical analysis of the cases in the addressable casualty data base. It is very important to note that:

The VTS casualty rate reduction factors are directly related to the definition of "addressable" casualties used in determining the study vessel casualty data base.

Considerable effort was devoted to the development and refinement of the framework for the VTS effectiveness analysis. Considerations for the framework included:

- The results of previous efforts in Canada and Europe.
- The nature of collisions in the U.S. port areas under study.
- The differing VTS performance features that must be addressed.
- The particular characteristics of the ports and waterways under study.
- Effective coordination with other portions of the risk analysis.

A major literature review was conducted directed toward reviewing and synthesizing the body of literature that addresses the estimation of VTS effectiveness. Previous work in this area was reviewed including that performed in the U.S. as well as foreign countries. In initially approaching the project, three potential alternative techniques were identified consisting of:

- Statistical analysis of casualties in situations "with and without" a VTS.
- Simulation of a VTS system.
- Synthesis of expert opinion

Based on this review the current state of experience suggests that statistical "with and without" analysis of VTS effectiveness may not be practical in the short run. Previous attempts of this type addressed in the literature were reviewed. It was concluded that although there are some isolated results that provide some evidence on VTS effectiveness, comprehensive results do not appear to be forthcoming. In most cases there are too many complicating factors to produce definitive answers.

There has been some discussion in the literature of simulation methods to address VTS effectiveness. These methods include the use of full bridge simulators coupled with a simulation of a VTS center as well as various forms of mathematical simulation. Some work of this type has been done in Europe. However, the conclusions to date suggest that such methods are nowhere near capable of addressing VTS effectiveness in the overall context.

Thus the current study used the synthesis of expert opinion as the primary method to develop VTS effectiveness estimates. Two major VTS effectiveness projects, one in Canada and one in Europe, used variations of this technique, apparently because of the lack of efficacy of the alternative approaches.

Vessel Traffic Systems (VTS) were first instituted in the United States in the early 1970's. Systems were installed in San Francisco, Valdez Alaska and Puget Sound and later New Orleans, New York a portion of the Intercoastal Waterway in Louisiana and Houston/Galveston.

Vessel traffic systems can either be voluntary or mandatory. Many of the systems that have been implemented in the United States have been voluntary, although compliance among the larger classes of vessels has generally been high. There is a wide range of system performance levels across VTS systems. These relate both to the technology employed as well as the level of operational procedures utilized. As noted above the basic distinction is between systems with and without radar coverage. The type and extent of radar coverage can vary greatly. Newly developed radar systems may utilize computer technology to provide automatic track analysis that can plot vessel tracks, predict future vessel trajectories, sound alarms if the vessel track indicates a hazardous situation and provide identification information on individual vessels.

Operational procedures are also important in defining VTS performance levels. These relate to the degree to which VTS operators are going to monitor individual vessel tracks with respect to traffic or hydrological hazards. A major principle of VTS operation in the United States to date has been that ultimate responsibility for controlling the vessel rests with the pilot or officer on duty and that VTS is to serve only an advisory and information-providing role.

Several ports in Europe have functioning VTS systems. Newly developed systems are being implemented which utilize the latest developments in technology and operating procedures. Interest is now being expressed in expanding the coverage of VTS systems in the European area to include extended coastal areas in addition to ports and their approaches.

There is a wide range of system performance levels across VTS systems. These relate both to the technology employed as well as the level of operational procedures utilized. As noted above the basic distinction is between systems with and without radar coverage. The type and extent of radar coverage can vary greatly. Newly developed radar systems may utilize computer technology to provide automatic track analysis that can plot vessels tracks, predict future vessel trajectories, sound alarms if the vessel track indicates a hazardous situation and provide identification information on individual vessels.

Operational procedures are also important in defining VTS performance levels. These relate to the degree to which VTS operators are going to monitor individual vessel tracks with respect to traffic or hydrological hazards. A major principle of VTS operation in the United States to date has been that ultimate responsibility for controlling the vessel rests with the pilot or officer on duty and that VTS is to serve only an advisory and information-providing role.

Section 2.0 of this report summarizes some of the key findings from the literature review. Section 3.0 discusses the results from the Focus Groups. Section 4.0 describes the procedure for the development of the casualty rate reduction factors. Section 5.0 describes the assessment of historical VTS coverage in U. S. ports that was developed for the adjustment of the casualty statistics in the risk model.

2.0 LITERATURE RELATED TO VTS EFFECTIVENESS

A literature search was initiated to review previous research and analysis relevant to the determination of VTS system effectiveness. This was directed toward evaluating alternative approaches to measuring VTS effectiveness as well as identifying actual data measuring the casualty reductions that could be expected through the implementation of a VTS.

Sources for the literature search included bibliographies of previous reports on the subject area, a review of shipping, navigation and other marine journals and a search of various maritime abstracts. In addition a computer index search was initiated through the Maribase on-line search facility of the National Maritime Research Center (Maritime Administration, Kings Point, New York). The primary thrust of the literature review was to identify:

- Previous studies of VTS effectiveness from which the relative value of alternative approaches could be assessed.

- Previous investigations of VTS effectiveness which could provide data for comparative purposes.

- General studies of navigation safety that could be used to help establish linkages between the functions of a VTS and the prevention of one of the chain of events leading to a vessel accident.

- Information having ancillary background relevance to understanding the functions and technology of a VTS system.

It was found that an abundance of literature exists that is related to describing the functions of VTS systems. The range of aspects of VTS-related literature includes: history; organization and functions; authority in which control of VTS is vested; equipment and capital projects; staffing; training and qualifications for personnel; and future plans for VTS programs.
Much of this literature, while helpful in developing an overall understanding of VTS, did not address the central question of: What is the quantitative effectiveness of a VTS?

The main source of data from previous research addressing VTS effectiveness can be found in previous work performed by the U.S. Coast Guard, a major research effort undertaken by Canada, research performed for the European COST 301 program and various papers presented at the Proceedings of International Symposiums on Vessel Traffic Services.

Based on the extensive literature search conducted, the following summaries are presented of key pieces of secondary information related to quantifying VTS effectiveness. Some of this work relates to overall estimates of VTS effectiveness, while other analyzes a specific aspect.

In interpreting the results it is important to bear in mind the differing circumstances to which they apply. In particular, it should be noted that a specific quantitative estimate of effectiveness is highly related to the precise character of the casualty statistics to which it applies.

2.1 Cost 301 Final Report - Annex to Main Report: Volume 2 The Maritime Environment, Traffic and Casualties[1]

The COST 301 project was a program established by the European Community in the early 1980's to assess the risk to marine traffic in European waters and promote safety through shore-based navigation aids including VTS systems. A large volume of material has been produced in conjunction with this program.

This particular report discussed potential approaches to establishing effectiveness measures for VTS systems. The study concluded that there are two primary approaches to measuring VTS effectiveness:

- **The collection of opinions of experienced mariners and/or VTS Operators.** It was pointed out that this method had been used in the Canadian Coast Guard Study (Canadian Coast Guard, 1984) and in a VTS effectiveness analysis previously performed in connection with the COST 301 program (Kemp et al., 1986).

- **The application of systems analysis.** The study pointed out that usually a maritime casualty can be seen as a dynamic sequence of certain events in the control loop(s) which results in poor control of the process, or to the breaking of the control loop. Information on the following questions, which is of primary importance in the assessment of the effect of VTS on casualty rates, is deficient:

  - What is the interaction between ships and the VTS operator?

  - How can a VTS system produce necessary or favorable environmental conditions for the ship?

It was proposed that the first question could potentially be answered by real-time simulations and the last one by mathematical simulations and analysis. It is noteworthy that consideration was

---

1 Commission of European Communities, 1987. The Maritime Environment, Traffic and Casualties, COST 301 Final Report - Annex to the Main Report: Volume Two.

not given to "before and after" statistical analysis, apparently because the efficacy of such an approach did not appear promising.

The authors feel there is a limitation in assessing the effectiveness of VTS by casualty analysis alone. In general, they conclude that all studies on causal factors of casualties are based on limited information collected after the casualties. This information does not usually cover the general situation in time or place. Therefore, the most important feature of the "ship plus VTS" system cannot be quantified. The effect of the VTS on the ship environment and time-dependent causal factors cannot be studied.

An analysis of VTS effects using the existing casualty data (generally inadequate) can consider only tactical interactions by a VTS. Generally, there is not sufficient data concerning the early events in an incident to be able to assess how effective strategic planning might have been.

According to the analysis, human and environmental factors contribute to approximately 90 percent of all casualties, while technical factors account for the remaining 10 percent. Strategic interactions by a VTS, by reducing the number of critical situations and providing warning of them in advance to navigators, can affect human and environmental factors. Thus, the unsuitability of existing casualty data for studying the effects of strategic planning by a VTS represents a significant shortcoming in the assessment of VTS benefits using a simulation approach.

2.2 Assessment of Risk to Shipping Through Collisions and Strandings in the COST 301 Area[2] .

The particular report discussed here includes a summary of the VTS effectiveness section of the most recently available COST 301 main report.

To develop estimates of the effectiveness of VTS on the collision and stranding (grounding) rate, a questionnaire was designed to measure the effectiveness of varying levels of VTS systems. The questionnaire was personally administered by an investigator to practicing mariners (mainly ship masters) with experience in a representative variety of European waters. The COST 301 study team felt the best way to gather estimates was from personally administering the questionnaires to the subjects to ensure they

---

2 Kemp, J.F., E. M. Goodwin and K. Pick. 1986. Assessment of Risk to Shipping Through Collisions and Strandings in the COST 301 Area. Problem Area Identifier Report on COST 301 Task No. 2.46. UK Department of Transport and Commission of European Communities.

fully understood the questions and the rating system.

The questionnaire results of the potential effectiveness of specified levels of VTS in reducing collision rates are summarized in Exhibit 2-1. From the questionnaire results the study noted three main conclusions related to the effectiveness of VTS on collision rates.

- The more sophisticated the shore support facilities become, the less difference there is between the effectiveness ratings.

- The results suggest that experienced mariners see little or no benefit in terms of risk reduction in the introduction of a control service rather than an information service.

- The maximum benefit to be obtained through the introduction of a VTS system is approximately 60 percent overall.

This study then weights collision effectiveness by the relative proportion of the different types of encounters (meeting, crossing or overtaking). For areas with a normal mix of the various types of encounters, the mean collision reduction factor was estimated to be approximately 0.5 for a VTS system with radar surveillance but no transponders.

The questionnaire results of the potential effectiveness of specified levels of VTS in reducing stranding rates (groundings) are summarized in Exhibit 2-2. For VTS effectiveness on vessel stranding rates the report notes two points of interest.

- The results are consistent with those for collision rates in that the subjects see only a small advantage in terms of risk reduction in the introduction of a control service rather than an information service at either of the VTS levels.

- The maximum benefit which is likely to be obtained through the introduction of any VTS system is estimated to be 55 percent.

Exhibit 2-1

Estimated Effect of VTS on Collision Rate Based on Expert Option from Research Under the Cost 301 Program

Shore Support Level	Estimated Reduction of Collision Rate — Type of Encounter: Meeting	Crossing	Overtaking
International Collision Regulations Only	0	0	0
IMO Traffic Separation	.68	.25	.04
Vessel Traffic Information Service Based on a Ship Reporting System	.47	.33	.22
Vessel Traffic Information Service Based on Ship Reporting & Surveillance	.57	.45	.32
Vessel Traffic Information Based on Transponder Identification, Location and Information Exchange	.61	.52	.42
Vessel Traffic Control Service Based on a Ship Reporting System	.44	.42	.30
Vessel Traffic Control Service Based on Ship Reporting and Surveillance	.53	.45	.39
Vessel Traffic Control Service based on Transponder Identification, Location and Information Exchange	.58	.54	.51

Source: Kemp, J.F., E. M. Goodwin and K. Pick. 1986. Assessment of Risk to Shipping Through Collisions and Strandings in the COST 301 Area. Problem Area Identifier Report on COST 301 Task No. 2.46. UK Department of Transport and Commission of European Communities.

Exhibit 2-2

Estimated Effect of Shore Support on Stranding Rate Based On Expert Option from Research Under the Cost 301 Program

Shore Support Level	Estimated Reduction of Stranding Rate
Existing Level of Lighthouses and Buoyage and Statutory On-Board Equipment	0
Enhanced Level of Lighthouses and Buoyage	.25
Accurate Radio Navigation Aid Coverage (i.e., Decca Navigator or Loran C) with Compulsory Carriage of Equipment on Ships	.44
IMO Traffic Separation	.29
Vessel Traffic Information Service Based on a Ship Reporting System With Radar Surveillance	.40
Vessel Traffic Information Service Based on Transponder Identification, Location, and Information Exchange	.49
Vessel Traffic Control Service Based on Ship Reporting System with Radar Surveillance	.45
Vessel Traffic Control Service based on Transponder Identification, Location and Information Exchange	.55

Source: Kemp, J.F., E. M. Goodwin and K. Pick. 1986. Assessment of Risk to Shipping Through Collisions and Strandings in the COST 301 Area. Problem Area Identifier Report on COST 301 Task No. 2.46. UK Department of Transport and Commission of European Communities.

The study points out that the potential of VTS for reducing stranding rates is somewhat less than for reducing collision rates. The study concluded that there is only a negligible reduction in the casualty rate as a result of a VTS having only VHF communication with no radar surveillance. This is because, if a VTS operator does not know where a ship is at a given moment he will be unable to give warning if it should be tracking outside a channel's limits. In the case of a VTS that includes radar surveillance capability, but does not have transponders the estimated reduction in strandings was estimated to be 0.40.

The questionnaire also requested estimates of the relative contribution respectively of environmental, on-board or shore-support factors on the collision and stranding rates. Shore-support factors would include VTS and similar systems. These results are presented in Exhibit 2-3.

Exhibit 2-3

Relative Effects of Factors Affecting the Collision and Stranding Rate

Component	Relative Affect on Collision Rate	Relative Affect on Stranding Rate
Environment Factors	29.7%	31.8%
On-board Factors	52.1%	51.7%
Shore Support Factors	18.2%	16.5%
Total	100.0%	100.0%

The study notes that shore support factors are rated the lowest of the three components affecting collisions. On-board factors have the highest impact, which, according to the study, suggests that work to improve on-board capabilities should continue as a parallel activity to VTS development.

2.3 National Vessel Traffic Services Study, Canadian Coast Guard, October 1984[3]

This study, performed to assess the benefits and costs of the Canadian VTS, is one of the primary documents specifically addressing the effectiveness of VTS. The geographic configuration

---

3 Canadian Coast Guard, 1984. Vessel Traffic Services, Final Report. National Vessel Traffic Services Study. Document TP5965-1E. Ottawa, Canada, October.

of the waterway, the complexity of vessels' interactions in these waterways, and the level of system sophistication were the primary factors considered in the development of a detailed model of VTS costs and benefits. The effectiveness portion of this study focused on developing effectiveness measures for four different waterway configurations and a number of alternative VTS system configurations. Some of the steps taken to develop the overall evaluation framework included:

- Definition of four waterway types or categories which represent the various configurations found in the 106 study areas;
- Classification of each study area by its waterway type;
- Projection of the amount of traffic and the associated risk factors in each of the study areas;
- Determination of the potential effectiveness of each VTS system configuration for each of the four waterway types.

The study assessed the effectiveness of the following VTS system features regarding their ability to reduce the probability of a casualty:

- Traffic Separation Schemes (TSS);
- Movement Restriction Regulations (MRR);
- Bridge-to-Bridge VHF reporting at designated points (B/B);
- Ship-to-Shore VHF reporting and information exchange plus simulated vessel tracking (S/S);
- Ship-to-Shore VHF communications and information exchange <u>plus</u> basic radar surveillance (i.e., without automated tracking and target analysis (S/R));
- Ship-to-Shore VHF communications and information exchange <u>plus</u> radar surveillance supplemented by computerized target tracking, interactive target analysis, hazard warning, and data storage and retrieval (S/R+).

The following four waterway types were defined as being representative of the study area:

- **Open Simple Waterways** (i.e., open bays or wide straits) are those in which vessel maneuverability is not unduly restricted by geographic constraints. The interactive movements of vessels are normally straightforward meetings, crossings and overtakings.

- **Open Complex Waterway** (i.e., an approach to a busy harbor or pilot boarding situation) are those in which vessel maneuverability is not unduly restricted by geographic constraints. The interactive movements of vessels are unstructured. Multiple interactions may occur simultaneously. Vessels may not be following predictable courses or speeds, and meetings or crossings may occur at any angle.

- **Confined Simple Waterways** (i.e., a river) are those in which vessel maneuverability is restricted because of its continuing proximity to fixed hazards such as the shoreline, shoals, rocks, bridges, and other stationary equipment. The interactive movements of vessels are normally straightforward meetings, crossings, and overtakings.

- **Combined Complex Waterways** (i.e., a harbor) are those in which vessel maneuverability is restricted because of its continuing proximity to fixed hazards such as the shoreline, shoals, rocks, bridges and other stationary structures. The interactive movement of vessels are unstructured. Multiple interactions may occur simultaneously. Meetings or crossings may occur at many angles.

Estimates of VTS effectiveness in terms of the percent reduction in accidents for "addressable" groundings, collisions, or strikings were developed using the knowledge and experience of a team of personnel with marine-related backgrounds. These persons included former mariners, VTS regulators and consultants, as well as Canadian Coast Guard management, both in the regions and at headquarters. The results are presented in Exhibit 2-4 by type of waterway and level of VTS service.

According to Exhibit 2-4, the various levels of VTS effectiveness in reducing casualties was estimated to range from 15 to 70 percent. When applied to the whole Canadian VTS program the average VTS effectiveness was estimated to be 43.3 percent. Note that the apparent baseline for the VTS effectiveness estimates consists of a traffic situation without mandatory bridge-to-bridge communication or traffic separation schemes.

Exhibit 2-4

VTS Effectiveness for Addressable Incidents
Based on Canadian National VTS Study

(Percent Reduction in Accidents)

VTS Level of Service	Open Waters: Simple Traffic Patterns	Open Waters: Complex Traffic Patterns	Confined Waters: Simple Traffic Patterns	Confined Waters: Complex Traffic Patterns
Bridge-to-Bridge				
Without TSS/MRR	12	10	15	10
With TSS/MRR	35	25	20	15
Vessel Movement Reporting (VMR)				
Without TSS/MRR	35	20	40	30
With TSS/MRR	40	30	45	35
Basic Radar Surveillance				
Without TSS/MRR	45	50	45	50
With TSS/MRR	55	55	55	65
Radar with Automatic Track Analysis				
Without TSS/MRR	55	65	50	55
With TSS/MRR	65	70	60	70

TSS stands for traffic separation schemes in which vessels moving in opposite directions are required to stay in their own lanes. MRR stands for movement restriction regulations in which vessel movements are actively controlled to prevent meetings at hazardous locations.

Source: Canadian Coast Guard, 1984. Vessel Traffic Services, Final Report. National Vessel Traffic Services Study. Document TP5965-1E. Ottawa, Canada, October.

2.4 Vessel Traffic Systems: Analysis of Port Needs, U.S. Coast Guard, August 1973[4]

This was one of the original VTS effectiveness studies performed by the U.S. Coast Guard nearly 20 years ago. The overall purpose of this study was to rank 23 ports of the U.S. in order of their VTS needs using a cost-benefit algorithm. As part of this study the Coast Guard analyzed the casualty data base and looked for accidents that could have been addressed and prevented by a VTS over a three year period (1969-1972). This study assessed the effectiveness of VTS by examining the casualty data base for these three years. The percent reduction of accidents as a result of VTS was derived by analyzing which accidents in the database were potentially preventable by a VTS system. Exhibit 2-5 summarizes the estimated reduction in vessel accidents by VTS level.

Exhibit 2-5

Estimated Reduction in Vessel Accidents by VTS Service Level

VTS Service Level	Collision, Ramming, or Grounding	Collision Only
Bridge to Bridge Radiotelephone	10%	21%
Regulations	13%	21%
Traffic Separation Scheme	12%	24%
Vessel Movement Reporting System	23%	49%
Basic Radar Surveillance	30%	60%
Advanced Radar Surveillance	32%	65%
Automated Advanced Surveillance	31%	65%

4 U. S. Coast Guard, 1973. Vessel Traffic Systems, Analysis of Port Needs, Final Report. Document Number AD-770-710. U. S. Coast Guard Headquarters, Washington D.C., August.

The last three estimates of VTS effectiveness for alternative types of radar surveillance systems hovered around the 60 to 65 percent range for collisions only and the 30 to 32 percent range for a mix of collisions, rammings and groundings.

2.5 Casualty Analysis of Selected Waterways[5]

The purpose of this paper was to update the previous Coast Guard analysis of several ports and waterways in light of marine casualties that had been reported during fiscal years 1973 through 1976. Five specific areas were analyzed including Delaware Bay, Chesapeake Bay, Tampa Bay, and two segments of the Gulf Intracoastal Waterway West, Mile 50-130 and Mile 260-290.

The approach taken for this analysis was to compile a four-year data base of operational marine casualties for the five selected waterways based on the U.S. Coast Guard's Vessel Casualty Reporting System. For those casualties within the VTS domain, certain information was extracted and a determination was made for each case whether the presence of some form of VTS would have affected the casualty incident.

The analysis estimated the effect VTS would have had on accidents in the five study areas noted above. The following is a summary of the VTS effectiveness findings for those five areas.

Delaware Bay.
This analysis assumed VTS would be a radar surveillance system with communication capability in the Precautionary Area of the lower Bay, and the implementation of regulations directed toward specifying the number and power requirements for tugs in the Marcus Hook Range and the C and D Canal junction area. In total, approximately 28.5 percent of the accidents could have been prevented by the presence of a VTS.

Chesapeake Bay.
It was assumed that radar would only provide coverage at the entrance Traffic Separation Scheme, Thimble Shoals Channel, Hampton Roads, and ports therein, the center of the bay up to the C & D Canal, and the Port of Baltimore. Major tributary rivers had insufficient traffic volume and casualties to be considered for possible VTS activity. In total, approximately 28.4 percent of the accidents could have been prevented by the presence of a VTS.

---

5 Ecker, William J. Casualty Analysis of Selected Waterways. In: Third International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Liverpool, 1978.

Tampa Bay.
It was assumed that VTS having radar capability extended to all areas of the Bay navigable by deep draft vessels. In this zone, it was estimated that 33.3 percent of the casualties could have been prevented by the presence of a VTS.

Gulf Intracoastal Waterway West Miles 50-130.
In this case, the casualty analysis assumed that all levels of VTS could be applied to all the waterways interfacing this Mile 50-130 section of the Gulf Intracoastal Waterway. It was found that approximately 28.4 percent of the casualties reported in this area could have been prevented by VTS.

Gulf Intracoastal Waterway West Miles 260-290.
It was assumed that all VTS levels could be extended over the entire waterway complex. It was judged that approximately 40.3 percent of the casualties could have been preventable by VTS.

Exhibit 2-6 summarizes the VTS preventable percentage of accidents from the five study areas.

Exhibit 2-6

Estimated Percentage of Accidents Preventable by VTS

Study Area	Percent VTS Preventable
Delaware Bay	29%
Chesapeake Bay	28
Tampa Bay	33
Gulf Intracoastal Waterway West Miles 50-130	28
Gulf Intracoastal Waterway West Miles 260-290	40
Average Preventable Accidents:	32%

2.6 Proceedings: Symposium on Piloting and VTS Systems[6]

In this presentation, Capt. Daniel Charter, who at the time was Chief, Port Safety and Law Enforcement Division, U.S. Coast Guard reviewed some of the U. S. experience with VTS systems. He reviewed some of the results from the earlier Coast Guard VTS study (U.S. Coast Guard, 1973) and presented some observations based on the current historical operating experience.

He noted that earlier study was based on a process that was largely theoretical because none of the Coast Guard VTS systems had been in operation long enough to tell what they could and could not do. Since the Coast Guard now had several years of VTS experience in the ports of San Francisco and Puget Sound, he focused on the conclusions that could be drawn from that experience. He reported that they were unable to isolate the effect of VTS from all the other dynamic changes in those harbors (i.e., varying port volume and types of cargo, regulatory actions and improvements in the harbor, and improved accident reporting accuracy). Therefore, the study was unable to conclude that accidents have been substantially reduced in these two ports.

He did, however, report some data for the port of San Francisco. The average number of accidents in the area covered by the VTS for the "pre-VTS" years was 13.3, while for the "post VTS" years it was 11.4. The number of collisions had dropped, however, he advanced skepticism over such a simple "before and after" analysis.

2.7 Casualty Analysis of Berwick Bay VTS[7]

This paper presents vessel casualty data useful for evaluating the effectiveness of the VTS at Berwick Bay, Louisiana. This is a relatively small VTS which has been set up to monitor the confluence of four waterways. At one point there is a railroad bridge across the Atchafalaya River, just above the intersection of two waterways. Bridge rammings or collisions in the vicinity of bridge have been a historical problem in this area. The combination of converging traffic patterns and winding waterways that inhibit visual warning of approaching traffic, coupled with

---

[6] Charter, Daniel, 1979. Proceedings: Symposium on Piloting and VTS Systems. The National Research Council, Maritime Transportation Research Board, Commission on Sociotechnical Systems.

[7] Carpenter, Steve, 1988. Cost Recovery for Vessel Traffic Service Operations: An Evaluation of Value Added and Fee Assessment. In: Sixth International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Gothenburg, Sweden.

a narrow channel in the vicinity of the bridge, has created a particular hazard. This is exacerbated by high currents, winding channels and other bridges in the area which create obstacles.

The Berwick Bay VTS began operation in February, 1974. During the five years from 1969 through 1973 there were 80 vessel casualties; whereas between 1974 and 1979, a period of six years there were only 32. Vessel collisions fell by 64 percent. Rammings were reduced 76 percent, from 9.4 to 1.3 per year. During this period the traffic volume was in a fairly steady state.

It is noted that there are several factors which may have influenced the accident rate. In 1971 the railroad bridge span was moved to more closely align with a highway bridge immediately up river. Also the riverstage in the waterway reached record high levels during the high water season of 1973.

2.8 Recent Trends in Navigational Safety in the Dover Strait[8]

This paper considers how the safety of Dover Strait shipping has been influenced by the emergence of a traffic separation scheme and a fully fledged radar surveillance VTS known as the Channel Navigation Information Service. The annual rate of collisions is used to measure variations in the level of safety.

A summary of the number of collisions in the Dover Strait over 15 years is presented in Exhibit 2-7. The years mid-1962 to mid-1967 are considered the baseline period. The years mid-1967 to mid-1972 coincide with the introduction of the Dover Strait traffic separation scheme. The years mid-1972 to mid-1977 represent the period after which the Channel Navigation Information Service had fully evolved.

The data in Exhibit 2-7 are presented in terms of the total number of collisions as well as collisions between ships on opposing courses. Data are also presented for the post 1967 period in terms of collisions in all waters in the area and collisions in the main traffic lanes. It was concluded that there was only a marginal increase in traffic in the period under consideration.

---

8 Johnson, D. R., 1978. Recent Trends in Navigational Safety in the Dover Strait. In: Third International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Liverpool.

Exhibit 2-7

Summary of Collisions Over 15 Years in the Dover Strait

	Baseline	Dover Strait Traffic Separation Scheme (TSS)		TSS & Channel Navigation Information Service (VTS)	
Years	Mid 62-Mid 67	Mid 67-Mid 72		Mid 72-Mid 77	
	A.W.	A.W	M.L.	A.W.	M.L.
All Collisions	69	53	32	24	11
Ships on Opposing Courses	50	52	16	7	1

A.W. stands for All Waters

M.L. stands for Main Lanes

From these data it is apparent that over the five year period following the introduction of the TSS there were 23 percent fewer collisions than in the previous five years. Sixty percent of the collisions that did occur, occurred in the main traffic lanes.

During the next five years, when the TSS routing scheme was supported by the evolution of the Channel Navigation Information Service, there was a further 55 percent reduction in the number of collisions. Only 46 percent occurred in the one-way shipping lanes. The reduction in collisions occurring in the one-way shipping lanes indicates that the disciplinary function of traffic surveillance has an effect on navigational safety.

According to the analysis in the paper, the record of collisions from 1960 to 1977 followed a generally downward trend in numbers. A major ingredient in the downward trend is the reduction in collisions involving vessels on opposing courses. Johnson concludes that despite the limitations in the statistical significance of the data that may preclude firm conclusions being drawn on a rigorous scientific basis, there is good reason to believe that the TSS and the VTS implemented in the Dover Strait have played a significant part in the favorable downward trend in vessel collisions over the study period.

2.9 Safety Assessment of Waterway Network in Tokyo Bay Area[9] [10]

The time trend of the number of traffic accidents in the Tokyo Bay is studied to evaluate the effectiveness of the Tokyo Bay Traffic Advisory Center. To cope with the increasing frequency of accidents during the 1960's in the Tokyo Bay the Maritime Traffic Safety Law[11] was enacted in 1973. This law established routing schemes in congested waters. A VTS system, the Tokyo Bay Traffic Advisory Service Center (TASC)[12] was established in 1975 and its operation began in 1977. This paper attempts to measure the relative effectiveness of the Maritime Traffic Safety Law and the Tokyo Bay Traffic Advisory Center by comparing the number of accidents prior to the establishment of the traffic schemes to the number of accidents after the establishment of the traffic schemes as well as after the establishment of the traffic advisory center.

Kuroda and Kita concede that evaluating and/or predicting the effects of marine safety policies are generally very difficult because many factors influence the marine disaster. However, they use a relatively straightforward approach by evaluating the effects before and after marine traffic system systems were implemented. In addition they provide information of the Japanese nationwide trend of marine accidents for comparison. Statistics of marine accidents in Tokyo Bay are presented in Exhibit 2-9. During the 1973 to 1976 period, after traffic separation schemes were initiated, the frequency of vessel collisions was reduced by 15 percent. During the same period vessel groundings were reduced 23 percent and the overall accident rate was reduced by 18 percent.

---

9 Kuroda, K. and H. Kita, 1990. Safety Assessment of Waterway Network in Bay Area. In: Proceedings of the 27th International Navigation Congress, Osaka - May 1990.

10 Fujii, Y. and S. Kaku, 1981. Time Trend of Traffic Accidents in Japan Before and After the Maritime Traffic Safety Law. In: Fourth International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Bremen.

11 The Marine Traffic Safety Law essentially established navigational rules in Tokyo Bay (i.e., traffic separation schemes and speed limits). It was a passive traffic management system.

12 TASC is an active VTS that provides information regarding collision avoidance, correcting navigation, scheduling arrival and departure of large ships, as well as advising on weather. The center has three radar sites, displays for traffic data, radio and communication equipment and recorders.

After the Tokyo Bay Traffic Advisory Center became operational in the 1977 to 1982 period, the frequency of vessel collisions was reduced another 32 percent. During the same period vessel groundings were reduced another 29 percent and the overall accident rate was reduced by 30 percent.

Exhibit 2-8

Tokyo Bay Percent Index of Historical Accidents (1969-1972= 100 percent)

Time Period	Collision	Grounding	Total
1969-1972 - Base	100%	100%	100%
1973-1976 - TSS	85%	77%	82%
1977-1982 - VTS	58%	55%	57%

Exhibit 2-9 outlines the trend in the national accident data where there was only one other port with any sort of marine safety system in place. This exhibit indicates that nationwide accident reduction was far less than for the Tokyo Bay where the marine safety systems were initiated.

Exhibit 2-9

Nationwide Percent Index of Historical Accidents in Japan **(1969-1972= 100 percent)**

Time Period	Collision	Grounding	Total
1969-1972 - Base	100%	100%	100%
1973-1976 - TSS	95%	86%	92%
1977-1982 - VTS	87%	75%	83%

From these data according to the authors, it is apparent that the implementation of the Marine Traffic Safety Law and the Tokyo VTS were instrumental in reducing the number of accidents in Tokyo Bay. They would also indicate that the Marine Traffic Safety Laws accounted for a larger incremental reduction than the TASC.

It should be noted that the figures presented in Exhibit 2-8 represent all accidents in the area under study and have not been sorted to identify VTS addressable accidents. Another study[13] presents data on the number of accidents in the main channels of the Tokyo VTS. These data may be more representative of VTS addressable accidents. These data indicate that the number of accidents dropped 58 percent after the introduction of the Tokyo VTS.

Normalizing this apparent accident reduction rate associated with the Tokyo VTS by taking into account the overall nationwide downward trend in marine accidents, would suggest that the percentage reduction in accidents due to the VTS would be on the order of 52 percent.

2.10 Summary of VTS Effectiveness Literature

In summary it can be seen that there is only a small body of research that has undertaken the estimation of the effectiveness of VTS. There have only been a few studies that have actually attempted to estimate the quantitative accident reduction associated with the introduction of a VTS. The results have been fragmentary. This is undoubtedly due to the severe statistical problems and confounding variables that permeate such an approach.

There have been three major efforts to estimate VTS effectiveness using the "expert opinion" approach. These include:

- The U.S. Coast Guard studies from the 1970's.
- The comprehensive Canadian Coast Guard study.
- Research associated with the European COST 301 Program.

The various studies did not measure the effectiveness using the same criteria. Differences in the traffic characteristics in each of the situations introduce unaccountable variables into the analysis. The results were presented according to a variety of categorization methods. The result is that comparing data among the studies is difficult. However, an assessment of some of the data presented in the above studies is assessed and compared with our results in Section 4.2.

A key conclusion that can be drawn from the review of literature is that estimating VTS effectiveness using a synthesis of expert opinion is probably the most viable approach of the alternatives

---

13 Hara, K., K. Inoue, Y. Ohara and A. Nagasawa, 1990. Safety Measures for Navigation at Narrow Channels in Japan. In: Proceedings of the 27th International Navigation Congress, Osaka - May 1990.

available. It appears that the statistical problems are too severe do effectively conduct a historical analysis at this time.

3.0 RESULTS OF VTS EFFECTIVENESS FOCUS GROUPS

This section presents the results of Focus Groups that were conducted by A. T. Kearney, Inc. in September, October and November of 1990 to assess the effectiveness that various configurations of Vessel Traffic Service (VTS) systems would have in reducing casualties (accidents) to vessels, including collisions, groundings and rammings.

The objective of these Focus Groups was to provide detailed quantitative estimates of the effectiveness of alternative VTS systems in reducing vessel accidents for a number of specific accident scenarios. These effectiveness estimates take the form of the percentage reduction in casualties for particular vessel accident scenarios. In Section 4.0 these estimates are combined with an analysis of the Coast Guard's historical commercial vessel accident record to provide casualty rate reduction factors applicable to the specific data base of "VTS addressable" casualties developed for the study.

Three Focus Groups were held, each of which was of two days duration, at the following dates and locations:

- Focus Group One - September 29, 30 - Washington D.C.
- Focus Group Two - October 25, 26 - Seattle, WA
- Focus Group Three - November 14, 15 - Washington D.C.

Between five and six participants participated in each Focus Group. These participants included active or retired Coast Guard personnel having extensive VTS experience, or related expertise in electronic navigation systems, as well as extensive shipboard operating experience. Some of the participants had merchant operating experience as well. Section 7 provides the list of participants for each of the Focus Group sessions.

3.1 Background

As part of the overall risk assessment, the concept of a "VTS addressable" casualty has been introduced. Certain types of casualties are not considered to be VTS addressable, in the sense that a VTS could have prevented the accident. Examples include explosions or mechanical malfunctions that were not caused by an event such as a collision or a grounding. Furthermore, within a given category of accident, such as a "collision", not all accidents are considered VTS addressable. For instance, a collision between a tug and a barge that it is handling, is not considered to be VTS addressable, since it involves a close-quarters maneuvering situation, and the tug is aware of the location of the barge. The study has reviewed the CASMAIN data base to produce a culled list of "VTS addressable casualties". Thus, the casualty rate reduction factors that are presented in this report are intended to apply to the study data base of "addressable casualties".

As part of the approach to the VTS Port Needs/Priority Evaluation Study, it is necessary to develop quantitative estimates for the vessel casualty rate reduction factors for a number of combinations of casualty types and water body types. Casualty types are being broken down into three categories consisting of:

- Collisions
- Groundings
- Rammings

Under these definitions, "collisions" involve two or more vessels striking each other, all of which are underway. "Groundings" consist of situations where a vessel comes into contact with the waterway bottom. "Rammings" include a vessel striking a stationary object which may either be a fixed structure such a bridge or an anchored vessel such as a dredge.

The casualty risk model divides the 23 study zones into six waterway types. These consist of:

- Open approach
- Convergence area
- Open harbor or bay
- Enclosed harbor
- Constricted waterway
- River

In Section 4.0 the effectiveness estimates developed from the Focus Groups are used to calculate casualty rate reduction factors for combinations of the above six waterbody types. However, members of a focus group could not effectively address the question of what the percentage reduction in accidents would be overall, within a particular waterway type. This is because there are so many types of accidents, some of which VTS is very effective in addressing and some of which VTS has a relatively low effectiveness in preventing. The panel participants are not privy to the actual statistical mix of accidents within a given waterway type.

The fundamental question that was posed at the Focus Groups was:

> **If a VTS system is installed in a port, what percentage reduction in vessel accidents is reasonable to expect?**

Since the answer to this question depends on so many complicating factors, it was necessary to segment the question into a series of sub-questions by focusing on specific vessel accident scenarios. These accident scenarios were defined in order to correspond to: 1) available data from the Coast Guard's CASMAIN data base of commercial vessel casualty information; 2) the structure of the study navigational risk model; and3) situations that the Focus Group panel members could visualize and relate to their own experience.

For this analysis it was concluded that the simple questionnaire approach used in the Canadian and some of the European efforts may be too limiting. This is because of the large number of variables relating to accident types, waterway characteristics and vessel types in our effort. Secondly, it was concluded that the simple questionnaire approach is not robust enough to realistically capture the complexities of real vessel traffic situations. Accordingly, the framework that was used consisted of carefully constructed "accident scenarios". These were based on factual situations, although they were not exact reconstructions of actual or named situations.

The panelists questioned and defined the scenarios presented until they had a very specific understanding of the situation under study. A structured set of questions were asked which elicited information on the degree to which specific VTS effectiveness attributes could have affected the chance of the accident occurring.

Initially an overview of the entire project being conducted by the Coast Guard and the Transportation Systems Center was presented. Alternative VTS configurations that may be appropriate to employ in the future were discussed. This lead into consideration of the effectiveness of VTS in addressing specific casualty situations. The assessments included, for instance, consideration of the VTS surveillance and alerting function, taking into consideration the distances over which VTS can discern a position error and the time necessary for VTS to communicate an alert to a vessel and for the vessel to concur and respond.

Heavy use was made of the panelists experience with vessel traffic systems. Throughout the exercises there was a free and open discussion. Consideration was given to issues both in terms of what has been done in the past as well as what could be more effectively done in the future. Although the main objective of this exercise was to make assessments of VTS effectiveness, issues such as operational problems were also discussed. Rarely if ever, was a bias overstating the effectiveness of a VTS detected. In fact the results were tempered by the realization that circumstances will prevent a VTS from being totally effective even in highly addressable situations. Valuable information on potential risk was provided through "near miss" and "dangerous" situations that have occurred in ports.

3.2 VTS System Features

The Focus Group panels evaluated VTS effectiveness with respect to a number of alternative system features. These are discussed in the following.

VTS systems have been variously defined and exist in a number of configurations, but their basic objective is to provide information and advice on other traffic and navigational hazards to ships and other vessels. In some instances the VTS control center has its own radar coverage of the waterway under its cognizance and directly maintains surveillance of vessel movements. Radio contact is maintained with vessels participating in the system. However in other instances, the VTS system will function without its own radar coverage, and will maintain estimated tracks of vessels based on vessel reports of passing waypoints and dead reckoning. This latter method is typically termed a vessel movement reporting system (VMRS).

Three levels of VTS performance were defined for Focus Groups One and Two as follows:

- Level I A vessel movement reporting system consisting of VHF communication and various vessel reporting waypoints. No radar surveillance is included.

- Level II The vessel movement reporting system of Level A coupled with basic radar surveillance. The radar technology was assumed to be equivalent to a good quality, recent vintage, standard shipboard radar without any advanced features.

- Level III This system includes complete communication plus an advanced state-of-the-art VTS radar surveillance system. Features include:
  - Automatic vessel track analysis
  - Track and collision alarms
  - Advanced rain and sea clutter control
  - High resolution
  - Overlaid port chart system with landmasses, channels, course leadlines, etc.
  - Provisions for vessel identifiers and particulars
  - Integrated display of multiple radars

For Focus Group Three a forth VTS system feature level was defined as Level IV and was assessed along with Levels A and C.

- Level IV Automatic dependent surveillance based on the use of differential GPS (Global Positioning Satellite) retransmission. This system consists of an automated transponder installed on the participating vessel that determines the vessel's position via differential GPS, and transmits this information automatically, along with vessel identification and ship particulars to the VTS control center. In practice, this system would include VHF or possibly other longer range radio communication and could exist either with or without a VTS radar surveillance system.

In addition to the four main VTS system alternatives, some consideration was given to additional VTS system features which as:

- Radar transponder providing positive vessel identification on radar display.
- System IV with Loran substituted for differential GPS.
- Remote temperature and wind sensors.
- Remote visibility sensors.
- Remote water level sensors.
- Remote current sensors.
- Radio direction finder capability to determine bearing to transmitting vessel.
- Closed circuit television surveillance systems.

These were viewed as augmenting features to a VTS, and the depth of analysis possible in the Focus Groups precluded the assignment of quantitative casualty rate reduction factors. However, these features were discussed and qualitative assessments were made regarding their value.

Concurrent efforts by the study identified 18 Technology Modules (See Exhibit 3-1) for development of a Candidate VTS Design for each study zone. The definition of these 18 modules were not available for Focus Groups One and Two.

Exhibit 3-1

Candidate VTS Design Technology Modules

Module Number	Description	Key Characteristic
1	Average Performance X-Band Radar	Baseline Radar Surveillance System
2	Average Performance S-Band Radar	Above with Better Rain Clutter Performance
3	High Performance X-Band Radar	Better Performance in Narrow Channels
4	High Performance S-Band Radar	Above with Better Rain Clutter Performance
5	Exceptional Performance X-Band Radar	Better Performance in Narrowly Confined Waterways
6	Exceptional Performance S-Band Radar	Above with Better Rain Clutter Performance
7	Radar Transponder on Vessel	Positive Identification of Radar Image
8	Differential GPS Retransmission	Ability to Obtain Vessel Position for Participating Vessels Similar to Radar System in Non-Radar Coverage Areas. Also Possible to Provide Positive Vessel Identification and Particulars.
9	Loran Retransmission	Same as Above with Somewhat Reduced Position Accuracy.
10	VHF Communications - Low Power	Reduced Radio Interference Between Areas.
11	VHF Communications - High Power	Wider Area Communications Coverage.

Exhibit 3-1 (cont.)

Candidate VTS Design Technology Modules

Module Number	Description	Key Characteristic
12	Temperature and Wind Sensors	More Complete Knowledge of Conditions Facing Mariners.
13	Module 12 Plus Visibility Sensors	Ability to Adjust VTS Monitoring Procedures to Low Visibility Situations.
14	Water Level Sensors	Ability to Warn of Unusual Conditions.
15	Water Current Sensors	Ability to Warn of Unusual Conditions.
16	Direction Finder Capability	Ability to Identify Communicating Vessel with Radar Image.
17	Closed Circuit TV Fixed Camera	Aid in Vessel Identification and Coverage in Radar Fade Areas.
18	Closed Circuit TV Controllable Camera	Above with More Flexible Field of View.

However, the correspondence between the Focus Groups' VTS system performance levels and the 18 Candidate VTS Design Technology Modules is as follows.
Modules 1 through 6 are alternative radar coverage systems, which consist essentially of combinations of either X-band or S-band radar and radar antennae having "average performance", "high performance" or "exceptional performance". The choice between X-band and S-band radar is essentially one of trading off bearing resolution versus ability to penetrate severe rain clutter conditions. The alternative antenna performance essentially relates to the ability to resolve targets in waterways obstructed by increasing levels of radar clutter.

It now appears that any VTS radar system under consideration will have a radar system with the processing characteristics of Level III defined for the Focus Groups. The Focus Groups did not consider, explicitly, the differences in the six radar Technology Modules. This is because the alternative radar Technology Modules are directed at achieving effective radar coverage under increasingly severe meteorological and geographic conditions. The Focus Groups made the assumption that the radar system in place would have whatever it took to obtain effective coverage in a specific situation.

Technology Module 8 (differential GPS retransmission) corresponds to Focus Group Performance Level IV. Technology Module 9 (Loran retransmission) is the same as Module 8 with somewhat degraded position accuracy.

Technology Modules 10 and 11 are alternative VHF communications systems. A VHF communication system would be common to any VTS and the Focus Groups assumed that the VTS would have consistently high quality communications.

The remaining Technology Modules correspond to system features which augment the basic capabilities of the VTS. In general, these features, many of which are desirable in a VTS, do not have extremely significant effects on overall VTS effectiveness.

3.3 Assumptions

It was necessary to note certain assumptions for this analysis. Each system was assumed to have:

- The utmost in equipment reliability, availability and redundancy (i.e. equipment malfunctions do not degrade the system to any significant extent).
- Complete radar coverage with no blind spots or fade areas in the case of systems having radar surveillance.

- Staffing by well-trained, experienced and motivated individuals who meet high selection standards (i.e. personnel deficiencies do not degrade the system).

- A fairly pro-active operating policy (i.e. watchstanders should be encouraged to look for hazardous situations and not be inhibited from communicating concern in a diplomatic manner).

- Mandatory participation in the VTS for all vessels subject to the "Bridge-to-Bridge Radiotelephone Act". Generally, this include all vessels more than 300 gross tons, commercial vessels 26 feet or more engaged in towing and vessels more than 100 tons carrying passengers.

- Watchstander workload such that watchstanders could give adequate attention to each vessel.

- Consistently effective communications capability.

The assumption concerning equipment reliability has been included since equipment problems have been a problem in the past. The effectiveness estimates do not include any percentage to account for VTS downtime.

The assumption concerning staffing is important since the Focus Groups pointed out that the performance of the watchstander has a very significant impact on VTS effectiveness. It was pointed out, that even among persons, all of whom are considered to be qualified under current criteria, certain individuals exhibit superior ability to recognize and react to potentially hazardous situations. One highly desirable trait is a certain type of inquisitiveness. The VTS watchstander develops his or her understanding of the developing traffic situation from the radar display, from direct communication with participating vessels and indirectly from overhearing bridge-to-bridge communication between vessels. The latter can be very important. The ability to interpret subtle cues and take active intervention has contributed to a number of VTS "saves". Such ability, and a management and personnel system to recognize, develop and channel such ability contributes significantly to VTS effectiveness.

It has been concluded that operating policies have a great effect on VTS effectiveness. One important factor that the Focus Group One pointed out is the degree to which a VTS takes what was described as a proactive stance. This is the inclination for the VTS to actively seek out potentially hazardous situations and bring to bear some sort of intervention to alleviate the situation. There is a fine distinction here. Under long established traditions of the sea, as well as issues of legal liability, and a recognition of the differing operating characteristics of individual vessels, the ultimate responsibility for the handling of a vessel must remain with the master or pilot. The VTS watchstander is understandably reluctant to issue helm commands. In some circumstances such action could make a dangerous situation worse. Also, the traffic and waterway characteristics of most U. S. ports makes the type of space management or "positive separation" employed in air traffic control impractical in most situations.

However, VTS effectiveness is increased significantly by taking a stance between the extremes of: 1) merely being an information provider; and 2) assuming vessel control. This is what is meant by the pro-active stance. It is an art that involves the ability to read subtle, indirect cues and to act decisively and diplomatically. An often employed technique is to issue alerts or warnings phased as questions. For example, if a watchstander detects a vessel overshooting a turn in a waterway, he or she might inquire of the vessel whether it intends to turn at such and such position. This communicates the warning, would it have been necessary, but minimizes the creation of friction between the VTS watchstander and the vessel operator.

Vessel traffic systems can either be voluntary or mandatory. Many of the systems that have been implemented in the United States have been voluntary, although compliance among the larger classes of vessels has generally been high. For the Focus Groups, mandatory participation in the system was assumed. Thus the effectiveness estimates are not degraded by a "non-participation" factor. However, it should be noted that the effectiveness of a voluntary system with high participation can approach the levels of a mandatory system.

3.4 Casualty Rate Reduction Factors

Exhibits 3-2 through 3-4 present the synthesized casualty rate reduction factors for groundings, rammings and collisions, respectively. The factors represent the fraction of vessel accidents of a given type that are estimated to be prevented because of the presence of a VTS.

Extensive discussion went on within the Focus Groups in the development of the casualty rate reduction factors. A significant amount of time was required to develop, within each individual group, the definition of each casualty scenario. Each group had to relate the scenario to their own experience. Some of the factors leading to the conclusions regarding the quantitative estimates provided included:

- Description of the mechanism through which VTS can prevent the particular accident scenario.

Preliminary Results Of Focus Group Panels – Groundings

	Estimated Casualty Reduction Percentage		
	System A Vessel Movement Reporting	System B Basic Radar	System C Advanced Radar
Single vessel grounding			
Distance factor less than 250 yd.	0	0	0
Distance factor 250-1000 yd.	0	0.2-0.6	0.3-0.7
Distance factor greater than 1000 yd.	0	0.7-0.9	0.9-1.0
Aid to navigation off station or light out	0.1	0.7	0.8
Shoaling	0.1	0.2	0.2
Grounding to avoid other vessel		Same as corresponding collision	

Preliminary Results Of Focus Group Panels – Rammings

	Estimated Casualty Reduction Percentage		
	System A Vessel Movement Reporting	System B Basic Radar	System C Advanced Radar
Bridge ramming			
No other vessel involved	0.0	0.05	0.05
Pinched by other vessel	0.6-0.8	0.8-0.9	0.8-0.9
Mis-communication with drawbridge	0.2	0.5	0.5
Hit dredge/disabled vessel in main waterway	0.4	0.5	0.5

Preliminary Results of Focus Group Panels – Collisions

	Estimated Casualty Reduction Percentage		
	System A Vessel Movement Reporting	System B Basic Radar	System C Advanced Radar
Collisions between two participating vessels			
– Open waterway	0.1	0.5-0.6	0.6-0.8
– Narrow waterway	0.2	0.4	0.5
Collision with non-participant (fishing or recreational vessel)			
– Concentration of fishing vessels	0	0.4	0.4
– Lone fishing vessel or recreational vessel transiting	0	0.1	0.2

- Discussion of "fault tree events" leading to a type of accident in the first place.

- Examples from actual VTS operating experience where a particular type of accident has likely been avoided.

Throughout the discussion of the various casualty scenarios, the Focus Group panel members were constantly considering the fact that there are always circumstances that prevent complete effectiveness in eliminating all instances of a particular category of accident. These include the facts that the:

- The VTS system itself cannot be 100 percent infallible, particularly when the personnel must make extremely rapid decisions based on often subtle cues.

- A certain small percentage of mariners will persist in perverse actions in spite of warnings and urgings by the VTS.

- A certain percentage of accidents will contain one or a combination of events that defy normal means of intervention.

These considerations were discussed and factored into the judgments made by the Focus Group panels. In the following, the derivation of each casualty rate reduction factor is discussed. Definition and comments are also provided as to the precise definition of the scenario to which the casualty rate reduction factors apply.

3.4.1 Groundings

Groundings are defined to include the striking of a vessel's hull with the bottom. The vessel may either require assistance to become free or may successfully free itself. Normally, for commercial vessels, an accident report is required for any grounding, even for a relatively minor event. The groundings considered here are "accidental groundings". These are distinguished from "intentional groundings", which are also reported in the Coast Guard data base, but are not considered to be a VTS addressable incident. An intentional grounding is typically a grounding to mitigate damage or avoid a hazard, such as running a vessel aground to prevent it from sinking, if it is taking on water.

Note that there may be some "intent" to ground when a vessel is forced aground in order to avoid a collision. Such a situation normally happens when two vessels are approaching in a narrow channel. However these events are VTS addressable and are normally included in the "accidental" grounding category in the CASMAIN data base.

VTS addressable groundings were categorized into:

- Single vessel groundings.
- Groundings due to an aid to navigation off station or light out.
- Groundings due to shoaling.
- Groundings involving a situation where a vessel was engaged in avoiding a collision with another vessel.

Single Vessel Groundings

"Single vessel groundings" were defined, for the purposes of the Focus Groups, to be situations where a single vessel got off course and ran aground, and the situation could not be attributed to any problem with an aid to navigation, shoaling, avoiding another vessel or any complications involving vessel traffic in the immediate area. The root cause of this type of situation can involve a number of factors such as:

- Inattention or error in judgment.
- Lack of familiarity with the area.
- Failure of on-board navigation equipment.
- Complicating effects of fog or adverse weather.
- Preoccupation with minor problem or other task.

The common factor that allows these situation to be lumped together is that the means of intervention for VTS to prevent these situations from developing into accidents is similar. From the viewpoint of VTS, these situations can be prevented, if the VTS operator is able to detect that the vessel is straying from its normal course, and is able to intervene by radio communication in sufficient time prevent the grounding.

The key issue is the "distance factor" of the waterway in which the grounding occurs. The selection criteria eliminates as not "VTS addressable" groundings or collisions in close quarter situations such as docking, undocking or maneuvering in a crowded anchorage. And clearly incidents where a vessel strays some miles from a safe waterway is appropriately categorized as "VTS addressable" for VTS systems having radar surveillance. However a grey area involves intermediate distances. There is a "distance factor" that relates the degree of "VTS addressability" to the distance of the positional error of the vessel involved in the incident.

Obviously, this "distance factor" issue relates very directly to the VTS casualty rate reduction factors.

The "distance factor" was defined as the distance between a vessel's normal or expected track, and the obstacle or point on which it grounded, minus the maneuvering distance needed for the vessel to make the necessary course correction to prevent grounding on the shoal. This is illustrated in Exhibit 3-5.

If a vessel is proceeding along a relatively straight channel and strays toward a shoal at a relatively shallow angle, the distance factor would approximate the perpendicular distance between the vessel's intended track in the channel and the shoal. This is Case A in Exhibit 3-5.

At the other extreme, assume a vessel's intended track would have been a 90 degree turn and it "overshot the turn." This is Case B in Exhibit 3-5. The distance factor would approximate the distance over which the vessel would travel after overshooting the turn until the VTS could detect the error and have the vessel begin issuing the necessary helm command to correct the error. The vessel would then "advance" a certain distance parallel to its original course until it had completed the 90 degree turn. Thus, the distance factor must be added to a consideration of a vessel's "advance" in a turn, in those accidents where the necessary corrective course change involves a large angle.

The development of the casualty rate reduction factors by distance factor included consideration of the VTS surveillance and alerting tasks and took into consideration the distances over which VTS can discern a position error, the time necessary for VTS to communicate an alert to a vessel and the time for the vessel to concur and respond.

Subsequently, a sample of specific grounding situations from the CASMAIN data base was examined to determine the relative magnitude of the "distance factors" that were involved. The appropriate VTS effectiveness was then assigned to the specific accident in the sample.

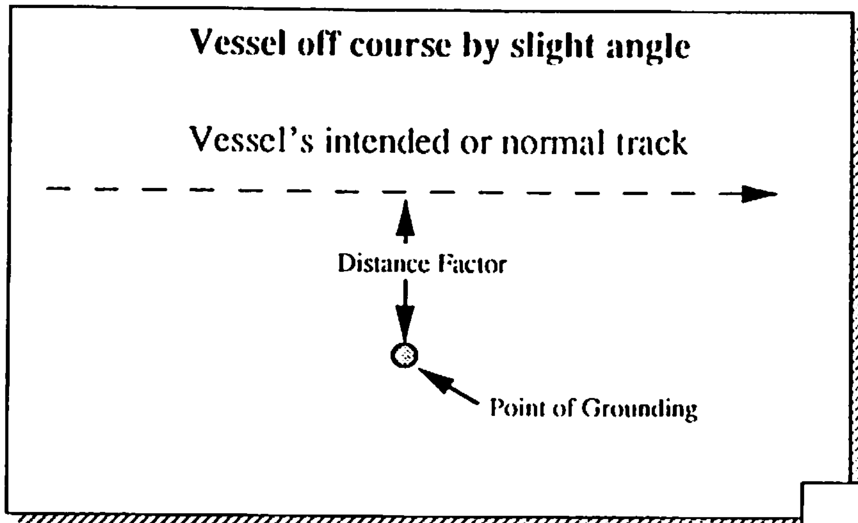
Groundings Associated with Aid-to-Navigation Problem

This category includes accidents where the primary cause is due to an aid-to-navigation that has gone off station or where a light has been extinguished. In either case the mariner has lost a reference upon which he may be depending, notwithstanding the fact that, officially, mariners are cautioned never to relay upon a single floating aid to navigation.

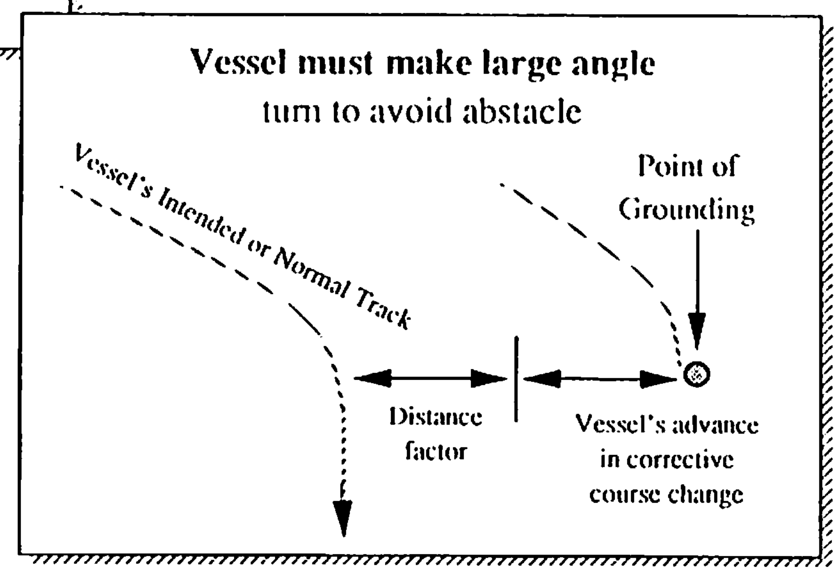
Normally, when the Coast Guard becomes informed of a problem with an aid to navigation, it will attempt to fix the problem at the earliest opportunity that resources permit. However, there is a

Conceptual Definition Of Distance Factor

Case A



Case B



ATK1/1545/2 kp

certain period of time that is required for the Coast Guard to become aware of the problem and to assign the necessary resources to correct it. An inoperative aid to navigation may be reported in the Local Notice to Mariners. However, not all mariners become cognizant of this information in a timely manner.

Thus, VTS can intervene in these situations in a number of ways. First, for a VTS system having radar surveillance, the Vessel Traffic Center can monitor the position of buoys. For a light or other aid-to-navigation in an area, not in a radar surveillance area, the VTS serves as a readily available point of contact for mariners to report aid-to-navigation problems that they observe. Some VTS systems may have systems in the Vessel Traffic Center to monitor the functioning of lights. Thus, the time for the Coast Guard to become aware of a aid to navigation problem is expedited.

Secondly, once the Vessel Traffic Center is aware of the problem, they function as an on-line source of information to warn mariners of any problems. Mariners can then take necessary precautionary action. In the case of radar surveillance systems, the VTS can provide supplementary position information to assist vessels.

Groundings Due to Shoaling

Vessel casualties attributable to shoaling tend to occur in certain water bodies susceptible to this phenomenon. Frequently, in these locations, shoaling occurs haphazardly and on short notice. The panels felt that it was not reasonable that VTS could intervene with a high degree of regularity to prevent groundings due to shoaling.

In some instances, however, it was felt that VTS could prevent a shoaling-related grounding. Some shoaling-related groundings occur to transient vessels in situations where the shoaling situation has become "local knowledge". In these situations VTS would be in a position to be aware of the situation and be able to pass the information along to a mariner not familiar with local conditions.

Grounding to Avoid Other Vessel

Upon reflection, these types of groundings were concluded to be analogous to the corresponding type of collision situation. Accordingly, the casualty rate reduction factor is the same as for the corresponding type of collision. In essence, the fault-tree causes are similar and the manner in which VTS could intervene to prevent the incident would be the same.

Thus, in applying casualty rate reduction factors to the set of VTS addressable casualties, groundings involving a situation caused by other vessel traffic will be analyzed as if it were a collision.

3.4.2 Rammings

Rammings were defined to include situations where an underway vessel hit a bridge or where an underway vessel hit an anchored vessel (including a dredge) or a vessel that was disabled.

Bridge Ramming

In discussing vessels that collide with bridges, it quickly became clear that the situation splits into two very distinct situations from the viewpoint of VTS intervention. These were:

1) Situations that do not involve any other vessel. That is, during the period where a vessel approaches, transits and departs from the bridge opening, no other vessels are in close proximity, such that the maneuvering decisions by the vessel transitting the bridge opening are affected.

2) Situations where one vessel was termed to be "pinched" by another vessel. These were defined to be situations where a vessel transitting a bridge had to depart from its optimum or preferred trajectory during the approach or transit through the bridge. Examples include: actually passing another vessel through a bridge span; moving to one side during an approach to a bridge to allow passage of another vessel, and thus having a less than desirable alignment to the bridge; and stopping or reducing speed in approaching a bridge to allow passage to another vessel, such that the first vessel becomes vulnerable to wind or current.

The operational distinction from the viewpoint of VTS is that the first situation involves accidents where the primary cause is related to ship handling and vessel maneuverability problems, often aggravated by wind or current. In these situations, it was concluded that the distances and time factors involved were so small that VTS would have no opportunity to intervene. The primary event in the fault tree leading to the accident was a misjudgment in the vessels micro position, helm response or response to prevailing wind or current.

It was concluded that the only situation where VTS could have any effect in the first situation would be a situation where a vessel operator was unaware of an unusually high current condition and VTS was able to provide that information such that it made a difference. Such situations were felt to be a small percentage of all bridge rammings with no other vessel involved.

The second situation, involving a bridge ramming where one vessel was "pinched" by another was concluded to be highly addressable by VTS. Avoiding this accident scenario was felt to be a classic example of the VTS traffic advisory function. The Focus Group panel members pointed out that most mariners want to avoid these types of situations involving meeting within close proximity to a bridge. However, these meetings do occur because mariners just do not have precise enough information far enough in advance to adjust speed in order to have the desired large enough time window for passage.

A VTS, with its global overview of both vessels' tracks is in a position to supply advanced information to both vessels of the other's presence and estimated time of arrival at the bridge. This in turn allows for the vessels to come to an orderly agreement regarding the bridge passage, which prevents one or both vessels from having to make last minute avoidance maneuvers. It is these last minute avoidance maneuvers that appears to be the primary event in the fault tree leading to this category of accident.

Note that the Focus Group panels assigned a relatively high effectiveness to a Vessel Movement Reporting System in avoiding the second category of "pinched by other vessel" bridge ramming. This is because it was felt that, even the relatively rough position and estimated time of arrivals available to the VMRS can make a significant contribution in preventing this type of accident.

Collisions with Dredge or Anchored/Disabled Vessel in Main Waterway

These situations were defined to involve collisions with an anchored vessel including a dredge in or adjacent to a main waterway. Also included were collisions with drifting or disabled vessels. These situations also include situations where a vessel is moored to shore in a relatively narrow waterway, such that the normal operating channel is constricted somewhat. Most of these situations involve relatively narrow channels or confined waters. The essence here was to consider situations where a vessel was located where it might not normally be expected, and where it was within, what the transitting vessel might consider to be normally clear waters.

A certain portion of these types of accidents could have been avoided if VTS could have provided advance information regarding the presence of the anchored or drifting vessel such that the approaching vessel could have been prepared to deal with the situation.

These situations were assigned a casualty rate reduction factor of 0.4 for VMRS and 0.5 for radar systems. It was felt that the VTS effectiveness would not be higher, because in a significant percentage of these incidents, the presence of the anchored or moored vessel simply causes close-quarters maneuverability problems in getting around the impeding vessel. These problems will confront the mariner in spite of advanced notification.

3.4.3 Collisions

Collisions addressed here include impacts between two vessels both of which are underway. Collisions between a tug and the ship it is assisting or between a tug and a barge have been eliminated for consideration as being "not VTS addressable". Also eliminated have been other types of collisions where a vessel is maneuvering in close quarters to another vessel.

The root causes of collisions include a number of reasons such as the following:

- Failure to keep a proper lookout

- Failure to keep to the right of a narrow channel.

- Failure to establish a proper passing agreement including not establishing any bridge-to-bridge communication, or having a mix-up in communication. The latter includes a number of cases where vessels had another vessel in sight or on radar with whom they thought they were communicating, but in actuality they were talking to another vessel.

In discussing collisions, a distinction has to be made between collisions where both vessels are participating in the VTS and collisions between one participant and one non-participant.

For the purposes of the Focus Groups, VTS addressable collisions were divided into four categories:

- Collisions in "open" waterways between participating vessels.

- Collisions in "narrow" waterways between participating vessels.

- Collisions between a participating vessel and a single non-participating vessel (which is usually either a recreational or a fishing vessel).

- Collisions between a participating vessel and a group of non-participating vessels.

Collisions Between Two VTS Participants

Open waterways were defined to be waterways where vessels normally do not pass close abreast of each other and where meeting situations can occur at a variety of aspect angles. Included are "mixing bowls" and precautionary areas as well as open bays. The key distinction here from the viewpoint of VTS is that, the VTS operator is able to see a potential collision situation developing and is able to issue necessary traffic advisory information. This situation was rated by the Focus Groups as being highly addressable by VTS.

Narrow waterways were defined as waterways such as channels, rivers or straits where the traffic is essentially moving parallel to each other. Traffic normally passes close abreast each other, such that the VTS operator is not able to detect the development of a hazardous collision situation until the time and distance parameters are so small that a successful VTS accident prevention intervention is not possible. In these situations VTS serves to prevent collisions by:

- Making vessels aware of approaching traffic so that they do not get surprised.
- Ensuring that proper communication is initiated, and that instances of mis-communication are prevented.
- Helping to see that passage of vessels is planned far enough in advance to prevent meeting at hazardous points in the waterway.

For these situations, VTS was rated as having a more moderate effectiveness. VTS effectiveness in these situations is lower than in the open water situations, because in a large portion of these accidents, the vessels' intended tracks take them in close proximity to one another and collisions result. Such collisions are typically due to vessel handling errors, errors in ascertaining the micro position of the vessel relative to the other, or (in the case of rivers and similar water bodies with strong currents) the adverse effects of current and the associated eddies.

Supplemental to the above information is that a VTS should be highly effective in preventing collisions that result from a vessel straying out of a traffic separation lane.

Collisions Between One VTS Participant and One Non- Participant

In the case of collisions with a non-participant vessel, VTS is more effective in preventing collisions where there is a fairly dense concentration of fishing or recreational vessels in a somewhat well defined area, than in the case where there is a collision with a lone non-participant vessel. In the former case, VTS is able to warn the approaching vessel of the concentration of small non-participating vessels. In the latter case it is impractical for the VTS to monitor and issue traffic advisories for individual small vessels.

In situations involving a non-participating vessel, one of the key ways that VTS intervenes to prevent collisions is by allowing the non-participants to listen to the radio traffic advisories without actually checking into the system. In these cases the non-participants essentially become passive participants.

3.5 VTS System Feature Level IV - Automatic Dependent Surveillance

This VTS system feature was discussed at length in Focus Group Three and was given some attention in the other Focus Groups. The primary focus was an automatic dependent surveillance system based on differential GPS. As conceived, this system would retransmit vessel position automatically to the VTS center, along with information on vessel identification and vessel particulars. The vessel particulars could include information on vessel size, type, nature of cargo, destination or any of a number of pieces of information.

It was noted that this system could provide much greater accuracy and reliability of vessel position and identification than a radar surveillance system. It was further noted that, because the system automatically communicates with the VTS center, radio channel usage and VTS watchstander workload could be reduced.

After a period of discussion, the use of automatic dependent surveillance (ADS) was segmented into three categories. These consisted of:

- Category 1) ADS in conjunction with a conventional VTS with radar surveillance.
- Category 2) ADS in an area outside of VTS radar coverage.
- Category 3) ADS on certain vessels frequenting an area, such as ferries, for use as an identification and communication aid to relieve radio congestion and VTS operator workload.

A key question in the discussion of ADS was the issue of which vessels would be so equipped. It was noted that if only an occasional vessel (such as large tankers) had ADS, the overall value would be marginal with respect to the total traffic situation, although the system would facilitate surveillance of that particular vessel with respect to single vessel events such as groundings. Panel members with VTS operating experience noted the importance of having information on the total traffic situation, and not just on the position of a limited number of vessels.

After a period of discussion it was concluded that under the Category 1 situation (ADS coupled with conventional radar), the overall system effectiveness in preventing accidents would not be significantly changed from System Level B or C (radar surveillance). The somewhat greater accuracy and vessel identification ability of the GPS ADS system does not significantly aid the VTS watchstander. Panel members with VTS operating experience noted that vessel identification for large vessels, particularly those involving hazardous cargo, is seldom a problem, and these are the vessels that would most likely be the candidates for the ADS system.

The somewhat greater positional accuracy of the differential GPS was also noted to be of only marginal usefulness. Panel members with VTS operating experience noted that current radar systems generally provide accuracy that is adequate with respect to the distances that VTS can affect accident situations. Having greater position accuracy does not necessarily improve VTS effectiveness because of the distances involved in vessel maneuvering. It was noted however, that the differential GPS ADS could provide the VTS watchstander with a somewhat quicker indication of vessel turning characteristics in a tight maneuvering situation. However, this could not be translated into any significantly increased overall effectiveness in preventing accidents.

Under the second category situation (ADS in an area outside of conventional radar coverage), it was concluded that ADS would have an overall effectiveness which is essentially the same as for VTS Performance Level C (advanced radar coverage), if all major vessels in the area participated in the ADS. If a significant portion of vessels in an area were not participants in the ADS, the overall effectiveness would degrade, and would range between that of System Level A and System Level C. The one exception to this is that VTS effectiveness with respect to single vessel grounding incidents for the ADS participants would be similar to that for System Level C.

Lastly, it was noted that the ADS system could offer a particular advantage to the VTS in the case of Category 3 situations (ADS on ferries, etc.). The effect here is primarily one of reducing communications load, because of the automatic reporting capabilities of the ADS. This reduces clutter on the VTS radio channel, which is becoming a problem in some areas, as well as reducing the clerical workload on the VTS watchstander.

4.0 DEVELOPMENT OF CASUALTY RATE REDUCTION FACTORS

Given the effectiveness factors for the accident scenarios derived from the Focus Groups, it was necessary to convert the results into "casualty rate reduction factors" that could be used by the risk model. The casualty rate reduction factors had to correspond to the database of VTS addressable casualties being used by the risk model. These factors are the expected percentage reduction in vessel accidents that can be expected due to the implementation of a VTS system.

The procedure to develop the casualty rate reduction factors consisted of statistically analyzing the casualty data base to determine the relative incidence of the accident scenarios analyzed by the Focus Groups. The casualty data base used was the set of "VTS addressable" casualties used in the overall risk model. The analysis segmented the casualty rate reduction factors into separate groups based on two vessel size categories and two categories of waterbody (subzone) types.

4.1 Synthesis of VTS Casualty Rate Reduction Factors

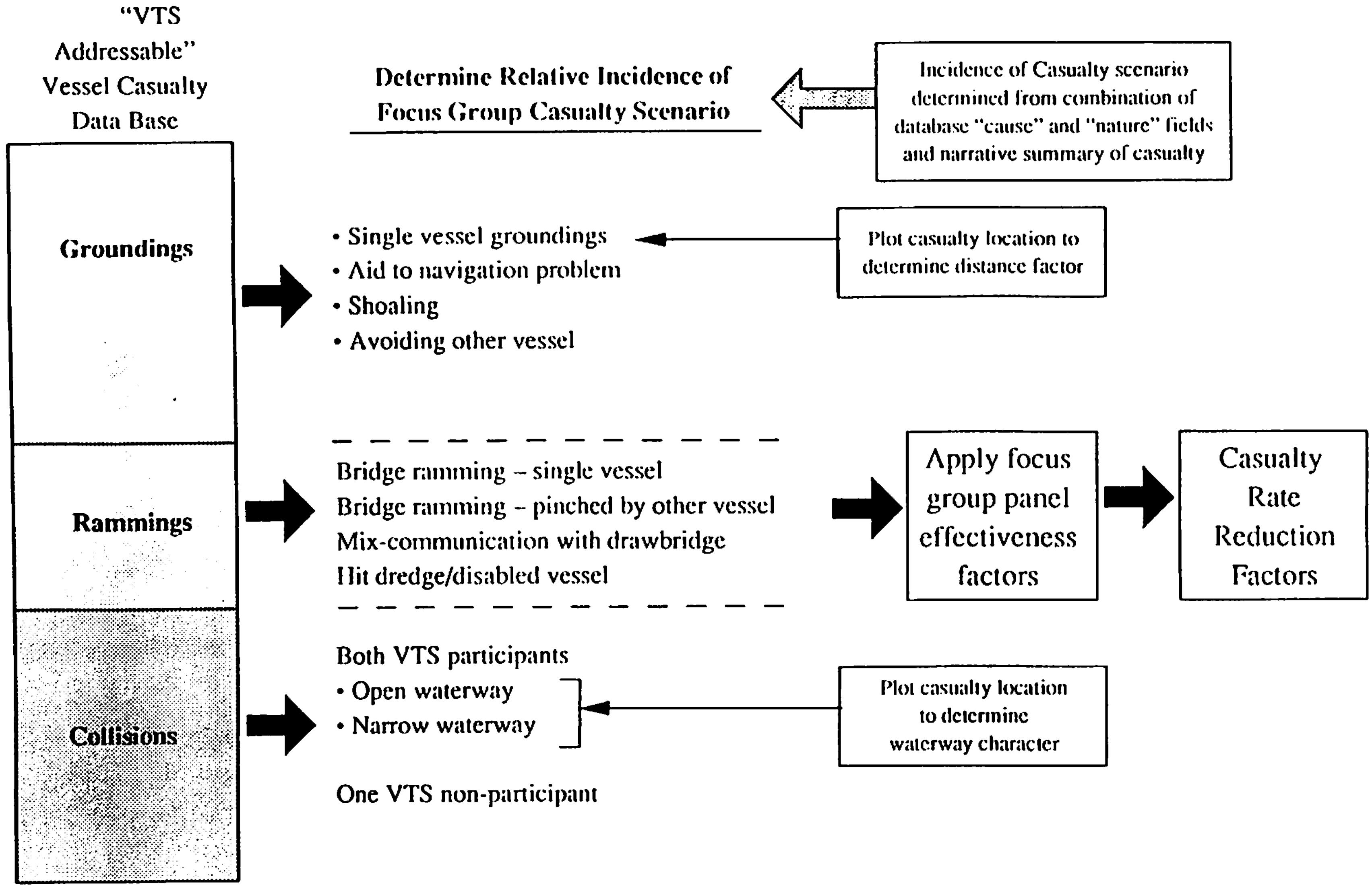
In order to synthesize the "Casualty Rate Reduction Factors" for use in the risk model, a detailed analysis of the casualties in the "CASFINI" casualty data base was conducted. An overview of this process is presented in Exhibit 4-1. The overall "casualty rate reduction factors" are directly sensitive to the mix of casualties in the "CASFINI" data base.

This process involved assigning each of the casualty records in the "CASFINI" data base to one of the accident scenario types from the VTS effectiveness Focus Groups. This assignment was done based on a combination of:

- The "CASFINI" "nature" and "cause" fields.
- The "CASFINI" "comment" field which was developed from the manual review of the Coast Guard casualty narrative reports.
- Plotting of accident locations on nautical charts, in the case of certain types of groundings in order to make an assessment of the "distance factor" involved in the casualty.
- Plotting of accident locations on nautical charts, in the case of certain types of collisions, in order to make an assessment as to whether the collision occurred in a waterway having the "narrow" or "open" characteristic.

The database of VTS addressable casualties had been developed based on the Coast Guard CASMAIN vessel casualty data base. The CASMAIN

Development of Casualty – Rate Reduction Factors



data base consists of the reported vessel casualties to commercial vessels. The VTS addressable database, termed the CASFINI database, was compiled as a subset of the CASMAIN data base. Cases were selected that occurred within the confines of the study areas for the 23 ports under study. Cases not included in the CASFINI data base included those for which the primary cause was due to fire, explosion, foundering, etc. for which the nature of the casualty was clearly outside the ability of a VTS to prevent.

A lengthy review process had been conducted to determine which of these selected CASMAIN casualties could be considered "addressable" by a VTS. By "addressable" it is meant that a VTS could potentially prevent the incident from occurring. It does not mean that a VTS could necessarily prevent it with 100 percent assurance. To determine which cases were "addressable", the Coast Guard accident report narratives were reviewed by a team of people.

Addressable cases included those where the possibility existed that some form of information, warning or advice conceivably could have prevented the casualty. For example, VTS can potentially prevent accidents in situations such as the following:

- Two vessels are unaware of the others' presence in sufficient time to undertake a successful collision avoidance maneuver.

- Difficulties exist in establishing effective communications which prevents the effective consummation of a passing, overtaking or crossing agreement.

- A vessel is unaware of temporary hazards to navigation.

- A vessel becomes off course in a situation where the distances and times involved are sufficiently great such that VTS could provide an effective warning to the vessel involved.

- Complex traffic situations cause vessels to meet in particularly hazardous locations.

- Conditions associated with traffic congestion are such that three or more vessels encounter each other more or less simultaneously resulting in ambiguity as to the proper collision avoidance maneuver.

Non-addressable cases include, for example, those where:

- The primary cause is a material failure such as to the propulsion, steering system or tow cable.

- A collision occurs during close quarters maneuvering such as docking or anchoring.

- Damage is clearly the direct result of severe wind or wave action.

- A grounding occurs in which the accident narrative clearly indicated the waters were extremely confined.

- Collisions occur between vessels maneuvering in close quarters such as a tug and its barge or a tug and an assisted vessel.

Cases were segmented into collisions, rammings and groundings. Collisions included accidents between underway vessels in a variety of meeting, crossing, overtaking and other types of maneuvering situations. The ramming category consisted of collisions with an aid to navigation, a bridge, a stationary vessel or some other fixed object. Groundings included a variety of circumstances where a vessel hit bottom due to errors in navigation or maneuvering or due to shoaling conditions in the waterway.

The CASFINI data base of addressable casualties ultimately consisted of about 1,084 cases involving 2,337 vessels. The number of vessels includes all the barges involved where a tug towing several barges had a collision, ramming or grounding.

The classification of casualties as "VTS addressable" was based on the information available in the written casualty reports. A number of incidents were initially categorized as "VTS addressable" for which further analysis was appropriate. Also, even an accident that is highly "VTS addressable" does not mean that it could have been prevented with 100 percent assurance.

A key issue, for example, relates to the distance factor of the waterway in which a grounding occurs. The selection criteria eliminates as not "VTS addressable" groundings or collisions in close quarter situations such as docking, undocking or maneuvering in a crowded anchorage. However, clearly, incidents where a vessel strays some miles from a safe waterway is appropriately categorized as "VTS addressable" for VTS systems having radar surveillance. However for intermediate distances, the "distance factor" that relates the degree of VTS effectiveness to the distance of the positional error of the vessel involved in the incident had to be determined. From the Coast Guard accident investigation narratives the distances involved in the positional error are not usually apparent. Thus this information had to be determined by plotting the position of the incident and noting the width and depth parameters of the waterway in which the incident took place.

Based on the analysis of the CASFINI data base, the statistical incidence of each Focus Group accident scenario was determined and a composite "casualty rate reduction factor" was computed. The results are presented in Exhibits 4-2 for large and medium vessels

Casualty Rate Reduction Factors For Candidate Systems

Large and Medium Vessels

	Waterbody Subzone Types A, B, and C A – Open Approach B – Convergence C – Open Harbor/Bay			Waterbody Subzone Types D, E, and F D – Enclosed Harbor E – Constricted Waterway F – River		
	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category
Collisions						
Both VTS Participants	0.11	0.68	0.51	0.19	0.52	0.89
One Non-participant	0.00	0.27	0.49	0.00	0.27	0.11
			1.00			1.00
Rammings						
Ramming ATN	0.00	0.00	0.35	00.0	0.00	0.39
Other Causes	0.22	0.43	0.65	0.22	0.36	0.61
			1.00			1.00
Groundings						
Shoaling	0.10	0.20	0.27	0.10	0.20	0.46
Other Causes	0.05	0.46	0.73	0.05	0.25	0.54
			1.00			1.00

Source: Application of results of focus group panels to a statistical analysis of the data base of addressable vessel casualties.

ATK1/15454/3 kp

Casualty Rate Reduction Factors For Candidate Systems

Small Vessels

	Waterbody Subzone Types A, B, and C A – Open Approach B – Convergence C – Open Harbor/Bay			Waterbody Subzone Types D, E, and F D – Enclosed Harbor E – Constricted Waterway F – River		
	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category
Collisions						
Both VTS Participants	0.13	0.65	0.40	0.18	0.55	0.67
One Non-participant	0.00	0.27	0.60	0.00	0.27	0.33
			1.00			1.00
Rammings						
Ramming ATN	0.00	0.00	0.43	00.0	0.00	0.33
Other Causes	0.25	0.50	0.57	0.20	0.38	0.67
			1.00			1.00
Groundings						
Shoaling	0.10	0.20	0.35	0.10	0.20	0.31
Other Causes	0.06	0.51	0.65	0.02	0.25	0.69
			1.00			1.00

Source: Application of results of focus group panels to a statistical analysis of the data base of addressable vessel casualties.

ATK1/15454/4 kp

and Exhibit 4-3 for small vessels. These were computed for 48 categories consisting of:

- Six casualty sub-types (two types of groundings - those due to shoaling and those due to other causes; two types of rammings - those that involved the ramming of an aid to navigation and other types of ramming; and two types of collisions - those where both vessels would be participants in the VTS and those where one vessel would be a non-participant).

- Two VTS technology levels (Level I - Vessel movement reporting system and Level III advanced radar surveillance system). These were the two technology levels ultimately used in the design of candidate VTS systems in the ports under study.

- Two waterbody subzone types (corresponding to an aggregation of sub-zones A through C and sub-zones D through F). Subzones A - Open Approach, B - Convergence Area and C - Open Harbor/Bay were those where the waters were relatively unconfined. Subzones D - Enclosed Harbor, E - Constricted Waterway and F - River consisted of confined waterways.

- Two vessel categories corresponding to: **Large and Medium** - an aggregation of vessel size categories "medium" and "large"; and **Small** - size category "small". Furthermore, a tow consisting of a tug and one or more barges was to be considered in the **Large and Medium** category. This was because a tug towing one or more barges was considered to have limited maneuverability more analogous to the larger vessels.

The casualty types "collisions", "rammings" and "groundings" were each segmented into two sub-categories. This was to be done in order that the "Casualty Rate Reduction Factors" better reflect situations of "high" VTS addressability and "low" VTS addressability for each of the three main casualty types.

The "CASFINI" data set of the "collision" casualty type includes a number of collisions where one vessel is a VTS non-participant (i.e. a vessel under 65 feet, typically a fishing vessel or a recreational vessel). The results of the Focus Groups indicated that such potential casualties have a considerably reduced effectiveness relative to collisions between two vessels, both of whom are VTS participants.

The "CASFINI" data set includes collisions with aids-to-navigation as part of the "ramming" casualty type. VTS has a negligible effectiveness in dealing with collisions with aids-to-navigation.

On a similar note, the "CASFINI" data set for "grounding" casualties includes a considerable number of casualties attributable to "shoaling" conditions in the waterway. These types of groundings have a relatively low VTS effectiveness.

If the above segmentation of each of the primary casualty types (i.e. groundings, rammings and collisions) were not made the overall "casualty rate reduction factors" would be unexpectedly low and would not be comparable with other effectiveness estimates that have been developed in other studies.

The relative incidence within the CASFINI data base of each sub-category relative to the corresponding main casualty category was computed. For example, In Exhibit 4-2 the casualty category "collisions" includes the sub-categories "both VTS participants" and "one non-participant". In the data base 51 percent of the "collisions" consisted of collisions categorized in the sub-category "both VTS participants". The other 49 percent were collisions involving one "non-participant".

4.2 Discussion of Results

In reviewing Exhibits 4-2 and 4-3 the key casualty rate reduction factors related to System III - Advanced Radar Surveillance. This is by far the predominant configuration in the TSC design of candidate VTS systems for the 23 ports under study. One of the primary objectives of a VTS is the prevention of collisions between participating vessels. For this sub-class of casualties, for large and medium vessels (Exhibit 4-2), the casualty rate reduction factors are:

- Open waterbody subzone types A, B and C - 0.68
- Confined waterbody subzone types D, E and F - 0.52

The factor is lower in the confined subzone types because there is a greater tendency for vessels to pass close to each other in the normal course of operation. Collisions that take place have a greater tendency to begin with a chain of events at distances below those in which a VTS can effectively intervene. In cases where one of the vessels is a non-participant in the VTS, the collision casualty rate reduction factor is 0.27 which is lower, but still significant.

With respect to groundings not due to shoaling, for large and medium vessels (Exhibit 4-2), the casualty rate reduction factors are:

- Open waterbody subzone types A, B and C - 0.46
- Confined waterbody subzone types D, E and F - 0.25

The factor is considerably lower in the confined waterbody subzones because of the preponderance of relatively narrow channels, in which the distance factor is below the threshold where VTS can be effective. The casualty rate reduction factor for groundings due to shoaling is relatively low at 0.20; however, prevention of these types of casualties has never been viewed as a primary function of VTS.

Again for large and medium vessels (Exhibit 4-2), the casualty rate reduction factors for rammings range from 0.36 to 0.43. The fact that a significant proportion of rammings are due to maneuverability problems of a vessel passing through a bridge lowered the value of these factors. A VTS system was considered to have a negligible effectiveness in preventing the ramming of an aid to navigation. These casualties were considered in Exhibit 4-2 since the CASFINI data base included these events.

The casualty rate reduction factors for small vessels, presented in Exhibit 4-3 tend to be quite similar to the factors for the large and medium vessels. Smaller vessels are more maneuverable, may have a different level of crew capability and may have a different probability of getting into an accident in the first place. However, the root causes of casualties among the smaller commercial vessels are similar to the larger ones and the relative ability of VTS to intervene appears to be largely similar.

It is worthwhile to draw some comparisons between the above results and results of other investigations as summarized in Section 2.0. Previous attempts to estimate VTS effectiveness have included approaches to:

- Synthesize expert opinion.
- Conduct a historical before and after statistical analysis.

Studies using the expert opinion approach have included the Canadian VTS study, the study for the COST 301 program and the previous Coast Guard project from the 1970's. The studies based on historical data provide some useful suggestive evidence, but in general have not been comprehensive and do not necessarily have great statistical reliability.

The Canadian study (see Section 2.3) indicated that the casualty rate reduction factor for a radar surveillance VTS with automatic track analysis (not counting the effect of traffic separation schemes or movement restriction regulations) would be expected to range between 0.50 and 0.65 depending on the type of waters. These results compare favorably with the figures for collisions between VTS participants (0.68 and 0.52) and for groundings in open subzones (0.46) presented in Exhibit 4-2. The current project results are lower for groundings in confined waters (0.25), probably because this figure is dominated by situations in the lower Mississippi River and Intracoastal Waterway where the conditions are quite different from those in Canada.

The Canadian figures did not differentiate between collision, rammings and groundings. Nor did it explicitly consider collisions with one VTS non-participant, rammings of an aid to navigation or groundings due to shoaling. Thus the above figures presented for comparison are believed to represent similar situations. This is encouraging given that the results were arrived at independently and the detailed procedures for eliciting the expert opinion varied.

The results of the synthesis of expert opinion from the COST 301 study (see Section 2.2) indicated that the casualty rate reduction factors for collisions would be as follows depending on the type of vessel encounter:

- Meeting encounter 0.57
- Crossing encounter 0.45
- Overtaking encounter 0.32

The weighted average over the mix of these types of encounters in a typical waterway in the European area under consideration was estimated to be 0.50. This is somewhat lower than our collision figures of 0.68 and 0.52. The COST 301 results for groundings (strandings) was estimated to be 0.40. This is somewhat lower than our results for groundings in open subzones of 0.46. These European results may be lower because of the higher traffic densities in that area as well as language problems between vessel and VTS operator.

The earlier Coast Guard analysis from the 1970's (see Sections 2.4 and 2.5) indicated VTS effectiveness figures in the 30 to 65 percent range for VTS systems having radar surveillance. These figures are not strictly comparable to the current study because of the definition of the casualty data base used and the criteria employed for determining what a VTS preventable accident was.

Using the historical data approach, the study of collisions in the Dover Strait (see Section 2.8) suggested a 55 percent reduction in the number of collisions with the implementation of a VTS. The studies of Tokyo Bay, suggest a VTS effectiveness in reducing collisions on the order of 52 percent. This at least provides some supportive data that VTS effectiveness in the general range of 50 percent or above can be achieved.

The historical study of casualties in Berwick Bay (see Section 2.7) is representative of a very specific type of casualty scenario. The VTS there was implemented to deal with hazards associated with heavy traffic passing a narrow bridge. This is analogous to the "bridge ramming - pinched by other vessel" accident scenario analyzed by the Focus Groups (See Exhibit 3-3). For that case the VTS effectiveness was rated at 0.8 to 0.9. The historical data from Berwick Bay indicated that bridge rammings were reduced by an estimated 76 percent. This is supportive of the results from the Focus Groups given that not all of the bridge rammings involved being pinched by another vessel.

From the above it can be concluded that the results presented in Exhibits 4-2 and 4-3 are generally supported by results from previous independent analysis. However, it must be recognized that there inherently is a high degree of variability in any estimate of VTS effectiveness. It is appropriate that the overall casualty rate reduction factors be considered variables that can take on a significant range for sensitivity analysis. Based on the general preponderance of uncertainty and complicating factors, a reasonable range of values for sensitivity analysis for the figures in Exhibits 4-2 and 4-3 would be in the area of plus or minus 15 percentage points. For example, the casualty rate reduction factor for groundings due to "other causes" for waterbody subzones A, B and C in Exhibit 4-2 is 0.46. It is suggested that the range for sensitivity analysis could range up to 0.36 to 0.66 for this particular factor.

5.0 ADJUSTMENT FACTORS FOR HISTORICAL VTS COVERAGE

As part of the overall risk model, factors were required to adjust the historical vessel casualty statistics to account for the presence of VTS systems that existed in the past in various ports. These factors were to be used to calculate the expected casualty rate had there been no VTS in those ports. Accordingly, various source documents were reviewed and contacts were made with individuals having knowledge of the type of VTS technology and coverage within the relevant ports. Consideration was given both to VTS systems run by the Coast Guard as well as quasi-VTS systems run by local port groups.

Exhibit 5-1 outlines historical coverage of Coast Guard-operated VTS's by port, port subzone, years of operation, and level of technology. Five ports are documented in Exhibit 5-1 including: 1) Puget Sound, Washington; 2) San Francisco, California; 3) Houston/Galveston, Texas; 4) New Orleans, Louisiana; and 5) New York, New York. Port subzones represent the Transportation Systems Center-defined segregation of ports into subzones. The years of operation refer to the time frame when the port had a fully functioning Coast Guard VTS in operation. The level of technology was broken down to three levels, including:

- **Level I** A vessel movement reporting system consisting of VHF communication and various vessel reporting waypoints. No radar surveillance is included.

- **Level II** The vessel movement reporting system of Level I is coupled with basic radar surveillance. The radar technology is assumed to be equivalent to a good quality, recent vintage, standard shipboard radar without any advanced features.

- **Level III** This system includes complete communication plus an advanced state-of-the-art VTS radar surveillance system. Features include:

  -Automatic vessel track analysis
  -Track and collision alarms
  -Advanced rain and sea clutter control
  -High resolution
  -Overlaid port chart system with landmasses, channels, course leadlines, etc.
  -Provisions for vessel identifiers and particulars
  -Integrated display of multiple radars

Levels of technology sometimes change within a zone (e.g., radar coverage may not extend to the boundaries of a zone), therefore, estimates of the spatial coverage of each level of technology are denoted by percents in parenthesis following the level of technology designations.

Exhibit 5-1
VTS Coverage in the United States
1979-1989 by Port, by Level of Technology

Port/Subzone	Years of Coverage	Level of Technology			
Puget Sound, WA	1975 to Present	79	80	81[1]-91	92>
201		I	I	II	II
202	1975-1978 VHF only	I	I	II	II
203		II	II,10%	II	II
204		I	I	II	II
205	1978-1981 installed 10 radar	I	II	II	II
206		I	I	I	I
207		II	II	II	II
208		I	I	I	I
209		I	I	I[2]	I
210		I	I	I	II
San Francisco, CA	1972 to Present				
1401	Upgraded 2 radars from 1st to 2nd generation ARPA's in 1985	-			
1402		II[3]			
1403		II (75%)			
1404		II			
1405		-			
Houston/Galveston, TX	1977 to Present				
701	1 radar replaced in 1985	I			
702		II (60%)[4], II (20%)			
703		II			
New Orleans, LA	1977-1980 1982-1988				
601		-			
602		I			
603		I			
604		I			
New York, NY	1978-1980 1/1/85 to 6/10/88 1990 to Present				
1101		-			
1102		II			
1103		II (70%)			
1104		-			
1105		I (40%)[5], II (60%)			
1106		II			
1107		I (60%)[6], II (40%)			

Footnotes to Exhibit 5-1

1. The three years represent the technology in each year of the changeover from a vessel movement reporting system to radar coverage. The levels of technology in 1981 remained the same through 1989.

2. The approaches to Tacoma, which constitute subzones 209 and 210 (i.e., from Johnson Point), are not covered by radar, but two are currently being installed.

3. The radar has 40 mile capability, but is usually set to 13 miles.

4. Includes VHS communications and 8 remote cameras to monitor vessels from Morgan Point to Houston Turning Basin.

5. Includes VHF communication and remote cameras in Arthur Kill.

6. Includes VHF communication and remote cameras in East River.

Exhibit 5-2 presents a matrix of non-Coast-Guard VTS operations in the United States by port, port subzone, participation, and level of technology. Participation refers to the vessels that report into the traffic centers and maintain regular contact. Five ports are documented in Exhibit 5-2 including: 1) Los Angeles/Long Beach, California; 2) Hampton Roads, Virginia/Baltimore, Maryland; 3) Corpus Christi, Texas; 4) Delaware Bay, Delaware; and 5) Mobile, Alabama. All of these ports have had the same coverage with the same level of technology for the 1979 to 1989 period.

In Exhibit 5-2 reference is made to "piloted" and "non-piloted" vessels. For use in estimating, it is suggested that the following vessel types be considered "piloted" vessels:

- Medium Passenger
- Large and medium dry cargo
- Large and medium tanker

The following provides a description of the systems in each of the 5 ports.

Los Angeles/Long Beach

A Vessel Traffic Information Service (VTIS), operated by the Marine Exchange of Los Angeles/Long Beach Harbor, Inc., monitors inbound and outbound vessels, and has been in operation since 1922. The primary purpose of this system is to coordinate pilots with inbound vessels. The system is set up to respond to inquiries, but is not proactive. In other words it does not offer traffic advisory services, but will respond to queries. One hundred percent of piloted vessels participate in the system. For the period 1979 to July 1989 the Marine Exchange relied on 1 radar with 24-mile radius coverage and VHF communication. The Marine Exchange also has 20 miles of daytime visibility. In July 1989, 2 radar were installed which did not increase coverage, but enhanced the quality of the display. For the purpose of this analysis, this system is considered to provide the traffic advisory service of a fully functioning Coast Guard-operated VTS for piloted vessels, and none for non-piloted vessels.

Exhibit 5-2
Quasi-VTS Coverage in the United States
1979-1989, by port, by Level of Technology

Port/Subzone	Participation	Level of Technology
Los Angeles/Long Beach, CA	100 percent of piloted vessels 0 percent of non-piloted vessels	
301		-
302		II
303		II
304		II
Hampton Roads, VA/Baltimore, MD	100 percent of piloted vessels 60 percent of barges	
801		II
802		II
803		II (50%)
804		-
805		-
806		-
901		-
902		-
903		I
Corpus Christi, TX	100 percent of all commercial vessels	
1001		-
1002		-
1003		I
1004		I
Delaware Bay	90 to 100 percent of commercial vessels in radar coverage 90 to 100 percent in VHF communication coverage, except for interpier movements	
1301		II (15%)
1302		II
1303		II (34%), I (66%)
1304		I
1305		I
Mobile, AL	100 percent of piloted vessels 0 percent of non-piloted vessels	
2301		-
2302		-
2303		-
2304		-
2305		-

Hampton Roads/Baltimore

This quasi-VTS operation is a joint effort of The Association of Maryland Pilots and The Association of Virginia Pilots. The purpose of this system is to assist pilots in making contact, as well as advising pilots of inbound and outbound traffic. This system will disseminate unsolicited traffic advisory information to vessels. One hundred percent of piloted vessels and approximately 60 percent of barges are part of the system. The two pilots associations operate a joint radar at Cape Henry, Virginia, which monitors vessels in a 24-mile radius. The center also maintains radio communications with vessels. The Baltimore Maritime Exchange monitors traffic 70 miles down the Chesapeake Bay from Baltimore Harbor with radio contact only. There is no radar past Cape Henry. For the purpose of this exercise, the Hampton Roads/Baltimore system is considered to provide a similar service as a Coast Guard VTS for 100 percent of piloted vessels and 60 percent of non-piloted barges.

Corpus Christi

The Corpus Christi traffic system has been in operation since 1928 and its primary function is to schedule refinery vessel traffic. For the period 1979 to the present vessels have been monitored solely by radio communication; no radar is used to track vessels. The harbormaster maintains records of all vessels movements in Corpus Christi Bay. One hundred percent of all commercial vessels participate in the system. Radio contact is established 1 mile off the beach at Port Aransas and continues through the 26 mile ship channel to the turning basin. The harbormaster also advises vessels on traffic at the meeting point of the Intercoastal Waterway and the Corpus Christi Ship Channel. For the purpose of this analysis, this system is considered to provide the equivalent of a Level I Coast Guard VTS.

Delaware Bay

Vessel traffic from the Delaware Bay to the Port of Philadelphia is monitored by the Pilots Association for the Bay and River Delaware. For the period 1979 to July 1989, vessels have been monitored in a 25-mile radius by radar at Cape Henlopen, and by VHF communication from outside radar coverage to the Port of Philadelphia. The system monitors the traffic in the inbound and outbound sea lanes and lightering activity in the lower Delaware Bay. Once the vessel leaves radar coverage, radio contact is maintained to the Port of Philadelphia. In July 1989, two advanced radar with automatic vessel tracking capability were installed. Participation in the radar coverage approaches 100 percent for commercial vessels. All commercial vessels including barges check into the system and are advised of traffic situations. Full coverage is maintained for vessels after they leave the radar up to Philadelphia by VHF communication. Inter-pier movements in the Port of Philadelphia, however, are not monitored in the system. For the purpose of this analysis, this system is considered the equivalent of a full-fledged Coast Guard operated VTS.

Mobile

The Pilots Association of the Port of Mobile controls vessels over 115 feet in beam. It monitors estimated time of arrivals for its pilots with VHF communication. For the purpose of this analysis, it is not considered to perform traffic advisory services similar to those of a Coast Guard-operated VTS.

Casualty Rate Reduction Factors

Exhibits 5-3 and 5-4 present the casualty rate reduction factors to be applied to the historical casualty rates for "large" and "small and medium" vessels respectively. These have been calculated for Technology Levels I and II. The procedures employed are the same as those discussed in Section 4.0.

Casualty Rate Reduction Factors For Historical Adjustments

Large and Medium Vessels

	Waterbody Subzone Types A, B, and C A – Open Approach B – Convergence C – Open Harbor/Bay			Waterbody Subzone Types D, E, and F D – Enclosed Harbor E – Constricted Waterway F – River		
	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category
Collisions						
Both VTS Participants	0.11	0.53	0.51	0.19	0.41	0.89
One Non-participant	0.00	0.20	0.49	0.00	0.20	0.11
			1.00			1.00
Rammings						
Ramming ATN	0.00	0.00	0.35	00.0	0.00	0.39
Other Causes	0.22	0.39	0.65	0.22	0.35	0.61
			1.00			1.00
Groundings						
Shoaling	0.10	0.20	0.27	0.10	0.20	0.46
Other Causes	0.05	0.38	0.73	0.05	0.22	0.54
			1.00			1.00

Source: Application of results of focus group panels to a statistical analysis of the data base of addressable vessel casualties.

ATK1/15454/5 kp

Casualty Rate Reduction Factors For Historical Adjustments

Small Vessels

	Waterbody Subzone Types A, B, and C A – Open Approach B – Convergence C – Open Harbor/Bay			Waterbody Subzone Types D, E, and F D – Enclosed Harbor E – Constricted Waterway F – River		
	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category	Vessel Movement Reporting System I	Advanced Radar Surveillance System III	Percentage of Casualties in Category
Collisions						
Both VTS Participants	0.13	0.51	0.40	0.18	0.44	0.67
One Non-participant	0.00	0.20	0.60	0.00-	0.20	0.33
			1.00			1.00
Rammings						
Ramming ATN	0.00	0.00	0.43	00.0	0.00	0.33
Other Causes	0.25	0.48	0.57	0.20	0.35	0.67
			1.00			1.00
Groundings						
Shoaling	0.10	0.20	0.35	0.10	0.20	0.31
Other Causes	0.06	0.43	0.65	0.02	0.21	0.69
			1.00			1.00

Source: Application of results of focus group panels to a statistical analysis of the data base of addressable vessel casualties.

ATK1/15454/6 kp

6.0 LITERATURE CITED

Canadian Coast Guard, 1984. Vessel Traffic Services, Final Report. National Vessel Traffic Services Study. Document TP5965-1E. Ottawa, Canada, October.

Carpenter, Steve, 1988. Cost Recovery for Vessel Traffic Service Operations: An Evaluation of Value Added and Fee Assessment. In: Sixth International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Gothenburg, Sweden.

Charter, Daniel, 1979. Proceedings: Symposium on Piloting and VTS Systems. The National Research Council, Maritime Transportation Research Board, Commission on Sociotechnical Systems.

Cockcroft, A. N., 1978. The Incidence of Sea and Harbor Collisions. In: Third International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Liverpool.

Commission of European Communities, 1987. The Maritime Environment, Traffic and Casualties, COST 301 Final Report - Annex to the Main Report: Volume 2.

Degree, Thomas and Peter Coles, 1988. Assessment of the Effects of Vessel Traffic Services on Marine Traffic Safety by Mathematical Modelling. In: Sixth International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Gothenburg, Sweden.

Drager, K. Harald, Jan E. Karlsen, Svein Kristiansen and P. Morton Wiencke, 1981. Cause Relationships of Collisions and Groundings - Research Project Conclusions. In: Fourth International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Bremen.

Ecker, William J., 1978. Casualty Analysis of Selected Waterways. In: Third International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Liverpool.

Fujii, Y. and S. Kaku, 1981. Time Trend of Traffic Accidents in Japan Before and After the Maritime Traffic Safety Law. In: Fourth International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Bremen.

Hara, K., K. Inoue, Y. Ohara and A. Nagasawa, 1990. Safety Measures for Navigation at Narrow Channels in Japan. In: Proceedings of the 27th International Navigation Congress, Osaka - May 1990.

Johnson, D. R., 1978. Recent Trends in Navigational Safety in the Dover Strait. In: Third International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Liverpool.

Kemp, J.F., E. M. Goodwin and K. Pick. 1986. Assessment of Risk to Shipping Through Collisions and Strandings in the COST 301 Area. Problem Area Identifier Report on COST 301 Task No. 2.46. UK Department of Transport and Commission of European Communities.

Kuroda, K. and H. Kita, 1990. Safety Assessment of Waterway Network in Bay Area. In: Proceedings of the 27th International Navigation Congress, Osaka - May 1990.

U. S. Coast Guard, 1973. Vessel Traffic Systems, Analysis of Port Needs, Final Report. Document Number AD-770-710. U. S. Coast Guard Headquarters, Washington D.C., August.

Van Riet, J. A. and K. J. de Vrijer, 1984. Aspects of V.T.S. and Deep Sea Pilotage on Board a V.L.C. - A V.T.S. from the Channel to the Baltic, Facts, Fiction or Vision? In: Fifth International Symposium on Vessel Traffic Services: Proceedings of the Symposium. Marseille, France.

7.0 FOCUS GROUP PANEL PARTICIPANTS

The objective of these Focus Groups was to develop estimates of the effectiveness in preventing marine casualties for various configurations of vessel traffic systems.

Focus Group One

The first two-day Focus Group Panel Discussion was held in Washington, D.C. on September 29 and 30, 1990. The participants in this session were:

Homer A. Purdy

Retired Captain, U. S. Coast Guard, former Commanding Officer, Prince William Sound VTS, former Coast Guard VTS program manager.

Alan B. Smith

Retired Captain, U. S. Coast Guard, Former VTS program manager. Extensive shipboard operating experience.

Richard J. Heym

Retired Captain, U. S. Coast Guard, former Commanding Officer, New York VTS, Former supervisor of Eighth Coast Guard District VTS operations (New Orleans, Berwick and Houston/Galveston).

Wayne R. Young

Retired Captain, U. S. Coast Guard, former Commanding Officer, New York VTS, extensive experience in port regulations, currently on the Marine Board of the National Academy of Sciences.

Edward L. Yarborough

Retired Chief Warrant Officer, U. S. Coast Guard, former VTS watchstander, former watchstanding supervisor for Houston/Galveston VTS, extensive vessel operating experience.

Focus Group Two

The second two-day Focus Group Panel Discussion was held at the Red Lion Inn, Belleview, Washington on October 25 and 26, 1990. The participants in this session were:

Homer A. Purdy

Retired Captain, U. S. Coast Guard, former Commanding Officer, Prince William Sound VTS, former Coast Guard VTS program manager.

James T. Cushman

Retired Captain, U. S. Coast Guard, Former Commanding Officer, San Francisco VTS.

Neal G. Nelson

Retired Commander, U. S. Coast Guard, former Commanding Officer, Seattle VTS.

Scott Schaefer

Watch Officer, San Francisco VTS.

Cdr. Mike Hauckey

Commander, U. S. Coast Guard, current VTS Commanding Officer, Seattle VTS.

Focus Group Three

The third two-day Focus Group Panel Discussion was held in Washington, D.C. on November 14 and 15, 1990. The participants in this session were:

Mike Sollosi

Currently with Coast Guard Headquarters, Vessel Traffic Services Branch, G-NSP. Former Watch Officer, San Francisco VTS.

Bruce Reilly

Currently with Coast Guard Headquarters, Vessel Traffic Services Branch, G-NSP. Former VTS Watch Officer.

Vic Pounds

Former Watch Officer, Seattle VTS. Currently working at U.S. Coast Guard Headquarters, G-NSP.

Lcdr William Cairns

Electronic systems specialist with Coast Guard Headquarters, Electronic Systems Division, G-TES-3.

Cdr Bob Vorthman

U. S. Coast Guard Engineering Center

Lcdr John Harrington

Branch Chief, Navigation Systems. U. S. Coast Guard Engineering Center

SECTION 3.

NAVIGATIONAL RISK MODEL DEVELOPMENT

Prepared By:

Tai-Kuo Liu, DTS 42
The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142
July 1991

3. NAVIGATIONAL RISK MODEL DEVELOPMENT

NOTE: This section documents Tai-Kuo Liu's effort in support of Section 5 of the Port Needs Study (Volume I).

SECTION 3. TABLE OF CONTENTS

SECTION 3. TABLE OF CONTENTS (Cont.)

INTRODUCTION

This Technical Supplement documents the data analyses, process and results involved in the calibration of a navigational risk model. The model is estimated from a selected sample group of VTS-addressable casualty data base and used to develop a matrix of casualty probabilities by subzone, vessel type, vessel size and casualty type. The casualty probabilities are then applied to predict the future VTS-addressable casualties and the subsequent consequences and benefits that are attributed to the proposed VTS systems around the 23 study zones.

The following are summary descriptions of each step in the process:

1. Table 1 describes the process of estimating casualty probabilities and the projection of casualties. The following tables and attachments describe the data and analysis results involved in each step of the process.

2. Table 2 summarizes the distribution of 99 subzones in the 23 study zones. It indicates that four subzones do not have dominant traffic routes nor any transit estimates within the subzone boundaries. Five other subzones do not have any medium or large, dry cargo and tanker vessel movements (selected as the sample group to estimate the model). It leaves 87 of the remaining 90 subzones except three subzone outliers as the pool of observations to calibrate the model on their distributions of casualties, transit movements and subzone characteristics. The calibrated parameters are then applied to develop subzone-specific risk adjustment factors for the 95 subzones with any vessel transits.

3. Table 3 is a description of the 99 subzones (refer to the main report [Volume I] for maps and descriptions of each of the subzones.)

4. Table 4 shows the total number of 10 year historical casualties, (after adjustment for the effect of the existing VTS systems), 10 year transit estimates, and the adjusted historical casualty rates for the combined medium and large, dry cargo and tanker vessel movements for the 90 subzones with the data available. The casualty rates represent the national averages and the averages by subzone type of this vessel group for the 23 study zones.

INTRODUCTION (Cont.)

5. Table 5 is a list of subzone variables that characterize the subzones and subzone dominant traffic routes. Those variables are all specified and tested in the regression analyses.

6. Table 6 contains the values of subzone variables and route characteristics for the 90 subzones, sorted by subzone type.

7. Table 7 lists the subzone historical casualties, casualty rates, predicted casualty rates and casualties (by the linear, multiple regression model, see Attachment 1), and the weighted casualty rates used to develop the subzone-specific risk adjustment factors for casualty projection.

8. Table 8 is the summary of subzone-specific risk adjustment factors. (i.e., Table 5-7 in the main report)

9. Table 9 is the national average casualty rate table (i.e., Table 5-2 in the main report) that will be multiplied by the subzone risk adjustment factors to derive the matrix of casualty probability table by subzone, vessel type, vessel size and casualty type.

10. Table 10 describes the dimensions of the matrix application with actual values to generate the casualty rate table.

11. Table 11 is the comparison, at the study zone level, of historical casualties versus predicted casualties by linear regression, as well as logistic regression models (see Attachments 2 and 3). The predicted casualties are also weighted with historical casualties individually.

12. Table 12 and 13 summarize the refit of the linear model and logistic model based on the historical casualty rates of the first seven year casualty data (1979 to 1986). The parameters are then used to predict the casualties for the remaining three years (1987 to 1989). The predicted casualties are compared with the observed casualties in sum squares of residuals.

TABLE 1. CASUALTY PROJECTION PROCESS

SAMPLE BASE	:	90 subzones with 10-year VTS-addressable casualties (adjusted with the existing VTS effects), in medium and large, dry cargo and tanker vessel movements.
MEAN CASUALTY RATE	:	9.62141 casualties per 100,000 movements.
HISTORICAL CASUALTY RATE	:	$\text{HIS\_RATE} = \dfrac{\text{SUBZONE HIST. CASUALTIES}}{\text{SUBZONE VESSEL MOVEMENTS}} * 100{,}000$
PREDICTED CASUALTY RATE BY LINEAR REGRESSION MODEL	:	PRD_RATE = - 0.372321 - 3.529773*OPEN + 16.327722*NARROW + 0.228527*RTLENGTH - 0.000407*AVGWIDTH + 0.012121*SUMHEADI + 0.000392*OTHER_ML
WEIGHTED CASUALTY RATE	:	WEI_RATE = (HIS_RATE + PRD_RATE) / 2
RISK ADJUSTMENT FACTOR FOR SUBZONE	:	RISK_FTR = WEI_RATE / 9.62141
NATIONAL CASUALTY RATE BY VESSEL TYPE VESSEL SIZE CASUALTY TYPE	:	$\text{NAL\_RATE} = \dfrac{\text{SUM OF ALL SUBZONE CASUALTIES}}{\text{SUM OF ALL SUBZONE VESSEL MOVEMENTS}}$
SUBZONE CASUALTY RATE BY VESSEL TYPE VESSEL SIZE CASUALTY TYPE	:	SBZ_RATE = NAL_RATE * RISK_FTR
SUBZONE CASUALTY PROJECTION	:	PREDICTED CASUALTIES = VESSEL MOVEMENTS ESTIMATE * SBZ_RATE

TABLE 2. VTS STUDY SUBZONES DISTRIBUTION

Subzone Type	Number of Subzones	Subzones With No Dominant Routes	Subzones With No Deep Draft Traffic	Outliers
A. OPEN APPROACH	22			
B. CONVERGENCE	10			
C. OPEN HARBOR OR BAY	18		2	1
D. ENCLOSED HARBOR	17		1	1
E. CONSTRICTED WATERWAY	20	3	2	1
F. RIVER	12	1		
TOTAL	99	4	5	3

* Number of Subzones for Calibration of Risk Models: 87

TABLE 3. STUDY ZONES AND SUBZONES CLASSIFICATIONS (1 OF 3)

NO.	STUDY ZONE	SUB-ZONE NO.	DESCRIPTION
1	BOSTON, MA	0101A	OPEN APPROACH
		0102B	CONVERGENCE
		0103C	OPEN HARBOR OR BAY
		0104D	ENCLOSED HARBOR
		0105E	CONSTRICTED WATERWAY
2	PUGET SOUND, WA	0201A	OPEN APPROACH
		0202B	CONVERGENCE
		0203C	OPEN HARBOR OR BAY
		0204E	CONSTRICTED WATERWAY
		0205C	OPEN HARBOR OR BAY
		0206D	ENCLOSED HARBOR
		0207D	ENCLOSED HARBOR
		0208E	CONSTRICTED WATERWAY
		0209E	CONSTRICTED WATERWAY
		0210D	ENCLOSED HARBOR
3.	LOS ANGELES/ LONG BEACH, CA	0301A	OPEN APPROACH
		0302B	CONVERGENCE
		0303C	OPEN HARBOR OR BAY
		0304D	ENCLOSED HARBOR
4.	SANTA BARBARA, CA	0401A	OPEN APPROACH
5.	PORT ARTHUR, TX	0501A	OPEN APPROACH
		0502E	CONSTRICTED WATERWAY
		0503E	CONSTRICTED WATERWAY
		0504F	RIVER
6.	NEW ORLEANS, LA	0601A	OPEN APPROACH
		0602E	CONSTRICTED WATERWAY
		0603F	RIVER
		0604E	CONSTRICTED WATERWAY
		0605F	RIVER
		0606F	RIVER
7.	HOUSTON/ GALVESTON, TX	0701A	OPEN APPROACH
		0702E	CONSTRICTED WATERWAY
		0703D	ENCLOSED HARBOR
8.	CHESAPEAKE SOUTH/ HAMPTON ROADS, VA	0801A	OPEN APPROACH
		0802B	CONVERGENCE
		0803C	OPEN HARBOR OR BAY
		0804D	ENCLOSED HARBOR
		0805E	CONSTRICTED WATERWAY
		0806C	OPEN HARBOR OR BAY

TABLE 3. STUDY ZONES AND SUBZONES CLASSIFICATIONS (2 OF 3)

NO.	STUDY ZONE	SUB-ZONE NO.	DESCRIPTION
9	CHESAPEAKE NORTH/ BALTIMORE, MD	0901C	OPEN HARBOR OR BAY
		0902D	ENCLOSED HARBOR
		0903F	RIVER
10	CORPUS CHRISTI, TX	1001A	OPEN APPROACH
		1002B	CONVERGENCE
		1003E	CONSTRICTED WATERWAY
		1004F	RIVER
11	NEW YORK CITY, NY	1101A	OPEN APPROACH
		1102B	CONVERGENCE
		1103C	OPEN HARBOR OR BAY
		1104D	ENCLOSED HARBOR
		1105E	CONSTRICTED WATERWAY
		1106C	OPEN HARBOR OR BAY
		1107E	CONSTRICTED WATERWAY
12	LONG ISLAND SOUND, NY	1201A	OPEN APPROACH
		1202B	CONVERGENCE
		1203C	OPEN HARBOR OR BAY
		1204D	ENCLOSED HARBOR
		1205D	ENCLOSED HARBOR
		1206E	CONSTRICTED WATERWAY
13	PHILADELPHIA, PA	1301A	OPEN APPROACH
		1302B	CONVERGENCE
		1303C	OPEN HARBOR OR BAY
		1304F	RIVER
		1305E	CONSTRICTED WATERWAY
14	SAN FRANCISCO, CA	1401A	OPEN APPROACH
		1402B	CONVERGENCE
		1403C	OPEN HARBOR OR BAY
		1404D	ENCLOSED HARBOR
		1405F	RIVER
15	PORTLAND, OR	1501A	OPEN APPROACH
		1502C	OPEN HARBOR OR BAY
		1503F	RIVER
16	ANCHORAGE, AK (COOK INLET)	1601A	OPEN APPROACH
		1602C	OPEN HARBOR OR BAY
		1603D	ENCLOSED HARBOR

TABLE 3. STUDY ZONES AND SUBZONES CLASSIFICATIONS (3 OF 3)

NO.	STUDY ZONE	SUB-ZONE NO.	DESCRIPTION
17	PORTLAND. ME	1701A	OPEN APPROACH
		1702C	OPEN HARBOR OR BAY
		1703D	ENCLOSED HARBOR
		1704E	CONSTRICTED WATERWAY
18	PORTSMOUTH, NH	1801A	OPEN APPROACH
		1802B	CONVERGENCE
		1803D	ENCLOSED HARBOR
		1804F	RIVER
19	PROVIDENCE, RI	1901A	OPEN APPROACH
		1902C	OPEN HARBOR OR BAY
		1903D	ENCLOSED HARBOR
20	WILMINGTON, NC	2001A	OPEN APPROACH
		2002E	CONSTRICTED WATERWAY
		2003F	RIVER
21	JACKSONVILLE, FL	2101A	OPEN APPROACH
		2102E	CONSTRICTED WATERWAY
22	TAMPA, FL	2201A	OPEN APPROACH
		2202C	OPEN HARBOR OR BAY
		2203D	ENCLOSED HARBOR
23	MOBILE, AL	2301A	OPEN APPROACH
		2302E	CONSTRICTED WATERWAY
		2303C	OPEN HARBOR OR BAY
		2304E	CONSTRICTED WATERWAY
		2305F	RIVER

TOTAL NUMBER OF ZONES: 23

TOTAL NUMBER OF SUB-ZONES: 99

TABLE 4. NATIONAL AVERAGE CASUALTY RATES BY SUBZONE TYPE

(Adjusted with the existing VTS effects)

- MEDIUM AND LARGE DRY CARGO AND TANK VESSELS ONLY -

(Unit: Number of Casualties per 100,000 transits)

OBS	ZONE TYPE	NUMBER OF SUBZONES	ADJUSTED CASUALTIES	NUMBER OF TRANSITS	CASUALTY RATE
1	A	22	40.478	1739631	2.3268
2	B	10	25.587	787142	3.2506
3	C	16	77.022	914702	8.4205
4	D	16	24.171	525546	4.5991
5	E	15	164.545	705754	23.3147
6	F	11	189.074	740949	25.5178
7	TOTAL	90	520.876	5413724	9.6214

NOTE: Subzones with no dominant route or no dry cargo or tanker traffic are excluded.

TABLE 5. SUBZONE VARIABLES TESTED IN RISK MODELS

Variable:	VARIABLE DESCRIPTION
RATE	Number of casualties per 100,000 transits
OPEN	is 1 if zonetype = Open Approach otherwise 0.
CONVERGE	is 1 if zonetype = Convergence otherwise 0.
OPENHBR	is 1 if zonetype = Open Bay or Harbor otherwise 0.
ENCLOSED	is 1 if zonetype = Enclosed Harbor otherwise 0.
NARROW	is 1 if zonetype = Constricted Waterway otherwise 0.
RIVER	is 1 if zonetype = Open Approach otherwise 0.
CURRAVG	The average maximum current velocity in knots for the subzone.
VIS1N	Percent of times visibility is less than 1 nautical mile.
WIND20N	Percent of times wind velocity is greater than 20 knots.
RTLENGTH	Length in statute miles of the primary traffic route in subzone.
MINWIDTH	Minimum channel/waterway width in yards.
AVGWIDTH	Average channel/waterway width in yards.
MINDEPTH	Minimum channel/waterway depth in feet.
SUMHEADI	Sum of total degrees of course changes along the primary route in subzone.
NUMTURNS	Total number of course changes along the primary route in subzone.
AVG_HEAD	Average degrees of a course change.
DRY_TNK	10 year medium and large dry cargo and tanker vessel transits.
ALLTRANS	Sum of 10 year all types transits for the subzone.
FERRYMIL	Total ferry miles estimated for the subzone.
OTHERVSL	Total number of registered other vessels for the subzone.
D_TNK_ML	DRY_TNK divided by RTLENGTH.
ALLT_ML	ALLTRANS divided by RTLENGTH.
TURN_ML	NUMTURNS divided by RTLENGTH.
SUMHD_ML	SUMHEADI divided by RTLENGTH.
OBST_ML	Total number of bridges, anchorages, and other obst. divided by RTLENGTH.
FRYML_SM	FERRYMIL divided by water surface area in bubzone.
OTHER_ML	OTHERVSL divided by RTLENGTH.

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART ONE) (1 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	COLRAM	GROUND	ALLCASU	ADJ_CASU	DRY_TNK	ALLTRANS	D_TNKVM	ALL_VKM	RATE	RATE_VM	CURRAVG	VIS1	WIND20
1	1	1	A	.	1	1	1.0000	14480	228342	138128	2762	6.9061	0.72397	0.84	0.060731	0.07180
2	2	1	A	2	1	3	4.1748	54934	4139170	3691628	277851	7.5997	0.11309	1.36	0.058904	0.00982
3	3	1	A	.	.	0	0.0000	95033	1285993	2031571	28170	0.0000	0.00000	0.19	0.024087	0.00400
4	4	1	A	1	.	1	1.0000	75846	93984	3752650	4560	1.3185	0.02665	0.19	0.046347	0.01027
5	5	1	A	3	1	4	4.0000	73693	413935	2612724	14494	5.4279	0.15310	2.30	0.048059	0.01655
6	6	1	A	4	15	19	20.3028	228924	852314	11377313	42352	8.8688	0.17845	1.30	0.032534	0.01279
7	7	1	A	.	.	0	0.0000	182200	848200	4973091	23190	0.0000	0.00000	2.30	0.032763	0.00559
8	8	1	A	.	.	0	0.0000	189689	2119406	6738631	75285	0.0000	0.00000	1.30	0.026941	0.07648
9	10	1	A	.	.	0	0.0000	30471	95305	708735	2370	0.0000	0.00000	1.21	0.035731	0.09281
10	11	1	A	.	.	0	0.0000	392257	3639925	10100140	58671	0.0000	0.00000	1.50	0.035731	0.06998
11	12	1	A	.	.	0	0.0000	10529	3325895	221357	70658	0.0000	0.00000	1.26	0.044178	0.05833
12	13	1	A	1	.	1	1.0000	37605	767831	1806996	36891	2.6592	0.05534	0.29	0.027968	0.01758
13	14	1	A	.	.	0	0.0000	145596	425161	4333773	12651	0.0000	0.00000	0.19	0.013128	0.14692
14	15	1	A	1	1	2	2.0000	79395	951267	1388842	16635	2.5191	0.14400	0.30	0.037443	0.01522
15	16	1	A	.	.	0	0.0000	3920	8645	267536	491	0.0000	0.00000	3.00	0.044977	0.01199
16	17	1	A	.	.	0	0.0000	3272	248743	26176	2664	0.0000	0.00000	0.30	0.072945	0.02272
17	18	1	A	.	.	0	0.0000	2306	47044	18590	452	0.0000	0.00000	0.50	0.057877	0.01610
18	19	1	A	1	1	2	2.0000	7512	65417	172120	1520	26.6241	1.16198	0.60	0.056963	0.04201
19	20	1	A	.	.	0	0.0000	14701	146564	101849	1010	0.0000	0.00000	0.50	0.037785	0.00959
20	21	1	A	1	.	1	1.0000	26491	144801	376505	2066	3.7749	0.26560	0.00	0.058790	0.00845
21	22	1	A	.	4	4	4.0000	31854	114772	891912	3169	12.5573	0.44847	0.86	0.022146	0.00342
22	23	1	A	.	.	0	0.0000	38923	338382	1378334	10394	0.0000	0.00000	1.50	0.058904	0.01701
23	1	2	B	.	.	0	0.0000	13483	219203	60107	1863	0.0000	0.00000	1.00	0.060731	0.07180
24	2	2	B	.	1	1	1.4957	52242	3794959	1582751	112324	2.8630	0.09450	1.69	0.058904	0.00982
25	3	2	B	5	.	5	7.4283	95033	1285993	834388	13642	7.8165	0.89026	0.19	0.024087	0.00400
26	8	2	B	3	1	4	6.0013	189689	2179925	7008892	80541	3.1638	0.08562	1.49	0.026941	0.07648
27	10	2	B	1	1	2	2.0000	30471	95305	478580	1752	6.5636	0.41790	1.21	0.035731	0.09281
28	11	2	B	.	5	5	5.4957	278702	1909356	2031070	14181	1.9719	0.27058	1.41	0.035731	0.06998
29	12	2	B	.	.	0	0.0000	10529	3329555	229371	73072	0.0000	0.00000	1.76	0.044178	0.05833
30	13	2	B	.	.	0	0.0000	37605	374564	1049812	10451	0.0000	0.00000	2.17	0.027968	0.01758
31	14	2	B	2	.	2	3.1661	77082	379433	1694168	8144	4.1074	0.18688	1.63	0.013128	0.14692
32	18	2	B	.	.	0	0.0000	2306	34959	6745	271	0.0000	0.00000	1.60	0.057877	0.01610
33	1	3	C	1	1	2	2.0000	14480	392759	57501	2662	13.8122	3.47820	0.74	0.060731	0.07180
34	2	3	C	.	1	1	1.4957	46136	4436951	2128651	119392	3.2419	0.07026	1.23	0.058904	0.00982
35	3	3	C	.	.	0	0.0000	95033	1308652	390098	8515	0.0000	0.00000	0.19	0.024087	0.00400
36	8	3	C	.	2	2	2.9913	189689	2407677	3425204	43470	1.5770	0.08733	1.12	0.026941	0.07648
37	8	6	C	.	.	0	0.0000	2697	425252	62638	9874	0.0000	0.00000	1.12	0.026941	0.07648
38	9	1	C	2	8	10	10.6613	73452	708379	7023482	66862	14.5147	0.15180	0.59	0.048402	0.02580
39	11	3	C	.	1	1	1.4957	197270	613107	638623	2334	0.7582	0.23420	0.87	0.035731	0.06998
40	11	6	C	3	2	5	5.0000	81432	2772575	235090	7157	6.1401	2.12685	1.87	0.035731	0.06998

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART ONE) (2 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	COLRAM	GROUND	ALLCASU	ADJ_CASU	DRY_TNK	ALLTRANS	D_TNKVM	ALL_VKM	RATE	RATE_VM	CURRAVG	VIS1	WIND20
41	12	3	C	.	1	1	1.0000	10529	983412	553035	44931	9.498	0.1808	1.21	0.044178	0.05833
42	13	3	C	.	3	3	3.2034	37605	874217	1997721	44380	8.519	0.1604	1.46	0.027968	0.01758
43	14	3	C	2	1	3	4.1748	77082	718983	2483494	14314	5.416	0.1681	1.81	0.013128	0.14692
44	15	2	C	4	8	12	12.0000	42739	587261	1358514	18662	28.077	0.8833	3.09	0.037443	0.01522
45	16	2	C	1	2	3	3.0000	3920	5142	649750	847	76.531	0.4617	2.78	0.044977	0.01199
46	17	2	C	.	.	0	0.0000	3272	409929	29622	3267	0.000	0.0000	1.10	0.072945	0.02272
47	19	2	C	1	1	2	2.0000	7512	181442	168128	1757	26.624	1.1896	0.88	0.056963	0.04201
48	22	2	C	5	23	28	28.0000	31854	124060	1001958	3698	87.901	2.7945	0.63	0.022146	0.00342
49	1	4	D	1	.	1	1.0000	13483	623618	60359	3034	7.417	1.6568	0.27	0.060731	0.07180
50	2	6	D	.	1	1	1.2671	2373	163795	21182	1502	53.397	5.9820	0.10	0.058904	0.00982
51	2	7	D	2	.	2	3.2621	22359	1753803	91510	12013	14.590	3.5648	0.10	0.058904	0.00982
52	2	10	D	.	.	0	0.0000	20611	594077	58009	1667	0.000	0.0000	0.29	0.058904	0.00982
53	3	4	D	1	1	2	2.5386	95033	1308652	121437	5256	2.671	2.0904	0.19	0.024087	0.00400
54	7	3	D	.	1	1	1.2671	102864	291898	276457	934	1.232	0.4583	1.25	0.032763	0.00559
55	8	4	D	2	4	6	7.9709	130751	1284413	600307	5966	6.096	1.3278	1.18	0.026941	0.07648
56	9	2	D	1	1	2	2.2337	57387	467118	531499	4532	3.892	0.4203	0.00	0.048402	0.02580
57	12	4	D	.	.	0	0.0000	1346	93309	5633	924	0.000	0.0000	0.43	0.044178	0.05833
58	12	5	D	.	.	0	0.0000	6251	57764	41678	380	0.000	0.0000	0.90	0.044178	0.05833
59	14	4	D	1	.	1	1.6311	26993	100948	124577	476	6.043	1.3093	1.60	0.013128	0.14692
60	16	3	D	.	1	1	1.0000	3920	5142	25257	28	25.510	3.9593	2.70	0.044977	0.01199
61	17	3	D	.	.	0	0.0000	3272	373205	4207	1440	0.000	0.0000	1.00	0.072945	0.02272
62	18	3	D	.	.	0	0.0000	2306	29429	5584	193	0.000	0.0000	2.23	0.057877	0.01610
63	19	3	D	.	1	1	1.0000	4743	28692	38196	283	21.084	2.6181	1.40	0.056963	0.04201
64	22	3	D	.	1	1	1.0000	31854	106051	346556	1058	3.139	0.2886	0.80	0.022146	0.00342
65	1	5	E	2	.	2	2.0000	5688	59560	16368	208	35.162	12.2190	0.18	0.060731	0.07180
66	2	4	E	.	.	0	0.0000	6106	1683889	81627	20265	0.000	0.0000	1.24	0.058904	0.00982
67	2	9	E	.	1	1	1.0787	793	406751	28755	6389	136.034	3.7515	1.56	0.058904	0.00982
68	5	2	E	8	3	11	11.0000	59559	409635	1892138	12852	18.469	0.5814	1.83	0.048059	0.01655
69	5	3	E	5	3	8	8.0000	14134	913464	629209	10445	56.601	1.2714	1.60	0.048059	0.01655
70	6	2	E	9	22	31	33.9971	214962	826792	4399464	16914	15.815	0.7728	0.90	0.032534	0.01279
71	6	4	E	2	10	12	12.0000	25785	205158	2281719	15376	46.539	0.5259	0.90	0.032534	0.01279
72	7	2	E	35	18	53	61.3464	182200	1479457	2045131	10673	33.670	2.9996	1.79	0.032763	0.00559
73	10	3	E	1	2	3	3.3125	30471	1537093	715067	6057	10.871	0.4632	1.20	0.035731	0.09281
74	11	5	E	8	3	11	11.8100	81432	1072053	428600	5966	14.503	2.7555	1.44	0.035731	0.06998
75	11	7	E	.	.	0	0.0000	4114	739133	62897	5617	0.000	0.0000	2.12	0.035731	0.06998
76	20	2	E	.	.	0	0.0000	14701	146564	105058	1043	0.000	0.0000	2.90	0.037785	0.00959
77	21	2	E	1	6	7	7.0000	26491	346411	736918	4218	26.424	0.9499	1.83	0.058790	0.00845
78	23	2	E	1	3	4	4.0000	22502	110403	613958	3007	17.776	0.6515	1.20	0.058904	0.01701
79	23	4	E	3	6	9	9.0000	16816	258702	792087	10031	53.520	1.1362	0.76	0.058904	0.01701
80	5	4	F	3	2	5	5.0000	25806	353103	72360	985	19.375	6.9099	1.34	0.048059	0.01655

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART ONE) (3 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	COLRAM	GROUND	ALLCASU	ADJ_CASU	DRY_TNK	ALLTRANS	D_TNKVM	ALL_VKM	RATE	RATE_VM	CURRAVG	VIS1	WIND20
81	6	3	F	10	42	52	56.6206	172524	2986655	12802700	77499	32.8189	0.4423	3.43	0.032534	0.01279
82	6	5	F	19	6	25	28.8932	261403	2020725	11088776	85714	11.0531	0.2606	3.43	0.032534	0.01279
83	6	6	F	22	34	56	62.1322	101931	563785	10936016	60484	60.9552	0.5681	3.26	0.032534	0.01279
84	9	3	F	2	2	4	4.5645	15588	66834	230319	984	29.2823	1.9818	0.80	0.048402	0.02580
85	10	4	F	.	2	2	2.1575	15375	63832	15833	60	14.0325	13.6266	1.20	0.035731	0.09281
86	13	4	F	1	7	8	8.7062	53193	379690	3190396	19383	16.3673	0.2729	1.87	0.027968	0.01758
87	14	5	F	1	5	6	6.0000	24606	84810	1673194	5763	24.3843	0.3586	1.48	0.013128	0.14692
88	15	3	F	3	9	12	12.0000	39006	691271	3346682	48404	30.7645	0.3586	2.20	0.037443	0.01522
89	20	3	F	.	3	3	3.0000	14701	301263	411807	4668	20.4068	0.7285	1.79	0.037785	0.00959
90	23	5	F	.	.	0	0.0000	16816	118002	264444	1851	0.0000	0.0000	1.00	0.058904	0.01701

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART TWO) (1 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	ALLCASU	RATE	RATE_VM	AREA	RTLENGTH	MINWIDTH	AVGWIDTH	MINDEPTH	SUMHEADI	NUMTURNS	AVG_HEAD	NUMOBSTR	FERRYMIL	OTRDENSI
1	1	1	A	1	6.9061	0.72397	91.0	9.5394	400	6684.17	37	59.560	2	29.7799	1	118225.0	14.64
2	2	1	A	3	7.5997	0.11309	4516.0	67.2012	9999	9999.00	186	222.122	7	31.7318	2	216040.0	0.53
3	3	1	A	0	0.0000	0.00000	457.0	21.3776	9999	9999.00	132	0.000	0	0.0000	0	382200.0	113.02
4	4	1	A	1	1.3185	0.02665	2448.0	49.4773	9999	9999.00	100	11.833	1	11.8335	0	76500.0	12.30
5	5	1	A	4	5.4279	0.15310	1257.0	35.4542	250	250.00	24	69.345	2	34.6727	1	3250.0	0.00
6	6	1	A	19	8.8688	0.17845	2470.0	49.6991	100	100.00	32	13.420	2	6.7101	0	0.0	1.01
7	7	1	A	0	0.0000	0.00000	745.0	27.2947	275	7710.92	44	9.509	1	9.5089	0	8025.0	0.00
8	8	1	A	0	0.0000	0.00000	1262.0	35.5246	9999	9999.00	31	0.000	0	0.0000	0	0.0	4.51
9	10	1	A	0	0.0000	0.00000	541.0	23.2594	200	200.00	33	0.000	0	0.0000	1	49975.0	0.00
10	11	1	A	0	0.0000	0.00000	663.0	25.7488	266	402.33	45	4.136	1	4.1356	5	217709.0	7.65
11	12	1	A	0	0.0000	0.00000	442.0	21.0238	9999	9999.00	102	19.618	1	19.6183	0	156925.0	66.61
12	13	1	A	1	2.6592	0.05534	2309.0	48.0521	100	100.00	58	0.000	0	0.0000	0	0.0	3.06
13	14	1	A	0	0.0000	0.00000	886.0	29.7658	666	666.00	55	0.000	0	0.0000	0	0.0	8.77
14	15	1	A	2	2.5191	0.14400	306.0	17.4929	775	825.21	35	34.337	1	34.3372	0	0.0	4.17
15	16	1	A	0	0.0000	0.00000	4658.0	68.2495	9999	9999.00	84	68.314	2	34.1569	1	3011.0	0.27
16	17	1	A	0	0.0000	0.00000	64.0	8.0000	9999	9999.00	49	0.000	0	0.0000	1	83438.0	68.92
17	18	1	A	0	0.0000	0.00000	65.0	8.0623	1000	1000.00	35	0.000	0	0.0000	0	23350.0	42.05
18	19	1	A	2	26.6241	1.16198	525.0	22.9129	1900	1962.75	68	5.432	1	5.4316	1	20787.0	2.68
19	20	1	A	0	0.0000	0.00000	48.0	6.9282	9999	9999.00	35	0.000	0	0.0000	0	0.0	36.50
20	21	1	A	1	3.7749	0.26560	202.0	14.2127	266	266.00	42	0.000	0	0.0000	0	5000.0	0.00
21	22	1	A	4	12.5573	0.44847	784.0	28.0000	233	1431.06	21	34.734	4	8.6835	0	7192.0	29.53
22	23	1	A	0	0.0000	0.00000	1254.0	35.4119	9999	9999.00	45	0.000	0	0.0000	0	17000.0	3.50
23	1	2	B	0	0.0000	0.00000	1.9	4.4581	600	5744.50	37	54.431	2	27.2154	0	116689.0	0.00
24	2	2	B	1	2.8630	0.09450	524.0	30.2966	9999	9999.00	288	37.980	2	18.9900	0	262080.4	10.15
25	3	2	B	5	7.8165	0.89026	52.0	8.7800	9999	9999.00	60	14.057	2	7.0284	1	382200.0	993.23
26	8	2	B	4	3.1638	0.08562	407.0	36.9494	1000	7837.21	31	27.855	2	13.9273	2	0.0	31.84
27	10	2	B	2	6.5636	0.41790	64.0	15.7061	33	172.18	8	1.050	1	1.0495	2	49975.0	0.00
28	11	2	B	5	1.9719	0.27058	65.0	7.2876	266	266.00	32	60.733	2	30.3667	1	47092.0	90.72
29	12	2	B	0	0.0000	0.00000	340.0	21.7849	9999	9999.00	102	27.672	1	27.6720	0	147797.0	94.85
30	13	2	B	0	0.0000	0.00000	310.0	27.9169	100	100.00	50	31.842	1	31.8422	0	0.0	22.81
31	14	2	B	2	4.1074	0.18688	180.0	21.9788	666	749.36	53	11.126	2	5.5631	0	61000.0	27.91
32	18	2	B	0	0.0000	0.00000	3.3	2.9259	650	847.25	35	26.884	1	26.8837	1	23350.0	0.00
33	1	3	C	2	13.8122	3.47820	40.0	3.9713	400	5265.76	35	46.351	2	23.1754	1	202982.0	81.17
34	2	3	C	1	3.2419	0.07026	738.0	46.1387	9999	9999.00	210	221.990	8	27.7487	2	1263319.0	53.90
35	3	3	C	0	0.0000	0.00000	1.8	4.1049	700	4499.15	60	73.599	2	36.7993	10	411140.0	28693.33
36	8	3	C	2	1.5770	0.08733	1376.0	18.0570	1000	1096.11	35	62.370	5	12.4739	1	0.0	4.43
37	8	6	C	0	0.0000	0.00000	80.0	23.2256	300	6109.15	14	363.907	11	33.0825	0	0.0	32.85
38	9	1	C	10	14.5147	0.15180	1714.0	95.6200	100	8249.59	40	309.433	20	15.4716	2	26202.0	52.25
39	11	3	C	1	0.7582	0.23420	80.0	3.2373	266	951.96	19	90.710	1	90.7104	0	43092.0	88.85
40	11	6	C	5	6.1401	2.12685	15.0	2.8870	266	1655.55	35	111.497	3	37.1657	5	423331.9	573.87

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART TWO) (2 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	ALLCASU	RATE	RATE_VM	AREA	RTLENGTH	MINWIDTH	AVGWIDTH	MINDEPTH	SUMHEADI	NUMTURNS	AVG_HEAD	NUMOBSTR	FERRYMIL	OTRDENSI
41	12	3	C	1	9.498	0.1808	1210.0	52.525	9999	9999.00	31	155.940	7	22.2772	5	282771.80	69.33
42	13	3	C	3	8.519	0.1604	695.0	53.124	100	100.00	32	21.770	6	3.6283	0	96000.00	85.32
43	14	3	C	3	5.416	0.1681	306.0	32.219	200	961.62	20	274.248	11	24.9316	17	346824.00	224.59
44	15	2	C	12	28.077	0.8833	147.0	31.786	40	219.86	6	234.136	14	16.7240	8	0.00	9.72
45	16	2	C	3	76.531	0.4617	3245.0	165.753	3050	8013.35	27	145.876	9	16.2084	6	0.00	0.58
46	17	2	C	0	0.000	0.0000	9.7	9.054	200	4792.40	30	193.070	5	38.6140	8	120080.00	1238.97
47	19	2	C	2	26.624	1.1896	110.0	22.382	200	504.45	40	209.623	11	19.0567	16	47767.00	89.41
48	22	2	C	28	87.901	2.7945	331.0	31.455	130	211.80	28	269.677	11	24.5161	0	23194.00	171.38
49	1	4	D	1	7.417	1.6568	2.3	4.477	200	329.43	35	70.580	3	23.5266	7	235070.00	752.61
50	2	6	D	1	53.397	5.9820	107.0	8.927	9999	9999.00	300	213.657	5	42.7313	0	10980.00	104.59
51	2	7	D	2	14.590	3.5648	4.9	4.093	9999	9999.00	270	0.000	0	0.0000	0	744614.00	2690.82
52	2	10	D	0	0.000	0.0000	4.9	2.815	9999	9999.00	354	34.144	1	34.1441	0	0.00	4750.61
53	3	4	D	2	2.671	2.0904	4.9	1.278	700	1271.98	60	26.568	1	26.5680	7	411140.00	6091.22
54	7	3	D	1	1.232	0.4583	32.0	2.688	350	350.00	8	57.657	3	19.2192	2	17425.00	334.34
55	8	4	D	6	6.096	1.3278	65.0	4.591	800	1111.97	45	50.667	3	16.8890	3	12962.00	64.37
56	9	2	D	2	3.892	0.4203	30.0	9.262	266	266.00	42	48.923	3	16.3077	2	43482.00	111.30
57	12	4	D	0	0.000	0.0000	4.6	4.187	1100	1100.00	40	0.000	0	0.0000	3	89011.80	1186.74
58	12	5	D	0	0.000	0.0000	11.0	6.668	66	3856.19	12	64.954	4	16.2386	6	0.00	992.55
59	14	4	D	1	6.043	1.3093	14.5	4.615	116	145.37	35	48.602	2	24.3012	3	2000.00	1434.90
60	16	3	D	1	25.510	3.9593	12.0	6.443	3050	3050.00	27	0.000	0	0.0000	1	0.00	52.17
61	17	3	D	0	0.000	0.0000	1.8	1.286	200	200.00	34	0.000	0	0.0000	3	116328.00	6676.67
62	18	3	D	0	0.000	0.0000	4.8	2.423	650	739.38	35	107.407	2	53.7033	1	16050.00	1423.54
63	19	3	D	1	21.084	2.6181	8.9	8.054	150	296.44	19	242.501	8	30.3126	5	6912.00	1262.92
64	22	3	D	1	3.139	0.2886	8.5	10.880	100	148.78	15	263.657	6	43.9428	2	8592.00	4691.06
65	1	5	E	2	35.162	12.2190	1.0	2.878	75	124.66	33	195.710	6	32.6183	4	11700.00	111.00
66	2	4	E	0	0.000	0.0000	491.0	13.369	100	6199.65	14	283.358	6	47.2264	1	307520.40	17.16
67	2	9	E	1	136.034	3.7515	175.0	36.262	100	7323.23	22	523.298	13	40.2537	1	38925.00	181.69
68	5	2	E	11	18.469	0.5814	187.0	31.769	200	412.11	13	336.558	19	17.7136	11	3250.00	116.50
69	5	3	E	8	56.601	1.2714	134.0	44.518	150	200.17	38	131.016	8	16.3770	15	13623.20	119.75
70	6	2	E	31	15.815	0.7728	120.0	20.466	100	100.00	40	83.618	11	7.6016	0	0.00	10.23
71	6	4	E	12	46.539	0.5259	14.0	88.490	100	104.33	17	344.730	16	21.5456	3	38570.00	400.07
72	7	2	E	53	33.670	2.9996	186.0	11.225	275	282.45	8	101.789	4	25.4472	4	125568.70	435.96
73	10	3	E	3	10.871	0.4632	97.0	23.467	33	290.35	8	87.491	5	17.4983	2	141665.50	82.10
74	11	5	E	11	14.503	2.7555	116.0	5.263	1500	2297.08	48	24.641	3	8.2138	7	51905.00	166.72
75	11	7	E	0	0.000	0.0000	22.0	15.289	75	516.90	15	391.467	13	30.1128	21	181925.36	686.41
76	20	2	E	0	0.000	0.0000	6.4	7.146	166	4077.21	35	35.409	2	17.7046	2	0.00	273.75
77	21	2	E	7	26.424	0.9499	44.0	27.818	100	234.77	26	778.934	35	22.2553	2	28976.00	690.50
78	23	2	E	4	17.776	0.6515	142.0	27.285	100	4651.66	13	194.689	11	17.6990	398	0.00	30.88
79	23	4	E	9	53.520	1.1362	437.0	47.103	133	2097.94	40	111.382	10	11.1382	9	16200.00	22.37
80	5	4	F	5	19.375	6.9099	7.2	2.804	100	100.00	12	0.000	0	0.0000	1	0.00	1072.22

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART TWO) (3 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	ALLCASU	RATE	RATE_VM	AREA	RTLENGTH	MINWIDTH	AVGWIDTH	MINDEPTH	SUMHEADI	NUMTURNS	AVG_HEAD	NUMOBSTR	FERRYMIL	OTRDENSI
81	6	3	F	52	32.8189	0.4423	34.5	74.208	100	548.530	24	739.97	30	24.6655	11	132847.56	391.01
82	6	5	F	25	11.0531	0.2606	25.3	42.420	500	733.239	26	930.52	26	35.7893	7	0.00	769.92
83	6	6	F	56	60.9552	0.5681	55.2	107.288	500	639.843	30	2399.39	78	30.7614	5	0.00	673.89
84	9	3	F	4	29.2823	1.9818	13.0	14.776	133	133.000	35	85.24	5	17.0470	0	0.00	268.46
85	10	4	F	2	14.0325	13.6266	1.9	1.030	500	500.000	45	0.69	1	0.6919	0	0.00	3157.89
86	13	4	F	8	16.3673	0.2729	100.0	59.978	100	100.000	21	567.66	31	18.3115	23	47188.00	327.08
87	14	5	F	6	24.3843	0.3586	88.0	68.000	66	358.638	21	743.95	55	13.5263	40	0.00	801.82
88	15	3	F	12	30.7645	0.3586	70.0	85.799	100	213.792	20	1218.71	70	17.4101	64	52852.00	495.64
89	20	3	F	3	20.4068	0.7285	34.0	28.012	133	140.628	38	469.08	23	20.3948	21	59710.00	333.32
90	23	5	F	0	0.0000	0.0000	12.0	15.726	125	187.578	8	425.68	20	21.2841	17	0.00	814.58

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART THREE) (1 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	ALLCASU	RATE	RATE_VM	D_TNK_ML	ALLT_ML	TURN_ML	SUMHD_ML	OBST_ML	FRYML_SM	OTHER_ML	VIS1N	WIND2ON
1	1	1	A	1	6.9061	0.72397	1517.92	23936.75	0.20966	6.2436	0.10483	1299.18	139.63	1.44500	1.89007
2	2	1	A	3	7.5997	0.11309	817.46	61593.70	0.10416	3.3053	0.02976	47.84	35.67	1.40154	0.25842
3	3	1	A	0	0.0000	0.00000	4445.46	60156.22	0.00000	0.0000	0.00000	836.32	2415.99	0.57311	0.10517
4	4	1	A	1	1.3185	0.02665	1532.95	1899.54	0.02021	0.2392	0.00000	31.25	608.76	1.10277	0.27044
5	5	1	A	4	5.4279	0.15310	2078.54	11675.20	0.05641	1.9559	0.02821	2.59	0.00	1.14351	0.43571
6	6	1	A	19	8.8688	0.17845	4606.20	17149.49	0.04024	0.2700	0.00000	0.00	50.40	0.77411	0.33655
7	7	1	A	0	0.0000	0.00000	6675.29	31075.64	0.03664	0.3484	0.00000	10.77	0.00	0.77954	0.14724
8	8	1	A	0	0.0000	0.00000	5339.65	59660.17	0.00000	0.0000	0.00000	0.00	160.25	0.64102	2.01327
9	10	1	A	0	0.0000	0.00000	1310.05	4097.48	0.00000	0.0000	0.04299	92.38	0.00	0.85016	2.44296
10	11	1	A	0	0.0000	0.00000	15234.00	141362.97	0.03884	0.1606	0.19418	328.37	196.86	0.85016	1.84199
11	12	1	A	0	0.0000	0.00000	500.81	158196.69	0.04757	0.9331	0.00000	355.03	1400.32	1.05116	1.53549
12	13	1	A	1	2.6592	0.05534	782.59	15979.15	0.00000	0.0000	0.00000	0.00	147.13	0.66546	0.46275
13	14	1	A	0	0.0000	0.00000	4891.39	14283.56	0.00000	0.0000	0.00000	0.00	261.00	0.31236	3.86728
14	15	1	A	2	2.5191	0.14400	4538.71	54380.31	0.05717	1.9629	0.00000	0.00	73.00	0.89090	0.40065
15	16	1	A	0	0.0000	0.00000	57.44	126.67	0.02930	1.0009	0.01465	0.65	18.32	1.07017	0.31551
16	17	1	A	0	0.0000	0.00000	409.00	31092.88	0.00000	0.0000	0.12500	1303.72	551.37	1.73563	0.59797
17	18	1	A	0	0.0000	0.00000	286.02	5835.09	0.00000	0.0000	0.00000	359.23	338.99	1.37710	0.42369
18	19	1	A	2	26.6241	1.16198	327.85	2855.03	0.04364	0.2371	0.04364	39.59	61.32	1.35537	1.10579
19	20	1	A	0	0.0000	0.00000	2121.91	21154.69	0.00000	0.0000	0.00000	0.00	252.88	0.89905	0.25241
20	21	1	A	1	3.7749	0.26560	1863.90	10188.16	0.00000	0.0000	0.00000	24.75	0.00	1.39883	0.22236
21	22	1	A	4	12.5573	0.44847	1137.64	4099.00	0.14286	1.2405	0.00000	9.17	826.75	0.52694	0.09015
22	23	1	A	0	0.0000	0.00000	1099.15	9555.61	0.00000	0.0000	0.00000	13.56	123.83	1.40154	0.44773
23	1	2	B	0	0.0000	0.00000	3024.37	49169.36	0.44862	12.2094	0.00000	61415.26	0.00	1.44500	1.89007
24	2	2	B	1	2.8630	0.09450	1724.35	125260.38	0.06601	1.2536	0.00000	500.15	175.63	1.40154	0.25842
25	3	2	B	5	7.8165	0.89026	10823.80	146468.45	0.22779	1.6010	0.11390	7350.00	5882.46	0.57311	0.10517
26	8	2	B	4	3.1638	0.08562	5133.75	58997.59	0.05413	0.7539	0.05413	0.00	350.75	0.64102	2.01327
27	10	2	B	2	6.5636	0.41790	1940.07	6068.01	0.06367	0.0668	0.12734	780.86	0.00	0.85016	2.44296
28	11	2	B	5	1.9719	0.27058	38243.27	262000.31	0.27444	8.3338	0.13722	724.49	809.18	0.85016	1.84199
29	12	2	B	0	0.0000	0.00000	483.32	152837.77	0.04590	1.2702	0.00000	434.70	1480.38	1.05116	1.53549
30	13	2	B	0	0.0000	0.00000	1347.03	13417.12	0.03582	1.1406	0.00000	0.00	253.25	0.66546	0.46275
31	14	2	B	2	4.1074	0.18688	3507.11	17263.59	0.09100	0.5062	0.00000	338.89	228.54	0.31236	3.86728
32	18	2	B	0	0.0000	0.00000	788.13	11948.05	0.34177	9.1881	0.34177	7075.76	0.00	1.37710	0.42369
33	1	3	C	2	13.8122	3.47820	3646.21	98900.57	0.50362	11.6716	0.25181	5074.55	817.63	1.44500	1.89007
34	2	3	C	1	3.2419	0.07026	999.94	96165.58	0.17339	4.8114	0.04335	1711.81	862.12	1.40154	0.25842
35	3	3	C	0	0.0000	0.00000	23151.09	318802.17	0.48722	17.9294	2.43611	228411.11	12582.03	0.57311	0.10517
36	8	3	C	2	1.5770	0.08733	10505.04	133337.89	0.27690	3.4541	0.05538	0.00	337.71	0.64102	2.01327
37	8	6	C	0	0.0000	0.00000	116.12	18309.64	0.47362	15.6684	0.00000	0.00	113.15	0.64102	2.01327
38	9	1	C	10	14.5147	0.15180	768.17	7408.27	0.20916	3.2361	0.02092	15.29	936.68	1.15166	0.67910
39	11	3	C	1	0.7582	0.23420	60936.39	189387.78	0.30890	28.0203	0.00000	538.65	2195.65	0.85016	1.84199
40	11	6	C	5	6.1401	2.12685	28206.78	960377.08	1.03915	38.6209	1.73192	28222.13	2981.68	0.85016	1.84199

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART THREE) (2 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	ALLCASU	RATE	RATE_VM	D_TNK_ML	ALLT_ML	TURN_ML	SUMHD_ML	OBST_ML	FRYML_SM	OTHER_ML	VISIN	WINDZON
41	12	3	C	1	9.498	0.1808	200.46	18722.65	0.13327	2.9689	0.0952	233.70	1597.14	1.05116	1.53549
42	13	3	C	3	8.519	0.1604	707.87	16456.21	0.11294	0.4098	0.0000	138.13	1116.24	0.66546	0.46275
43	14	3	C	3	5.416	0.1681	2392.45	22315.58	0.34141	8.5120	0.5276	1133.41	2133.04	0.31236	3.86728
44	15	2	C	12	28.077	0.8833	1344.57	18475.26	0.44044	7.3659	0.2517	0.00	44.96	0.89090	0.40065
45	16	2	C	3	76.531	0.4617	23.65	31.02	0.05430	0.8801	0.0362	0.00	11.32	1.07017	0.31551
46	17	2	C	0	0.000	0.0000	361.41	45278.39	0.55227	21.3254	0.8836	12379.38	1327.44	1.73563	0.59797
47	19	2	C	2	26.624	1.1896	335.63	8106.78	0.49148	9.3659	0.7149	434.25	439.43	1.35537	1.10579
48	22	2	C	28	87.901	2.7945	1012.69	3944.08	0.34971	8.5735	0.0000	70.07	1803.45	0.52694	0.09015
49	1	4	D	1	7.417	1.6568	3011.72	139298.38	0.67011	15.7655	1.5636	102204.35	386.66	1.44500	1.89007
50	2	6	D	1	53.397	5.9820	265.82	18347.93	0.56009	23.9333	0.0000	102.62	1253.59	1.40154	0.25842
51	2	7	D	2	14.590	3.5648	5462.96	428505.66	0.00000	0.0000	0.0000	151962.04	3221.48	1.40154	0.25842
52	2	10	D	0	0.000	0.0000	7323.04	211074.21	0.35530	12.1313	0.0000	0.00	8270.62	1.40154	0.25842
53	3	4	D	2	2.671	2.0904	74368.98	1024098.09	0.78256	20.7911	5.4779	83906.12	23357.05	0.57311	0.10517
54	7	3	D	1	1.232	0.4583	38273.30	108608.46	1.11623	21.4530	0.7442	544.53	3980.85	0.77954	0.14724
55	8	4	D	6	6.096	1.3278	28478.41	279753.39	0.65342	11.0356	0.6534	199.42	911.30	0.64102	2.01327
56	9	2	D	2	3.892	0.4203	6196.17	50435.53	0.32392	5.2823	0.2159	1449.40	360.52	1.15166	0.67910
57	12	4	D	0	0.000	0.0000	321.49	22286.86	0.00000	0.0000	0.7166	19350.39	1303.88	1.05116	1.53549
58	12	5	D	0	0.000	0.0000	937.49	8663.16	0.59990	9.7416	0.8999	0.00	1637.43	1.05116	1.53549
59	14	4	D	1	6.043	1.3093	5848.72	21872.93	0.43335	10.5309	0.6500	137.93	4508.15	0.31236	3.86728
60	16	3	D	1	25.510	3.9593	608.37	798.02	0.00000	0.0000	0.1552	0.00	97.15	1.07017	0.31551
61	17	3	D	0	0.000	0.0000	2543.39	290099.63	0.00000	0.0000	2.3320	64626.67	9341.83	1.73563	0.59797
62	18	3	D	0	0.000	0.0000	951.86	12147.52	0.82555	44.3346	0.4128	3343.75	2820.48	1.37710	0.42369
63	19	3	D	1	21.084	2.6181	588.93	3562.66	0.99335	30.1111	0.6208	776.63	1395.66	1.35537	1.10579
64	22	3	D	1	3.139	0.2886	2927.88	9747.73	0.55149	24.2342	0.1838	1010.82	3665.04	0.52694	0.09015
65	1	5	E	2	35.162	12.2190	1976.46	20695.88	2.08488	68.0053	1.3899	11700.00	38.57	1.44500	1.89007
66	2	4	E	0	0.000	0.0000	456.74	125957.32	0.44881	21.1956	0.0748	626.31	630.35	1.40154	0.25842
67	2	9	E	1	136.034	3.7515	21.87	11217.15	0.35851	14.4312	0.0276	222.43	876.85	1.40154	0.25842
68	5	2	E	11	18.469	0.5814	1874.74	12894.11	0.59806	10.5939	0.3462	17.38	685.73	1.14351	0.43571
69	5	3	E	8	56.601	1.2714	317.49	20519.18	0.17970	2.9430	0.3369	101.67	360.44	1.14351	0.43571
70	6	2	E	31	15.815	0.7728	10503.24	40397.83	0.53747	4.0856	0.0000	0.00	60.00	0.77411	0.33655
71	6	4	E	12	46.539	0.5259	291.39	2318.43	0.18081	3.8957	0.0339	2755.00	63.30	0.77411	0.33655
72	7	2	E	53	33.670	2.9996	16232.12	131804.18	0.35636	9.0683	0.3564	675.10	7224.09	0.77954	0.14724
73	10	3	E	3	10.871	0.4632	1298.45	65499.62	0.21306	3.7282	0.0852	1460.47	339.37	0.85016	2.44296
74	11	5	E	11	14.503	2.7555	15471.63	203684.18	0.56998	4.6817	1.3300	447.46	3674.30	0.85016	1.84199
75	11	7	E	0	0.000	0.0000	269.08	48343.94	0.85028	25.6044	1.3735	8269.33	987.70	0.85016	1.84199
76	20	2	E	0	0.000	0.0000	2057.09	20508.53	0.27986	4.9548	0.2799	0.00	245.16	0.89905	0.25241
77	21	2	E	7	26.424	0.9499	952.31	12452.88	1.25819	28.0013	0.0719	658.55	1092.18	1.39883	0.22236
78	23	2	E	4	17.776	0.6515	824.71	4046.34	0.40316	7.1355	14.5869	0.00	160.71	1.40154	0.44773
79	23	4	E	9	53.520	1.1362	357.00	5492.22	0.21230	2.3646	0.1911	37.07	207.52	1.40154	0.44773
80	5	4	F	5	19.375	6.9099	9203.07	125925.45	0.00000	0.0000	0.3566	0.00	2753.15	1.14351	0.43571

TABLE 6. VTS SUBZONE VARIABLES FOR RISK MODELS (PART THREE) (3 OF 3)

- CASUALTIES FOR MEDIUM OR LARGE DRY CARGO AND TANK VESSEL TRANSITS ONLY -

OBS	ZONE	SUBZONE	ZONETYPE	ALLCASU	RATE	RATE_VM	D_TNK_ML	ALLT_ML	TURN_ML	SUMHD_ML	OBST_ML	FRYML_SM	OTHER_ML	VISIN	WINDZON
81	6	3	F	52	32.8189	0.4423	2324.86	40246.95	0.40427	9.9715	0.14823	3850.65	181.79	0.77411	0.33655
82	6	5	F	25	11.0531	0.2606	6162.22	47635.87	0.61291	21.9358	0.16502	0.00	459.19	0.77411	0.33655
83	6	6	F	56	60.9552	0.5681	950.07	5254.85	0.72701	22.3639	0.04660	0.00	346.72	0.77411	0.33655
84	9	3	F	4	29.2823	1.9818	1054.99	4523.29	0.33840	5.7687	0.00000	0.00	236.20	1.15166	0.67910
85	10	4	F	2	14.0325	13.6266	14929.32	61981.70	0.97101	0.6719	0.00000	0.00	5826.08	0.85016	2.44296
86	13	4	F	8	16.3673	0.2729	886.88	6330.51	0.51686	9.4644	0.38348	471.88	545.34	0.66546	0.46275
87	14	5	F	6	24.3843	0.3586	361.86	1247.21	0.80883	10.9405	0.58824	0.00	1037.65	0.31236	3.86728
88	15	3	F	12	30.7645	0.3586	454.62	8056.84	0.81586	14.2042	0.74593	755.03	404.37	0.89090	0.40065
89	20	3	F	3	20.4068	0.7285	524.81	10754.68	0.82107	16.7455	0.74967	1756.18	404.57	0.89905	0.25241
90	23	5	F	0	0.0000	0.0000	1069.32	7503.71	1.27179	27.0689	1.08103	0.00	621.59	1.40154	0.44773

TABLE 7. COMPARISON OF PREDICTED AND HISTORICAL CASUALTIES PREDICTED BY LINEAR REGRESSION AND WEIGHTED WITH HISTORICAL RATES (1 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

---------- ZONE=BOSTON, MA ----------

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
1	1	A	14480	1	6.9061	0.3115	0.04409	0.52255	0.37508
2	2	B	13483	0	0.0000	0.6017	0.07931	0.04057	0.03127
3	3	C	14480	2	13.8122	0.6496	0.09195	1.04703	0.75154
4	4	D	13483	1	7.4167	1.5237	0.20084	0.60272	0.46461
5	5	E	5688	2	35.1617	18.9497	1.05367	1.53893	2.81203
				----------			----------	-------------	
ZONE				6			1.46985	3.75180	

---------- ZONE=PUGET SOUND, WA ----------

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
6	1	A	54934	4.1748	7.600	10.0919	5.4195	4.8594	0.91939
7	2	B	52242	1.4957	2.863	3.0109	1.5376	1.5343	0.30525
8	3	C	46136	1.4957	3.242	9.1307	4.1180	2.8541	0.64297
9	4	E	6106	0.0000	0.000	20.1689	1.2039	0.6158	1.04813
10	5	C	.	.	0.000	0.3793	.	.	0.01971
11	6 *	D	2373	1.2671	53.397	0.9230	0.0214	0.6445	0.09593
12	7	D	22359	3.2621	14.590	0.4444	0.0971	1.6807	0.78129
13	9 *	E	793	1.0787	136.034	27.9482	0.2167	0.6502	2.90479
14	10	D	20611	0.0000	0.000	0.7515	0.1514	0.0774	0.03905
				----------			----------	-------------	
ZONE				12.7741			12.7656	12.9164	

---------- ZONE=LA/LONG BEACH, CA ----------

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
15	1	A	95033	0.00000	0.00000	0.45620	0.4238	0.2168	0.02371
16	2	B	95033	7.42826	7.81651	0.78680	0.7309	4.0880	0.44709
17	3	C	95033	0.00000	0.00000	4.55885	4.2352	2.1662	0.23691
18	4	D	95033	2.53856	2.67124	8.88001	8.2495	5.4887	0.60029
				----------			----------	-------------	
ZONE				9.96682			13.6395	11.9597	

---------- ZONE=SANTA BARBARA, CA ----------

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
19	1	A	75846	1	1.31846	3.71727	2.75613	1.90970	0.26169

TABLE 7. COMPARISON OF PREDICTED AND HISTORICAL CASUALTIES PREDICTED BY LINEAR REGRESSION AND WEIGHTED WITH HISTORICAL RATES (2 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

ZONE=PORT ARTHUR, TX

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
20	1	A	73693	4	5.4279	4.9389	3.5580	3.8198	0.53874
21	2	E	59559	11	18.4691	27.3960	15.9506	13.6584	2.38349
22	3	E	14134	8	56.6011	27.7767	3.8379	5.9630	4.38490
23	4	F	25806	5	19.3753	1.3070	0.3297	2.6686	1.07481
ZONE				28			23.6761	26.1098	

ZONE=NEW ORLEANS, LA

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
24	1	A	228924	20.303	8.8688	7.5972	17.002	18.847	0.85570
25	2	E	214962	33.997	15.8154	21.6288	45.450	40.245	1.94588
26	3	F	172524	56.621	32.8189	25.4034	42.843	50.224	3.02567
27	4	E	25785	12.000	46.5387	40.3386	10.168	11.201	4.51479
28	5	F	261403	28.893	11.0531	20.4823	52.340	41.217	1.63881
29	6	F	101931	62.132	60.9552	53.1045	52.915	58.131	5.92739
ZONE				213.946			220.718	219.865	

ZONE=HOUSTON, TX

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
30	1	A	182200	0.0000	0.0000	0.6558	1.1680	0.5974	0.03408
31	2	E	182200	61.3464	33.6698	22.4712	40.0237	51.1445	2.91751
32	3	D	102864	1.2671	1.2318	2.3588	2.3719	1.8467	0.18659
ZONE				62.6135			43.5636	53.5886	

ZONE=CHESAPEAKE SOUTH, VA

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
33	1	A	189689	0.0000	0.00000	0.8207	1.5218	0.7784	0.04265
34	2	B	189689	6.0013	3.16376	5.3570	9.9336	8.0815	0.44280
35	3	C	189689	2.9913	1.57696	4.1964	7.7815	5.4757	0.30003
36	4	D	130751	7.9709	6.09627	1.1957	1.5283	4.7672	0.37894
37	5	E	.	3.2919	0.00000	24.0695	.	.	1.25083
38	6	C	2697	0.0000	0.00000	6.9042	0.1820	0.0931	0.35879
ZONE				20.2555			20.9472	19.1958	

TABLE 7. COMPARISON OF PREDICTED AND HISTORICAL CASUALTIES PREDICTED BY LINEAR REGRESSION AND WEIGHTED WITH HISTORICAL RATES (3 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

ZONE=BALTIMORE, MD

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
39	1	C	73452	10.6613	14.5147	22.2397	15.9689	13.4984	1.91003
40	2	D	57387	2.2337	3.8924	2.3703	1.3297	1.7970	0.32546
41	3	F	15588	4.5645	29.2823	4.0759	0.6211	2.5999	1.73354
				----------			----------	------------	
ZONE				17.4596			17.9197	17.8953	

ZONE=CORPUS CHRISTI, TX

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
42	1	A	30471	0.00000	0.0000	1.3319	0.39674	0.20292	0.06922
43	2	B	30471	2.00000	6.5636	3.1596	0.94115	1.48138	0.50529
44	3	E	30471	3.31250	10.8710	22.3936	6.67042	5.06803	1.72868
45	4	F	15375	2.15750	14.0325	1.9517	0.29334	1.22879	0.83066
				----------			----------	------------	
ZONE				7.47000			8.30166	7.98112	

ZONE=NEW YORK CITY, NY

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
46	1	A	392257	0.0000	0.0000	1.9457	7.4610	3.8162	0.10112
47	2	B	278702	5.4957	1.9719	2.2382	6.0979	5.8668	0.21879
48	3	C	197270	1.4957	0.7582	1.9402	3.7416	2.6616	0.14023
49	4	D	.	.	0.0000	2.9390	.	.	0.15273
50	5	E	81432	11.8100	14.5029	17.9623	14.2988	13.2185	1.68713
51	6	C	81432	5.0000	6.1401	2.1339	1.6987	3.3688	0.42998
52	7	E	4114	0.0000	0.0000	24.3711	0.9801	0.5013	1.26651
				----------			----------	------------	
ZONE				23.8013			34.2781	29.4332	

ZONE=LONG ISLAND SOUND, NY

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
53	1	A	10529	0	0.00000	0.4295	0.04421	0.02261	0.02232
54	2	B	10529	0	0.00000	1.4522	0.14948	0.07645	0.07547
55	3	C	10529	1	9.49758	10.0778	1.03727	1.03054	1.01728
56	4	D	1346	0	0.00000	0.9157	0.01205	0.00616	0.04759
57	5	D	6251	0	0.00000	1.0112	0.06179	0.03160	0.05255
58	6	E	.	.	0.00000	20.1773	.	.	1.04856
				----------			----------	------------	
ZONE				1			1.30479	1.16738	

TABLE 7. COMPARISON OF PREDICTED AND HISTORICAL CASUALTIES PREDICTED BY LINEAR REGRESSION AND WEIGHTED WITH HISTORICAL RATES (4 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

ZONE=PHILADELPHIA, PA

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
59	1	A	37605	1.0000	2.6592	7.0961	2.6086	1.8342	0.50696
60	2	B	37605	0.0000	0.0000	6.4520	2.3718	1.2131	0.33529
61	3	C	37605	3.2034	8.5186	12.4286	4.5689	3.9386	1.08857
62	4	F	53193	8.7062	16.3673	20.3878	10.6015	9.7756	1.91007
				---------			---------	------------	
ZONE				12.9097			20.1508	16.7616	

ZONE=SAN FRANCISCO, CA

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
63	1	A	145596	0.0000	0.0000	2.7314	3.8876	1.9884	0.14195
64	2	B	77082	3.1661	4.1074	4.5699	3.4435	3.3443	0.45094
65	3	C	77082	4.1748	5.4161	10.7595	8.1075	6.2342	0.84060
66	4	D	26993	1.6311	6.0425	2.9795	0.7862	1.2177	0.46885
67	5	F	24606	6.0000	24.3843	24.4456	5.8801	6.0075	2.53756
				---------			---------	------------	
ZONE				14.9719			22.1049	18.7922	

ZONE=PORTLAND, OR

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
68	1	A	79395	2	2.5191	0.8196	0.6362	1.3254	0.17350
69	2	C	42739	12	28.0774	9.6578	4.0350	8.0638	1.96100
70	3	F	39006	12	30.7645	34.0726	12.9943	12.6463	3.36973
				---------			---------	------------	
ZONE				26			17.6655	22.0355	

ZONE=ANCHORAGE, AK

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
71	1	A	3920	0	0.0000	8.4604	0.32420	0.16582	0.43966
72	2	C	3920	3	76.5306	36.0179	1.38021	2.20595	5.84886
73	3	D	3920	1	25.5102	0.7590	0.02908	0.51488	1.36514
				---------			---------	------------	
ZONE				4			1.73350	2.88665	

TABLE 7. COMPARISON OF PREDICTED AND HISTORICAL CASUALTIES PREDICTED BY LINEAR REGRESSION AND WEIGHTED WITH HISTORICAL RATES (5 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

ZONE=PORTLAND, ME

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
74	1	A	3272	0	0	0.17696	0.00566	0.00290	0.00920
75	2	C	3272	0	0	2.60670	0.08338	0.04265	0.13546
76	3	D	3272	0	0	3.50227	0.11202	0.05730	0.18200
ZONE				0			0.20106	0.10284	

ZONE=PORTSMOUTH, NH

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
77	1	A	2306	0	0	0.43455	0.009796	0.005010	0.02258
78	2	B	2306	0	0	0.83472	0.018817	0.009624	0.04338
79	3	D	2306	0	0	2.28789	0.051575	0.026379	0.11890
ZONE				0			0.080187	0.041014	

ZONE=PROVIDENCE, RI

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
80	1	A	7512	2	26.6241	0.91054	0.06686	1.03420	1.43090
81	2	C	7512	2	26.6241	7.25025	0.53241	1.27232	1.76036
82	3	D	4743	1	21.0837	4.83393	0.22413	0.61464	1.34687
ZONE				5			0.82341	2.92116	

ZONE=WILMINGTON, NC

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOD 2-C Rate	MOD 2-C Prediction	Weighted MD2C Prediction	Risk Factor
83	1	A	14701	0	0.0000	0.1617	0.02323	0.01188	0.00840
84	2	E	14701	0	0.0000	16.4544	2.36468	1.20948	0.85509
85	3	F	14701	3	20.4068	11.8163	1.69813	2.36856	1.67455
ZONE				3			4.08604	3.58992	

TABLE 7. COMPARISON OF PREDICTED AND HISTORICAL CASUALTIES PREDICTED BY LINEAR REGRESSION AND WEIGHTED WITH HISTORICAL RATES (6 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

ZONE=JACKSONVILLE, FL

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOO 2-C Rate	MOO 2-C Prediction	Weighted MD2C Prediction	Risk Factor
86	1	A	26491	1	3.7749	0.6437	0.16668	0.58526	0.22962
87	2	E	26491	7	26.4241	32.0866	8.30928	7.75002	3.04065
				----------			----------	-------------	
ZONE				8			8.47596	8.33528	

ZONE=TAMPA, FL

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOO 2-C Rate	MOO 2-C Prediction	Weighted MD2C Prediction	Risk Factor
88	1	A	31854	4	12.5573	2.6593	0.82809	2.4235	0.79077
89	2	C	31854	28	87.9010	10.7054	3.33358	15.7051	5.12433
90	3	D	31854	1	3.1393	6.6859	2.08192	1.5649	0.51059
				----------			----------	-------------	
ZONE				33			6.24359	19.6935	

ZONE=MOBILE, AL

OBS	SUBZONE	ZONETYPE	Dry Cargo & Tanker	10 Year Casualties	Observed Rate	MOO 2-C Rate	MOO 2-C Prediction	Weighted MD2C Prediction	Risk Factor
91	1	A	38923	0.000	0.0000	0.8125	0.309	0.158	0.04222
92	2	E	22502	4.000	17.7762	22.7203	4.998	4.556	2.10450
93	3	C	.	.	0.0000	8.5307	.	.	0.44332
94	4	E	16816	9.000	53.5205	27.2973	4.487	6.795	4.19989
95	5	F	16816	0.000	0.0000	8.5485	1.405	0.719	0.44424
				----------			----------	-------------	
ZONE				13.000			11.199	12.228	
				==========			==========	=============	
				524.168			494.104	513.162	

* **Puget Sound Subzones 2-6 and 2-9 are predicted by Model 2-C rates without weighting by historical rates because the historical rates in these two subzones are biased by a very small number of transits.**

TABLE 8. SUBZONE RISK ADJUSTMENT FACTORS

Subzone	Type	Risk Value
1 BOSTON, MA		
1	A	0.37508
2	B	0.03127
3	C	0.75154
4	D	0.46461
5	E	2.81203
2 PUGET SOUND, WA		
1	A	0.91939
2	B	0.30525
3	C	0.64297
4	E	1.04813
5	C	0.01971
6	D	0.09593
7	D	0.78129
9	E	2.90479
10	D	0.03905
3 LA/LONG BEACH, CA		
1	A	0.02371
2	B	0.44709
3	C	0.23691
4	D	0.60029
4 SANTA BARBARA, CA		
1	A	0.26169
5 PORT ARTHUR, TX		
1	A	0.53874
2	E	2.38349
3	E	4.38490
4	F	1.07481
6 NEW ORLEANS, LA		
1	A	0.85570
2	E	1.94588
3	F	3.02567
4	E	4.51479
5	F	1.63881
6	F	5.92739
7 HOUSTON, TX		
1	A	0.03408
2	E	2.91751
3	D	0.18659
8 CHESAPEAKE SOUTH, VA		
1	A	0.04265
2	B	0.44280
3	C	0.30003
4	D	0.37894
5	E	1.25083
6	C	0.35879
9 BALTIMORE, MD		
1	C	1.91003
2	D	0.32546
3	F	1.73354
10 CORPUS CHRISTI, TX		
1	A	0.06922
2	B	0.50529
3	E	1.72868
4	F	0.83066
11 NEW YORK CITY, NY		
1	A	0.10112
2	B	0.21879
3	C	0.14023
4	D	0.15273
5	E	1.68713
6	C	0.42998
7	E	1.26651

Subzone	Type	Risk Value
12 LONG ISLAND SOUND, NY		
1	A	0.02232
2	B	0.07547
3	C	1.01728
4	D	0.04759
5	D	0.05255
6	E	1.04856
13 PHILADELPHIA, PA		
1	A	0.50696
2	B	0.33529
3	C	1.08857
4	F	1.91007
14 SAN FRANCISCO, CA		
1	A	0.14195
2	B	0.45094
3	C	0.84060
4	D	0.46885
5	F	2.53756
15 PORTLAND, OR		
1	A	0.17350
2	C	1.96100
3	F	3.36973
16 ANCHORAGE, AK		
1	A	0.43966
2	C	5.84886
3	D	1.36514
17 PORTLAND, ME		
1	A	0.00920
2	C	0.13546
3	D	0.18200
18 PORTSMOUTH, NH		
1	A	0.02258
2	B	0.04338
3	D	0.11890
19 PROVIDENCE, RI		
1	A	1.43090
2	C	1.76036
3	D	1.34687
20 WILMINGTON, NC		
1	A	0.00840
2	E	0.85509
3	F	1.67455
21 JACKSONVILLE, FL		
1	A	0.22962
2	E	3.04065
22 TAMPA, FL		
1	A	0.79077
2	C	5.12433
3	D	0.51059
23 MOBILE, AL		
1	A	0.04222
2	E	2.10450
3	C	0.44332
4	E	4.19989
5	F	0.44424

Note: Subzones 2-8, 13-5, 17-4 and 18-4 are not included because they have no dominant vessel route nor VTS addressable transits.

TABLE 9. NATIONAL AVERAGE CASUALTY RATES BY VESSEL TYPE, VESSEL SIZE AND CASUALTY TYPE (1979 TO 1989) - 23 STUDY ZONES

		(Number of Casualties per 100,000 Transits)			
		Collision	Ramming	Grounding	Total
Passenger	Small	0.218	0.056	0.343	0.617
	Medium	8.425	0.000	16.764	25.189
	Large	---	---	---	---
Dry Cargo	Small	0.582	0.114	0.162	0.858
	Medium	1.552	0.507	1.123	3.182
	Large	3.872	1.336	8.717	13.925
Tanker	Small	0.462	0.000	0.578	1.040
	Medium	0.960	0.183	1.069	2.212
	Large	7.718	3.634	19.373	30.725
Dry Cargo Barge	Small	2.986	1.551	1.907	6.444
	Medium	---	---	---	---
	Large	18.901	0.000	29.270	48.171
Tanker Barge	Small	3.221	0.966	3.455	7.642
	Medium	---	---	---	---
	Large	2.277	2.167	2.708	7.152
Tug/Tow Boat	Small	0.388	0.226	0.454	1.068
	Medium	---	---	---	---
	Large	---	---	---	---

TABLE 10. DEVELOPMENT OF SUBZONE CASUALTY RATE TABLE

1) NATIONAL CASUALTY RATES BY CASUALTY TYPE, VESSEL TYPE AND VESSEL SIZE

COLLISION

	L	M	S
PASSENGER	*****		
DRY CARGO			
TANKER			
DRY BARGE		*****	
TNK BARGE		*****	
TOW BOAT	*****	*****	

RAMMING

	L	M	S
PASSENGER	*****	*****	
DRY CARGO			
TANKER			*****
DRY BARGE	*****	*****	
TNK BARGE		*****	
TOW BOAT	*****	*****	

GROUNDING

	L	M	S
PASS	*****		
DRY CARGO			
TANKER			
DRY BARGE		*****	
TNK BARGE		*****	
TOW BOAT	*****	*****	

2) APPLY SUBZONE-SPECIFIC RISK FACTORS (SUBZONE CASUALTY RATE ADJUSTMENT FACTORS)

NATIONAL_RATE [1 X 36]

SUBZONE RISK_FACTOR [95 X 1]

RISK_FACTOR X NATIONAL_RATE

3) SUBZONE CASUALTY RATE TABLE

SUBZONE CASUALTY RATE [95 X 36]

TABLE 11. COMPARISON OF PREDICTED AND HISTORICAL CASUALTIES, 1979-1989 PREDICTED BY LINEAR AND LOGISTIC REGRESSION, AND WEIGHTED WITH HISTORICAL RATES

(Medium and Large Dry Cargo and Tank Vessels)

Zone	Name	10 Year Casualties	MOD 2-C Prediction	% of Difference	LOG 3-D Prediction	% of Difference	Weig. MD2C Prediction	% of Difference	Weig. LG3D Prediction	% of Difference
6	NEW ORLEANS, LA	213.950	220.720	3.16%	212.280	-0.78%	219.870	2.77%	213.120	-0.39%
7	HOUSTON, TX	62.614	43.564	-30.42%	45.721	-26.98%	53.589	-14.41%	54.167	-13.49%
22	TAMPA, FL	33.000	6.244	-81.08%	3.410	-89.67%	19.693	-40.32%	18.205	-44.83%
5	PORT ARTHUR, TX	28.000	23.676	-15.44%	29.560	5.57%	26.110	-6.75%	28.780	2.79%
15	PORTLAND, OR	26.000	17.666	-32.05%	20.930	-19.50%	22.036	-15.25%	23.465	-9.75%
11	NEW YORK CITY, NY	23.801	34.278	44.02%	42.462	78.40%	29.433	23.66%	33.132	39.20%
9	BALTIMORE, MD	17.460	17.920	2.63%	16.049	-8.08%	17.895	2.49%	16.754	-4.04%
8	CHESAPEAKE SOUTH	16.964	20.947	23.48%	18.017	6.21%	19.196	13.16%	17.490	3.10%
14	SAN FRANCISCO, CA	14.972	22.105	47.64%	13.304	-11.14%	18.792	25.51%	14.138	-5.57%
23	MOBILE, AL	13.000	11.199	-13.85%	15.851	21.93%	12.228	-5.94%	14.425	10.96%
13	PHILADELPHIA, PA	12.910	20.151	56.09%	17.581	36.18%	16.762	29.84%	15.245	18.09%
2	PUGET SOUND, WA	12.774	12.766	-0.06%	9.289	-27.28%	12.916	1.11%	11.032	-13.64%
3	LA/LONG BEACH, CA	9.967	13.639	36.84%	14.378	44.26%	11.960	20.00%	12.172	22.13%
21	JACKSONVILLE, FL	8.000	8.476	5.95%	10.476	30.95%	8.335	4.19%	9.238	15.48%
10	CORPUS CHRISTI, TX	7.470	8.302	11.13%	9.528	27.55%	7.981	6.84%	8.499	13.78%
1	BOSTON, MA	6.000	1.470	-75.50%	3.196	-46.73%	3.752	-37.47%	4.598	-23.37%
19	PROVIDENCE, RI	5.000	0.823	-83.53%	1.104	-77.91%	2.921	-41.58%	3.052	-38.96%
16	ANCHORAGE, AK	4.000	1.734	-56.66%	2.645	-33.88%	2.887	-27.83%	3.322	-16.94%
20	WILMINGTON, NC	3.000	4.086	36.20%	3.515	17.18%	3.590	19.66%	3.258	8.59%
4	SANTA BARBARA, CA	1.000	2.756	175.61%	1.672	67.15%	1.910	90.97%	1.336	33.58%
12	LONG ISLAND SOUND, NY	1.000	1.305	30.48%	1.193	19.31%	1.167	16.74%	1.097	9.65%
17	PORTLAND, ME	0.000	0.201		0.607		0.103		0.304	
18	PORTSMOUTH, NH	0.000	0.080		0.296		0.041		0.148	
	TOTAL	520.88	494.11		493.07		513.17		506.98	

TABLE 12. COMPARISON OF PREDICTED CASUALTIES WITH OBSERVED CASUALTIES

(Models Are Estimated Based On 1979-1986 Casualty Data)

- Predicted For 1987 - 1989 Casualties -

ZONE	NAME	10 Year Casualties	3 Year Casualties	Linear Model Prediction	% of Difference	Logistic Regression Prediction	% of Difference	7-Year Historical Rate Prediction	% of Difference	Weighted Historical & Linear Prediction	% of Difference	Weighted Historical & Logistic Prediction	% of Difference
6	NEW ORLEANS, LA	213.95	36.159	72.648	100.91%	70.903	96.09%	76.194	110.72%	74.421	105.82%	73.549	103.40%
7	HOUSTON, TX	62.614	19.586	13.020	-33.52%	13.465	-31.25%	18.440	-5.85%	15.730	-19.69%	15.952	-18.55%
15	PORTLAND, OR	26.000	15.000	5.851	-60.99%	6.764	-54.91%	4.714	-68.57%	5.283	-64.78%	5.739	-61.74%
5	PORT ARTHUR, TX	28.000	10.000	7.466	-25.34%	9.105	-8.95%	7.714	-22.86%	7.590	-24.10%	8.410	-15.90%
8	CHESAPEAKE SOUTH	16.964	8.696	6.222	-28.45%	5.496	-36.80%	3.543	-59.26%	4.883	-43.85%	4.520	-48.02%
11	NEW YORK CITY, NY	23.801	7.543	9.255	22.70%	12.101	60.43%	6.968	-7.62%	8.111	7.53%	9.535	26.41%
21	JACKSONVILLE, FL	8.000	5.000	2.691	-46.18%	3.138	-37.24%	1.286	-74.28%	1.989	-60.22%	2.212	-55.76%
13	PHILADELPHIA, PA	12.910	4.391	6.634	51.08%	5.537	26.10%	3.651	-16.85%	5.142	17.10%	4.594	4.62%
2	PUGET SOUND, WA	10.428	4.331	4.050	-6.49%	2.688	-37.94%	2.613	-39.67%	3.332	-23.07%	2.651	-38.79%
22	TAMPA,FL	5.000	4.000	0.867	-78.33%	0.572	-85.70%	0.429	-89.28%	0.648	-83.80%	0.500	-87.50%
14	SAN FRANCISCO, CA	14.972	3.340	6.955	108.23%	4.188	25.39%	4.985	49.25%	5.970	78.74%	4.587	37.34%
23	MOBILE, AL	13.000	3.000	3.512	17.07%	4.876	62.53%	4.286	42.87%	3.899	29.97%	4.581	52.70%
3	LA/LONG BEACH, CA	9.967	2.611	3.587	37.38%	3.895	49.18%	3.152	20.72%	3.370	29.07%	3.524	34.97%
19	PROVIDENCE, RI	5.000	2.000	0.250	-87.50%	0.304	-84.80%	1.286	-35.70%	0.768	-61.60%	0.795	-60.25%
10	CORPUS CHRISTI, TX	7.470	1.079	2.482	130.03%	2.924	170.99%	2.739	153.85%	2.611	141.98%	2.832	162.47%
9	BALTIMORE, MD	17.460	1.068	5.907	453.09%	4.801	349.53%	7.025	557.77%	6.466	505.43%	5.913	453.65%
16	ANCHORAGE, AK	4.000	1.000	0.591	-40.90%	0.879	-12.10%	1.286	28.60%	0.938	-6.20%	1.082	8.20%
1	BOSTON, MA	6.000	0.000	0.410		0.927		2.571		1.491		1.749	
4	SANTA BARBARA, CA	1.000	0.000	0.900		0.514		0.429		0.664		0.471	
12	LONG ISLAND SOUND, NY	1.000	0.000	0.401		0.354		0.429		0.415		0.391	
17	PORTLAND, ME	0.000	0.000	0.049		0.166		0.000		0.024		0.083	
18	PORTSMOUTH, NH	0.000	0.000	0.019		0.089		0.000		0.009		0.044	
20	WILMINGTON, NC	3.000	0.000	1.261		1.078		1.286		1.273		1.182	
	TOTAL	490.536	128.804	155.028		154.764		155.026		155.027		154.896	

Note: The predicted casualties do not include the three outlier subzones 2-6, 2-9 and 22-2.

TABLE 13. COMPARISON OF PREDICTED CASUALTIES WITH OBSERVED CASUALTIES

(Models Are Estimated Based On 1979-1986 Casualty Data)

- Predicted For 1987 - 1989 Casualties -

ZONE	NAME	10 Year Casualties	3 Year Casualties	Linear Model Prediction	Square of Residual	Logistic Regression Prediction	Square of Residual	7-Year Historical RAte Prediction	Square of Residual	Weighted Historical & Linear Prediction	Square of Residual	Weighted Historical & Logistic Prediction	Square of Residual
6	NEW ORLEANS, LA	213.95	36.159	72.648	1,331.447	70.903	1,207.146	76.194	1,602.801	74.421	1,463.981	73.549	1,398.012
7	HOUSTON, TX	62.614	19.586	13.020	43.112	13.465	37.467	18.440	1.313	15.730	14.869	15.952	13.206
15	PORTLAND, OR	26.000	15.000	5.851	83.704	6.764	67.832	4.714	105.802	5.283	94.420	5.739	85.766
5	PORT ARTHUR, TX	28.000	10.000	7.466	6.421	9.105	0.801	7.714	5.226	7.590	5.808	8.410	2.528
8	CHESAPEAKE SOUTH	16.964	8.696	6.222	6.121	5.496	10.240	3.543	26.553	4.883	14.539	4.520	17.439
11	NEW YORK CITY, NY	23.801	7.543	9.255	2.931	12.101	20.775	6.968	0.331	8.111	0.323	9.535	3.968
21	JACKSONVILLE, FL	8.000	5.000	2.691	5.331	3.138	3.467	1.286	13.794	1.989	9.066	2.212	7.773
13	PHILADELPHIA, PA	12.910	4.391	6.634	5.031	5.537	1.313	3.651	0.548	5.142	0.564	4.594	0.041
2	PUGET SOUND, WA	10.428	4.331	4.050	0.079	2.688	2.699	2.613	2.952	3.332	0.998	2.651	2.822
22	TAMPA,FL	5.000	4.000	0.867	9.816	0.572	11.751	0.429	12.752	0.648	11.236	0.500	12.250
14	SAN FRANCISCO, CA	14.972	3.340	6.955	13.068	4.188	0.719	4.985	2.706	5.970	6.917	4.587	1.555
23	MOBILE, AL	13.000	3.000	3.512	0.262	4.876	3.519	4.286	1.654	3.899	0.808	4.581	2.500
3	LA/LONG BEACH, CA	9.967	2.611	3.587	0.953	3.895	1.649	3.152	0.293	3.370	0.576	3.524	0.834
19	PROVIDENCE, RI	5.000	2.000	0.250	3.063	0.304	2.876	1.286	0.510	0.768	1.518	0.795	1.452
10	CORPUS CHRISTI, TX	7.470	1.079	2.482	1.968	2.924	3.404	2.739	2.756	2.611	2.347	2.832	3.073
9	BALTIMORE, MD	17.460	1.068	5.907	23.416	4.801	13.935	7.025	35.486	6.466	29.138	5.913	23.474
16	ANCHORAGE, AK	4.000	1.000	0.591	0.167	0.879	0.015	1.286	0.082	0.938	0.004	1.082	0.007
1	BOSTON, MA	6.000	0.000	0.410	0.168	0.927	0.859	2.571	6.610	1.491	2.223	1.749	3.059
4	SANTA BARBARA, CA	1.000	0.000	0.900	0.810	0.514	0.264	0.429	0.184	0.664	0.441	0.471	0.222
12	LONG ISLAND SOUND, NY	1.000	0.000	0.401	0.161	0.354	0.125	0.429	0.184	0.415	0.172	0.391	0.153
17	PORTLAND, ME	0.000	0.000	0.049	0.002	0.166	0.028	0.000	0.000	0.024	0.001	0.083	0.007
18	PORTSMOUTH, NH	0.000	0.000	0.019	0.000	0.089	0.008	0.000	0.000	0.009	0.000	0.044	0.002
20	WILMINGTON, NC	3.000	0.000	1.261	1.590	1.078	1.162	1.286	1.654	1.273	1.621	1.182	1.397
	TOTAL	490.536	128.804	155.028	1,539.622	154.764	1,392.055	155.026	1,824.189	155.027	1,661.569	154.896	1,581.539

ATTACHMENT 1. MODEL 2-C: SUBZONE RISK VARIABLES WEIGHTED BY TRAFFIC INCLUDING SUBZONES WITH ZERO CASUALTIES (1 OF 3)

(Excluding Subzone 2-6, 2-9 and 22-2)

WEIGHTED BY: NDRY_TNK (normalized dry cargo and tanker transits)

Model: MODEL1
Dependent Variable: RATE

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	6	11014.32711	1835.72118	39.488	0.0001
Error	80	3719.09135	46.48864		
C Total	86	14733.41846			

Root MSE	6.81826	R-square	0.7476
Dep Mean	9.11987	Adj R-sq	0.7286
C.V.	74.76270		

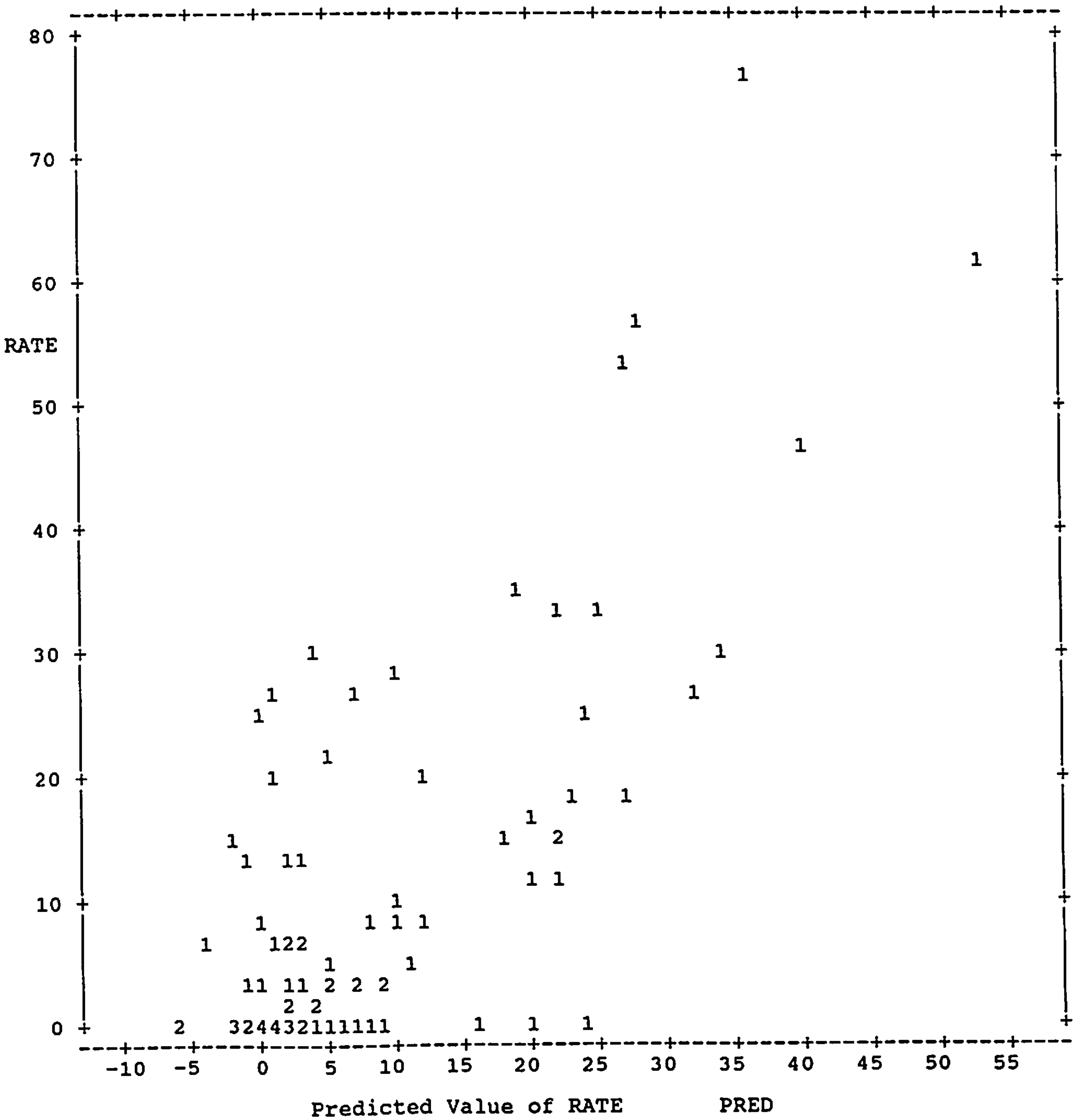
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-0.372321	1.58138192	-0.235	0.8145
OPEN	1	-3.529773	1.89522160	-1.862	0.0662
NARROW	1	16.327722	2.27181418	7.187	0.0001
RTLENGTH	1	0.228527	0.04758889	4.802	0.0001
AVGWIDTH	1	-0.000407	0.00021664	-1.879	0.0638
SUMHEADI	1	0.012121	0.00285160	4.251	0.0001
OTHER_ML	1	0.000392	0.00021669	1.809	0.0741

ATTACHMENT 1. MODEL 2-C: SUBZONE RISK VARIABLES WEIGHTED BY TRAFFIC INCLUDING SUBZONES WITH ZERO CASUALTIES (2 OF 3)

(Excluding Subzone 2-6, 2-9 and 22-2)

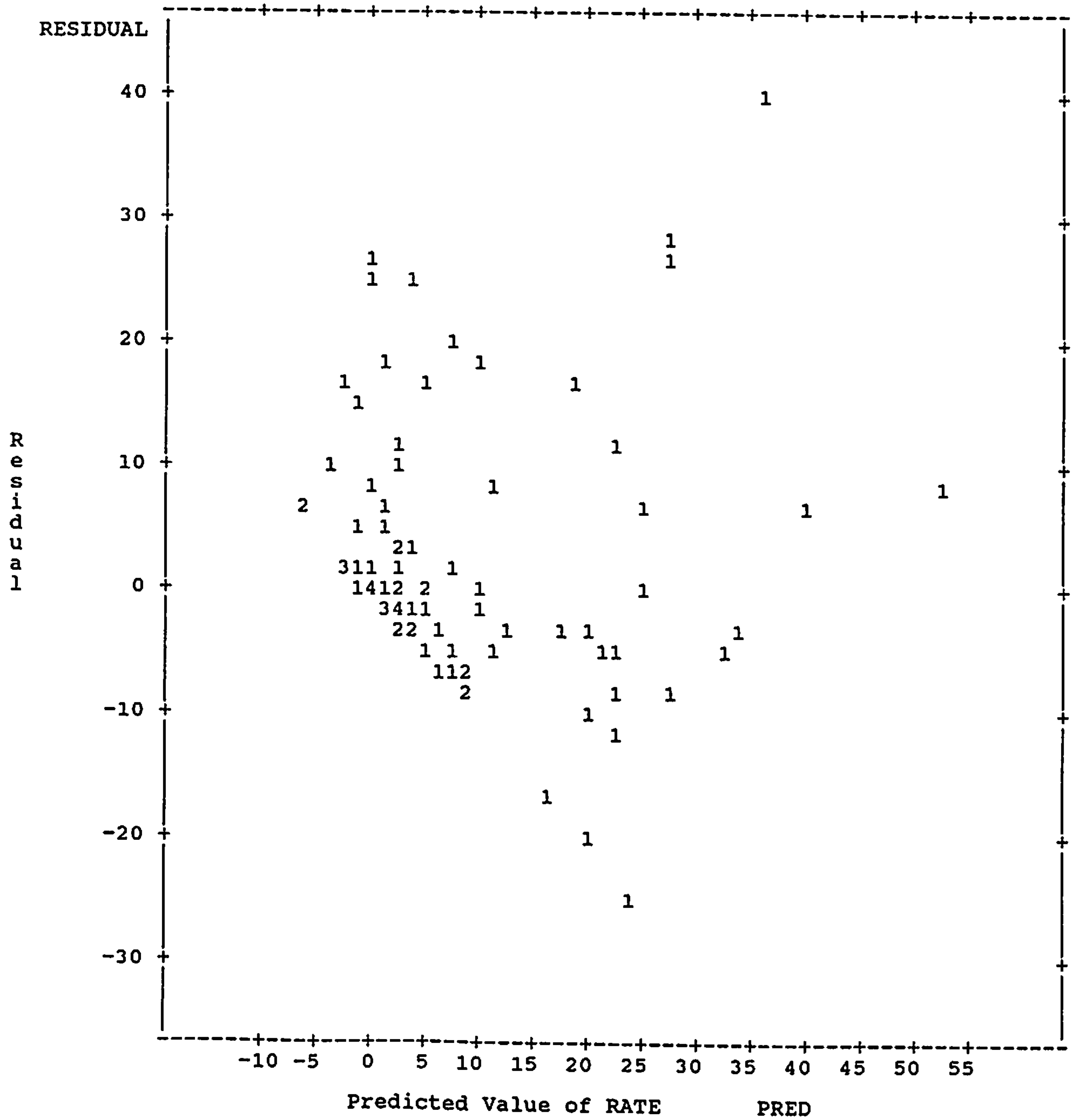
WEIGHTED BY: NDRY_TNK (normalized dry cargo and tanker transits)



ATTACHMENT 1. MODEL 2-C: SUBZONE RISK VARIABLES WEIGHTED BY TRAFFIC INCLUDING SUBZONES WITH ZERO CASUALTIES (3 OF 3)

(Excluding Subzone 2-6, 2-9 and 22-2)

WEIGHTED BY: NDRY_TNK (normalized dry cargo and tanker transits)



ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (1 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

MAXIMUM LIKELIHOOD ANALYSIS OF VARIANCE TABLE

Source	DF	Chi-Square	Prob
INTERCEPT	1	2129.53	0.0000
CONVERGE	1	7.92	0.0049
OPENHBR	1	12.88	0.0003
ENCLOSED	1	4.97	0.0257
NARROW	1	121.26	0.0000
RIVER	1	56.76	0.0000
VIS1N	1	12.71	0.0004
RTLENGTH	1	132.03	0.0000
AVGWIDTH	1	13.42	0.0002
OTHER_ML	1	12.36	0.0004
LIKELIHOOD RATIO	77	196.45	0.0000

ANALYSIS OF MAXIMUM LIKELIHOOD ESTIMATES

Effect	Parameter	Estimate	Standard Error	Chi-Square	Prob
INTERCEPT	1	11.8146	0.2560	2129.53	0.0000
CONVERGE	2	-0.7225	0.2567	7.92	0.0049
OPENHBR	3	-0.7772	0.2166	12.88	0.0003
ENCLOSED	4	-0.6797	0.3047	4.97	0.0257
NARROW	5	-2.0882	0.1896	121.26	0.0000
RIVER	6	-1.4936	0.1982	56.76	0.0000
VIS1N	7	-0.8459	0.2373	12.71	0.0004
RTLENGTH	8	-0.0209	0.00182	132.03	0.0000
AVGWIDTH	9	0.000091	0.000025	13.42	0.0002
OTHER_ML	10	-0.00006	0.000017	12.36	0.0004

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (2 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

CATMOD PROCEDURE

Response: IC	Response Levels	(R)=	2
Weight Variable: WEIG	Populations	(S)=	87
Data Set: LOGR	Total Frequency	(N)=	5.38E6
	Observations	(Obs)=	146

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (3 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

POPULATION PROFILES

Sample	CONVERGE	OPENHBR	ENCLOSED	NARROW	RIVER	VIS1N
1	0	0	0	0	0	0.3123597097
2	0	0	0	0	0	0.5269372495
3	0	0	0	0	0	0.5731121631
4	0	0	0	0	0	0.6410164478
5	0	0	0	0	0	0.6654619903
6	0	0	0	0	0	0.7741088459
7	0	0	0	0	0	0.7795411887
8	0	0	0	0	0	0.8501616448
9	0	0	0	0	0	0.8501616448
10	0	0	0	0	0	0.8909042156
11	0	0	0	0	0	0.8990527298
12	0	0	0	0	0	1.0511583276
13	0	0	0	0	0	1.0701715273
14	0	0	0	0	0	1.102765584
15	0	0	0	0	0	1.1435081548
16	0	0	0	0	0	1.3553695232
17	0	0	0	0	0	1.3770988943
18	0	0	0	0	0	1.3988282654
19	0	0	0	0	0	1.4015444368
20	0	0	0	0	0	1.4015444368
21	0	0	0	0	0	1.445003179
22	0	0	0	0	0	1.7356335176
23	0	0	0	0	1	0.3123597097
24	0	0	0	0	1	0.6654619903
25	0	0	0	0	1	0.7741088459
26	0	0	0	0	1	0.7741088459
27	0	0	0	0	1	0.7741088459
28	0	0	0	0	1	0.8501616448
29	0	0	0	0	1	0.8909042156
30	0	0	0	0	1	0.8990527298
31	0	0	0	0	1	1.1435081548
32	0	0	0	0	1	1.151656669
33	0	0	0	0	1	1.4015444368
34	0	0	0	1	0	0.7741088459
35	0	0	0	1	0	0.7741088459
36	0	0	0	1	0	0.7795411887
37	0	0	0	1	0	0.8501616448
38	0	0	0	1	0	0.8501616448
39	0	0	0	1	0	0.8501616448
40	0	0	0	1	0	0.8990527298

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (4 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

POPULATION PROFILES

Sample	CONVERGE	OPENHBR	ENCLOSED	NARROW	RIVER	VIS1N
41	0	0	0	1	0	1.1435081548
42	0	0	0	1	0	1.1435081548
43	0	0	0	1	0	1.3988282654
44	0	0	0	1	0	1.4015444368
45	0	0	0	1	0	1.4015444368
46	0	0	0	1	0	1.4015444368
47	0	0	0	1	0	1.445003179
48	0	0	1	0	0	0.3123597097
49	0	0	1	0	0	0.5269372495
50	0	0	1	0	0	0.5731121631
51	0	0	1	0	0	0.6410164478
52	0	0	1	0	0	0.7795411887
53	0	0	1	0	0	1.0511583276
54	0	0	1	0	0	1.0511583276
55	0	0	1	0	0	1.0701715273
56	0	0	1	0	0	1.151656669
57	0	0	1	0	0	1.3553695232
58	0	0	1	0	0	1.3770988943
59	0	0	1	0	0	1.4015444368
60	0	0	1	0	0	1.4015444368
61	0	0	1	0	0	1.445003179
62	0	0	1	0	0	1.7356335176
63	0	1	0	0	0	0.3123597097
64	0	1	0	0	0	0.5731121631
65	0	1	0	0	0	0.6410164478
66	0	1	0	0	0	0.6410164478
67	0	1	0	0	0	0.6654619903
68	0	1	0	0	0	0.8501616448
69	0	1	0	0	0	0.8501616448
70	0	1	0	0	0	0.8909042156
71	0	1	0	0	0	1.0511583276
72	0	1	0	0	0	1.0701715273
73	0	1	0	0	0	1.151656669
74	0	1	0	0	0	1.3553695232
75	0	1	0	0	0	1.4015444368
76	0	1	0	0	0	1.445003179
77	0	1	0	0	0	1.7356335176
78	1	0	0	0	0	0.3123597097
79	1	0	0	0	0	0.5731121631
80	1	0	0	0	0	0.6410164478

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (5 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

POPULATION PROFILES

Sample	CONVERGE	OPENHBR	ENCLOSED	NARROW	RIVER	VIS1N
81	1	0	0	0	0	0.6654619903
82	1	0	0	0	0	0.8501616448
83	1	0	0	0	0	0.8501616448
84	1	0	0	0	0	1.0511583276
85	1	0	0	0	0	1.3770988943
86	1	0	0	0	0	1.4015444368
87	1	0	0	0	0	1.445003179

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (6 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

POPULATION PROFILES

Sample	RTLENGTH	AVGWIDTH	OTHER_ML	Sample Size
1	29.765752132	666	261.0046595	145596
2	28	1431.060301	826.75	31858
3	21.377558326	9999	2415.9915371	95033
4	35.524639337	9999	160.25496969	189689
5	48.052055107	100	147.13210464	37606
6	49.699094559	100	50.403332741	228944.3
7	27.294688128	7710.923244	0	182200
8	23.259406699	200	0	30471
9	25.748786379	402.33376548	196.86364729	392257
10	17.492855685	825.20551457	73.001231076	79397
11	6.9282032303	9999	252.87941791	14701
12	21.023796042	9999	1400.3179988	10529
13	68.249542123	9999	18.315141188	3920
14	49.477267507	9999	608.76441884	75847
15	35.454195802	250	0	73697
16	22.912878475	1962.7527565	61.319227156	7514
17	8.0622577483	1000	338.98692963	2306
18	14.212670404	266	0	26492
19	35.411862419	9999	123.82856197	38923
20	67.201190466	9999	35.669010971	54938.17
21	9.5393920142	6684.1706979	139.63154025	14481
22	8	9999	551.375	3272
23	67.999560184	358.63813987	1037.6537702	24612
24	59.977796589	100	545.33513834	53201.71
25	42.420238677	733.23937181	459.19119287	261431.9
26	74.208235788	548.52972543	181.78575271	172580.6
27	107.28844145	639.84331064	346.7195487	101993.1
28	1.0298523356	500	5826.0779653	15377.16
29	85.799224039	213.79227682	404.37428646	39018
30	28.012271503	140.62838169	404.57268875	14704
31	2.8040637715	100	2753.1470855	25811
32	14.775517653	133	236.20153838	15592.56
33	15.725814059	187.57766063	621.58944289	16816
34	20.466248825	100	60.001224967	214996
35	88.49021236	104.3341209	63.295135706	25797
36	11.224659491	282.44623552	7224.0944207	182261.3
37	5.2633100187	2297.0825903	3674.3037995	81443.81
38	15.289050863	516.89808703	987.7002919	4114
39	23.46720327	290.34823505	339.36723982	30474.31

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (7 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

POPULATION PROFILES

Sample	RTLENGTH	AVGWIDTH	OTHER_ML	Sample Size
40	7.146490561	4077.2080683	245.15529476	14701
41	31.769155504	412.11321451	685.72801683	59570
42	44.517570363	200.16641934	360.4419529	14142
43	27.817751486	234.76652825	1092.1802941	26498
44	13.368727225	6199.6518824	630.351705	6106
45	27.284676143	4651.6612363	160.71292095	22506
46	47.103344497	2097.9411941	207.52241915	16825
47	2.8778669456	124.66263138	38.570233474	5690
48	4.6152017448	145.37122833	4508.1452882	26994.63
49	10.87955999	148.7783821	3665.0379277	31855
50	1.2778580636	1271.9774607	23357.05416	95035.54
51	4.5912330651	1111.972389	911.30202729	130759
52	2.6876176026	350	3980.8490575	102865.3
53	4.1867269641	1100	1303.882495	1346
54	6.6677713006	3856.190974	1637.4286861	6251
55	6.4434326279	3050	97.15318467	3921
56	9.2616853648	266	360.51753741	57389.23
57	8.0535378389	296.44143383	1395.659923	4744
58	2.4226351682	739.37742217	2820.4824605	2306
59	2.8145409274	9999	8270.6205384	20611
60	4.0928350417	9999	3221.4833644	22362.26
61	4.4768502695	329.43153749	386.65577265	13484
62	1.2864718135	200	9341.8292368	3272
63	32.218875822	961.61671042	2133.0353169	77086.17
64	4.1049030952	4499.1506132	12582.026616	95033
65	18.05695993	1096.1090812	337.70911735	189692
66	23.22558458	6109.1510936	113.15108091	2697
67	53.123851942	100	1116.2405931	37608.2
68	2.8869649851	1655.5536512	2981.6780059	81437
69	3.2373102048	951.95994881	2195.6499533	197271.5
70	31.786339405	219.86248878	44.956419228	42751
71	52.525260816	9999	1597.1362864	10530
72	165.75302564	8013.3467116	11.318043775	3923
73	95.620049371	8249.5866802	936.67594389	73462.66
74	22.381513041	504.45143379	439.42516228	7514
75	46.138659278	9999	862.11867926	46137.5
76	3.9712512471	5265.7620758	817.62643509	14482
77	9.0535246653	4792.4017358	1327.4388091	3272
78	21.978797152	749.35777061	228.53843935	77085.17

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (8 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

POPULATION PROFILES

Sample	RTLENGTH	AVGWIDTH	OTHER_ML	Sample Size
79	8.78	9999	5882.4601367	95040.43
80	36.949390952	7837.213683	350.75003041	189695
81	27.916872485	100	253.25186421	37605
82	7.2876097487	266	809.18163889	278707.5
83	15.706143223	172.17888186	0	30473
84	21.784897164	9999	1480.383394	10529
85	2.9259174679	847.25146647	0	2306
86	30.296561864	9999	175.63048982	52243.5
87	4.4581214643	5744.5045264	0	13483

RESPONSE PROFILES

Response	IC
1	0
2	1

ATTACHMENT 2. MODEL 3-D: LOGISTIC REGRESSION INCLUDING SUBZONES WITH ZERO CASUALTIES (9 OF 9)

(Excluding Subzones 2-6, 2-9 and 22-2)

MAXIMUM LIKELIHOOD ANALYSIS

Iteration	Sub Iteration	-2 Log Likelihood	Convergence Criterion	Parameter Estimates 1	2	3	4
0	0	7457147	1.0000	0	0	0	0
1	0	1367970.1	0.8166	2.0004	-0.000211	-0.000172	-0.000276
2	0	461548.53	0.6626	3.1366	-0.000684	-0.000558	-0.000896
3	0	168179.45	0.6356	4.1823	-0.001971	-0.001608	-0.002579
4	0	65173.758	0.6125	5.2038	-0.005456	-0.004449	-0.007135
5	0	28415.909	0.5640	6.2258	-0.0148	-0.0120	-0.0193
6	0	15511.963	0.4541	7.2697	-0.0390	-0.0317	-0.0505
7	0	11221.492	0.2766	8.3664	-0.0974	-0.0786	-0.1236
8	0	9929.9794	0.1151	9.5315	-0.2153	-0.1738	-0.2598
9	0	9596.4861	0.0336	10.6536	-0.3893	-0.3342	-0.4232
10	0	9537.3153	0.006166	11.4591	-0.5748	-0.5683	-0.5604
11	0	9532.7663	0.000477	11.7744	-0.6972	-0.7441	-0.6575
12	0	9532.7043	6.5048E-6	11.8139	-0.7219	-0.7766	-0.6792
13	0	9532.7043	1.9849E-9	11.8146	-0.7225	-0.7772	-0.6797

Iteration	Parameter Estimates 5	6	7	8	9	10
0	0	0	0	0	0	0
1	-0.000860	-0.000512	-0.000161	-0.000013	2.1934E-8	-1.937E-8
2	-0.002790	-0.001661	-0.000523	-0.000041	7.1161E-8	-6.284E-8
3	-0.008035	-0.004784	-0.001508	-0.000119	2.0506E-7	-1.81E-7
4	-0.0222	-0.0132	-0.004185	-0.000328	5.6847E-7	-5.014E-7
5	-0.0602	-0.0358	-0.0114	-0.000885	1.5455E-6	-1.36E-6
6	-0.1584	-0.0941	-0.0306	-0.002312	4.1151E-6	-3.599E-6
7	-0.3923	-0.2329	-0.0799	-0.005611	0.0000105	-9.049E-6
8	-0.8490	-0.5089	-0.1966	-0.0115	0.0000244	-0.00002
9	-1.4450	-0.9110	-0.4265	-0.0176	0.0000473	-0.000037
10	-1.8862	-1.2898	-0.7049	-0.0203	0.000073	-0.000052
11	-2.0624	-1.4674	-0.8319	-0.0208	0.0000885	-0.000058
12	-2.0877	-1.4931	-0.8458	-0.0209	0.0000911	-0.000059
13	-2.0882	-1.4936	-0.8459	-0.0209	0.0000911	-0.000059

ATTACHMENT 3. MODEL 3-D: LOGISTIC REGRESSION COMPARISON OF PREDICTED AND HISTORICAL CASUALTY NUMBERS (1 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

--- ZONE=BOSTON ---

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
1	1	A	14480	6.9061	1.6809	1	0.24339
2	2	B	13483	0.0000	3.3635	0	0.45350
3	3	C	14480	13.8122	3.8549	2	0.55819
4	4	D	13483	7.4167	5.4014	1	0.72828
5	5	E	5688	35.1617	21.3213	2	1.21276
				--------	--------	--------	--------
ZONE				63.2967	35.6220	6	3.19611

--- ZONE=PUGET SOUND ---

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
6	1	A	54934	7.600	3.9731	4.1748	2.18260
7	2	B	52242	2.863	3.8152	1.4957	1.99316
8	3	C	46136	3.242	5.8433	1.4957	2.69584
9	4	E	6106	0.000	15.2373	0.0000	0.93039
10	6	D	2373	53.397	2.4923	1.2671	0.05914
11	7	D	22359	14.590	2.5301	3.2621	0.56571
12	9	E	793	136.034	22.5181	1.0787	0.17857
13	10	D	20611	0.000	3.3183	0.0000	0.68393
				--------	--------	--------	--------
ZONE				217.725	59.7277	12.7741	9.28934

--- ZONE=LA/LONG BEACH ---

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
14	1	A	95033	0.0000	0.8707	0.00000	0.8274
15	2	B	95033	7.8165	1.6909	7.42826	1.6069
16	3	C	95033	0.0000	3.9691	0.00000	3.7720
17	4	D	95033	2.6712	8.5989	2.53856	8.1718
				--------	--------	--------	--------
ZONE				10.4877	15.1296	9.96682	14.3781

--- ZONE=SANTA BARBARA ---

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
18	1	A	75846	1.31846	2.20387	1	1.67155

ATTACHMENT 3. MODEL 3-D: LOGISTIC REGRESSION COMPARISON OF PREDICTED AND HISTORICAL CASUALTY NUMBERS (2 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

ZONE=PORT ARTHUR

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
19	1	A	73693	5.4279	3.9900	4	2.9404
20	2	E	59559	18.4691	30.5817	11	18.2142
21	3	E	14134	56.6011	39.9196	8	5.6422
22	4	F	25806	19.3753	10.7086	5	2.7634
				--------	--------	--------	--------
ZONE				99.8734	85.1999	28	29.5602

ZONE=NEW ORLEANS

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
23	1	A	228924	8.869	3.998	20.303	9.151
24	2	E	214962	15.815	17.520	33.997	37.661
25	3	F	172524	32.819	28.736	56.621	49.577
26	4	E	25785	46.539	72.551	12.000	18.707
27	5	F	261403	11.053	14.783	28.893	38.643
28	6	F	101931	60.955	57.436	62.132	58.545
				--------	--------	--------	--------
ZONE				176.050	195.024	213.946	212.285

ZONE=HOUSTON

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
29	1	A	182200	0.0000	1.2532	0.0000	2.2834
30	2	E	182200	33.6698	21.7760	61.3464	39.6758
31	3	D	102864	1.2318	3.6567	1.2671	3.7614
				--------	--------	--------	--------
ZONE				34.9017	26.6859	62.6135	45.7206

ZONE=CHESAPEAKE SOUTH

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
32	1	A	189689	0.0000	1.0850	0.0000	2.0581
33	2	B	189689	3.1638	2.8349	6.0013	5.3775
34	3	C	189689	1.5770	3.7254	2.9913	7.0667
35	4	D	130751	6.0963	2.6344	7.9709	3.4445
36	6	C	2697	0.0000	2.5942	0.0000	0.0700
				--------	--------	--------	--------
ZONE				10.8370	12.8739	16.9636	18.0168

ATTACHMENT 3. MODEL 3-D: LOGISTIC REGRESSION COMPARISON OF PREDICTED AND HISTORICAL CASUALTY NUMBERS (3 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

ZONE=BALTIMORE

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
37	1	C	73452	14.5147	15.6699	10.6613	11.5098
38	2	D	57387	3.8924	4.6775	2.2337	2.6843
39	3	F	15588	29.2823	11.9010	4.5645	1.8551
				--------	--------	--------	--------
ZONE				47.6894	32.2484	17.4596	16.0493

ZONE=CORPUS CHRISTI

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
40	1	A	30471	0.0000	2.4238	0.00000	0.73857
41	2	B	30471	6.5636	4.2738	2.00000	1.30227
42	3	E	30471	10.8710	19.8760	3.31250	6.05643
43	4	F	15375	14.0325	9.3063	2.15750	1.43085
				--------	--------	--------	--------
ZONE				31.4671	35.8800	7.47000	9.52812

ZONE=NEW YORK CITY

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
44	1	A	392257	0.0000	2.5359	0.0000	9.9474
45	2	B	278702	1.9719	3.7276	5.4957	10.3888
46	3	C	197270	0.7582	3.6881	1.4957	7.2756
47	5	E	81432	14.5029	13.7779	11.8100	11.2196
48	6	C	81432	6.1401	3.5969	5.0000	2.9290
49	7	E	4114	0.0000	17.0514	0.0000	0.7015
				--------	--------	--------	--------
ZONE				23.3731	44.3778	23.8013	42.4619

ZONE=LONG ISLAND SOUND

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
50	1	A	10529	0.00000	1.2197	0	0.12842
51	2	B	10529	0.00000	2.5644	0	0.27000
52	3	C	10529	9.49758	5.1849	1	0.54592
53	4	D	1346	0.00000	3.7863	0	0.05096
54	5	D	6251	0.00000	3.1640	0	0.19778
				--------	--------	--------	--------
ZONE				9.49758	15.9192	1	1.19308

ATTACHMENT 3. MODEL 3-D: LOGISTIC REGRESSION COMPARISON OF PREDICTED AND HISTORICAL CASUALTY NUMBERS (4 OF 6)

ZONE=PHILADELPHIA

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
55	1	A	37605	2.6592	3.5433	1.0000	1.3325
56	2	B	37605	0.0000	4.8210	0.0000	1.8129
57	3	C	37605	8.5186	9.0738	3.2034	3.4122
58	4	F	53193	16.3673	20.7228	8.7062	11.0231
				--------	--------	--------	--------
ZONE				27.5451	38.1609	12.9097	17.5807

ZONE=SAN FRANCISCO

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
59	1	A	145596	0.0000	1.7149	0.0000	2.4968
60	2	B	77082	4.1074	2.9731	3.1661	2.2917
61	3	C	77082	5.4161	4.2688	4.1748	3.2905
62	4	D	26993	6.0425	2.6951	1.6311	0.7275
63	5	F	24606	24.3843	18.2782	6.0000	4.4975
				--------	--------	--------	--------
ZONE				39.9503	29.9300	14.9719	13.3040

ZONE=PORTLAND, OR

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
64	1	A	79395	2.5191	2.1099	2	1.6752
65	2	C	42739	28.0774	6.5276	12	2.7898
66	3	F	39006	30.7645	42.2120	12	16.4652
				--------	--------	--------	--------
ZONE				61.3609	50.8495	26	20.9302

ZONE=ANCHORAGE

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
67	1	A	3920	0.000	3.0653	0	0.12016
68	2	C	3920	76.531	61.2559	3	2.40123
69	3	D	3920	25.510	3.1449	1	0.12328
				--------	--------	--------	--------
ZONE				102.041	67.4662	4	2.64467

ZONE=PORTLAND, ME

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
70	1	A	3272	0	1.5767	0	0.05159
71	2	C	3272	0	5.8979	0	0.19298
72	3	D	3272	0	11.0887	0	0.36282
				--------	--------	--------	--------
ZONE				0	18.5632	0	0.60739

ATTACHMENT 3. MODEL 3-D: LOGISTIC REGRESSION COMPARISON OF PREDICTED AND HISTORICAL CASUALTY NUMBERS (5 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

------------------------------------ ZONE=PORTSMOUTH, NH ------------------------------------

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
73	1	A	2306	0	2.6132	0	0.06026
74	2	B	2306	0	4.8049	0	0.11080
75	3	D	2306	0	5.4333	0	0.12529
				--------	--------	--------	--------
ZONE				0	12.8514	0	0.29635

------------------------------------ ZONE=PROVIDENCE ------------------------------------

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
76	1	A	7512	26.6241	3.1534	2	0.23689
77	2	C	7512	26.6241	7.9224	2	0.59513
78	3	D	4743	21.0837	5.7439	1	0.27243
				--------	--------	--------	--------
ZONE				74.3318	16.8197	5	1.10445

------------------------------------ ZONE=WILMINGTON, NC ------------------------------------

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
79	1	A	14701	0.0000	0.7465	0	0.10974
80	2	E	14701	0.0000	10.3742	0	1.52511
81	3	F	14701	20.4068	12.7920	3	1.88055
				--------	--------	--------	--------
ZONE				20.4068	23.9127	3	3.51541

------------------------------------ ZONE=JACKSONVILLE ------------------------------------

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
82	1	A	26491	3.7749	3.1720	1	0.8403
83	2	E	26491	26.4241	36.3747	7	9.6360
				--------	--------	--------	--------
ZONE				30.1989	39.5467	8	10.4763

------------------------------------ ZONE=TAMPA ------------------------------------

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
84	1	A	31854	12.557	1.9110	4	0.60874
85	2	C	31854	87.901	5.2895	28	1.68491
86	3	D	31854	3.139	3.5036	1	1.11604
				--------	--------	--------	--------
ZONE				103.598	10.7041	33	3.40970

ATTACHMENT 3. MODEL 3-D: LOGISTIC REGRESSION COMPARISON OF PREDICTED AND HISTORICAL CASUALTY NUMBERS (6 OF 6)

- Medium and Large Dry Cargo and Tank Vessels -

-- ZONE=MOBILE, AL --

OBS	SUBZONE	ZONETYPE	DRY_TNK	OBS_RATE	LG3_RATE	ADJ_CASU	LG3_CASU
87	1	A	38923	0.00	2.055	0.000	0.800
88	2	E	22502	17.78	22.824	4.000	5.136
89	4	E	16816	53.52	43.695	9.000	7.348
90	5	F	16816	0.00	15.265	0.000	2.567
				--------	--------	--------	--------
ZONE				71.30	83.840	13.000	15.851
				========	========	========	========
				1257.25	953.537	520.876	493.070

SECTION 4.

VTS DESIGN FINAL REPORT

Prepared For:

The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

By:

NavCom Systems, Inc.
7203 Gateway Court
Manassas, VA 22110
March 1991

NOTE: This section summarizes the NavCom Systems, Inc., total effort in developing of the Candidate VTS Designs for each of the 23 study zones and their respective costs. This task was performed in support of Section 7 of the Port Needs Study (Volume I), under Contract DTRS-57-88-C-00088 Technical Task Directive 13.

Table Of Contents

LIST OF TABLES

APPENDICES

VESSEL TRAFFIC SERVICES STUDY FINAL REPORT

1.0 TASK OVERVIEW

NavCom Systems, Inc was tasked to develop Vessel Traffic Service (VTS) systems designs and costs for 23 ports in the U.S. These ports are listed in Table 1. This task was part of the Ports Needs Study, conducted by the Volpe National Transportation Systems Center (VNTSC) for the U.S. Coast Guard. A three step approach was used to perform this task:

1. Conducted a technology survey of state-of-the-art VTS hardware. This survey addressed capabilities and costs.

2. Conducted surveys of the 23 selected ports to identify existing traffic management problem areas. Seven ports, representative of generic classes, were chosen for on-site visits. These ports were: Boston, Puget Sound, Los Angeles/Long Beach, Santa Barbara, Port Arthur/Lake Charles, New Orleans, and Chesapeake Bay. The remaining 16 ports were surveyed using existing literature, charts and trip reports provided by the Volpe National Transportation Systems Center. A detailed survey report of each port was prepared with emphasis placed on the traffic management problems found.

3. Developed a VTS design for each port by applying state-of-the-art technology to the problems identified in the port survey. Estimates were developed of implementation costs for the VTS design chosen for each port.

Boston Harbor was selected to test this three step approach.

2.0 METHODOLOGY

Successful accomplishment of this task required the development of a uniform data gathering process to acquire complete and comparable information about each port. This process resulted in a consistent design process for every port.

2.1 VTS Technology Survey

A survey of state-of-the-art technology was undertaken by contacting leading operators, manufacturers, designers and system integrators of modern VTS systems. Recent reports and data prepared by European and Japanese sources also were studied.

As this survey progressed, it became necessary to establish generic technology performance levels to allow the application of modern technology capabilities to problems identified in the port survey. Accordingly a set of 18 VTS surveillance technology "modules" were defined and their performance and costs delineated in the VTS Technology Survey Report, dated November 1, 1990 Appendix D.

2.2 Port Surveys

Processes were developed to conduct surveys at the seven ports selected for on-site visits and also for literature-based surveys of ports which would not be visited. In each case a multi-step method was used to complete the surveys and to design appropriate VTS systems.

2.2.1 Survey Process for Visited Ports

2.2.1.1 Survey Questions. An extensive list of survey questions was prepared to assure the gathering of similar core data at each port (Appendix B). These questions served two purposes: 1) they represented the best means of obtaining an estimate of the minimum level of information needed to conduct a VTS traffic management survey, and 2) they were designed to stimulate a discussion of specific topics.

2.2.1.2 Data Collection and Analysis. A list of the minimum data required to evaluate traffic management problems at each port was prepared. This list included:

- A complete set of harbor charts.
- The applicable <u>Light Lists</u> and <u>Current Tables</u>.
- The <u>Coast Pilot</u>.
- The <u>U.S. Navy Fleet Guide</u>.
- Corps of Engineers publications on commodity flow.
- VNTSC reports of visits to ports.
- <u>Code of Federal Regulations</u>.
- U.S. Coast Guard Captain of the Port Orders.

These documents were studied and combined with information obtained through a literature search of recent trade journals and research papers. This process allowed the survey team to become familiar with each port, to identify potential problems, and to prepare an initial list of concerns to be investigated. The results of this activity were used to develop a survey plan which included a list of contacts and preliminary problem areas.

2.2.1.3 Local U.S. Coast Guard contacts. Next, applicable USCG personnel at each port such as the USCG Captain of the Port (COTP), the existing VTS service office, if applicable, and the cognizant Coast Guard District Office were contacted.

2.2.1.4 Interviews and Physical Surveys. Landside and waterside surveys of locations were accomplished and all pertinent interviews were conducted. When these activities were completed, the gathered data were analyzed and the COTP was briefed on the results of this phase of the survey process.

2.2.1.5 Survey Report. After further analysis, a written report was prepared on the physical survey process. The report contained the initial selection of sub-zones within the port and a list of specific problem area identifiers (PAI's) within each sub-zone. Sub-zones were developed from an analysis of areas which could benefit from the use of a specific technology. Some areas were judged to require only procedural monitoring; but other areas were deemed to require various levels of active surveillance. The PAI's represented the survey team's assessment of the most serious potential problem areas in each sub-zone.

2.2.2 Process for Analyzing Unvisited Ports

2.2.2.1 Literature Survey of Remaining Ports. Sixteen of the 23 selected ports were not visited. They were, however, surveyed using published literature. This literature served as a basis for a study to gain a general overview of the ports in question and to identify areas where potential traffic management problems could arise.

2.2.2.2 Comparison with data from Visited Ports. The results from the analysis of each literature survey were compared with problem area templates which were developed during surveys of the seven ports actually visited. Problems identified during visits to ports were matched to similar problems revealed during the literature-based research. Once the problem areas were identified, the process followed was similar in all respects to that used for the seven visited ports. Finally, appropriate nautical charts for each port were annotated to show all known port facilities.

2.3 VTS Design and Costs

Survey reports were used to develop preliminary VTS designs. Hardware to implement a design was selected from the database developed as part of the technology survey. Each harbor was examined to determine the minimum number of surveillance modules needed to respond to identified problems. A trade-off analysis was conducted to define optimal equipment suites for acceptable VTS performance. The detailed design approach, including assumptions and costing methodology, are described in the following paragraphs.

2.3.1 VTS Design Approach

Surveillance sensors were chosen to achieve the VTS mission which was defined as insuring the safety of navigation and the protection of the environment. In order to accomplish this mission, mandatory participation of all vessels over 20 meters would be essential. Moreover, the Vessel Traffic Center (VTC) must provide navigation safety advice to all vessels. Traditionally, the VTS in the United States is not intended to facilitate commerce nor to offer piloting assistance.

The primary criteria developed for determining adequate surveillance sensors were:

- Percentage of vessels of the desired minimum size detected in designated surveillance areas
- Percentage of lost tracks
- Accuracy of the position and track obtained
- Reliability of the surveillance system
- Timeliness of the data obtained
- Ability to interpret and use the data obtained

Secondary criteria were:

- Cost of the VTS system -- reduction of manpower by the use of technology
- Expandability -- increased VTS: responsibility, area, and/or support of other missions

Active surveillance sensors including radar, communications, and closed circuit television (CCTV) installations were used when detection and tracking of vessels was paramount to providing safety advice. The performance and reliability characteristics of these sensors are known from worldwide operational VTS experience. They were selected to assure that the necessary operational criteria identified for each sub-zone would be realized.

Many dependent surveillance techniques were considered ranging from voice radio reporting of required VTS data to automatic position and identification recording devices that can be interrogated from shore (Automatic Dependent Surveillance or ADS). Some form of position and/or movement dependent surveillance is used in existing VTS systems in regions which do not require active surveillance. To apply ADS technology to a specific sub-zone within a VTS zone the following criteria must be considered:

- The number and class of vessels interacting in the sub-zone and the identification of interactions that are important to the VTS mission. Since all vessel classes of interest must be appropriately equipped with an ADS device, full deployment of an ADS system could be very difficult. In areas where only one class of vessel is of interest, however, ADS is more easily implemented.

- The interactions, or transits, to be monitored must not require a surveillance system that can positively detect failures in its own operation because it is realized that proper surveillance depends on position reports which may not always occur. It is obvious that VTS has limited control over this type of operation.

- It must be established that the additional information obtained from ADS, beyond that obtained from active surveillance, is necessary.

- If the class or group of vessels to be monitored is a "controllable" group, ADS can be more easily implemented and satisfactory operation more readily achieved. A controllable group would be a defined as a subset of vessels such as a particular barge company, or vessels carrying specific cargo, etc.

- The number of different vessels in each class of interest that passes through the sub-zone in question must be determined in order to estimate the cost of selecting this option.

- A specific ADS solution for one sub-zone in one harbor could affect VTS designs for sub-zones in other harbors.

2.3.2 Design Assumptions

The design of each VTS system started with the following set of assumptions:

- As recommended by the IMO, all vessels of 20 meters or more in length would be required to participate in the VTS. Participation is defined (at a minimum) as monitoring the VTS frequency and reporting as required.

- The VTS system would be implemented with the cooperation and assistance of port authorities, pilots associations, and where appropriate, the marine exchange. Existing facilities, services, and procedures established and operated by these organizations would be major elements of an integrated VTS system as defined in the IMO VTS Guidelines.

- The software architecture would allow upgrades to process ADS data.

- The minimum life-cycle of all system hardware would be ten years.

2.3.3 Costing Approach

Based on extensive interviews with VTS system designers, suppliers and operators, an approach for estimating VTS system costs was developed. This model is based on 1) determining total equipment costs, and 2) selecting multipliers of equipment costs to develop costs of other system elements. This approach is described in Appendix A.

3.0 SUMMARY OF METHODS

The VTS design and cost methodologies were tested for Boston Harbor and, with minor adjustments, found to be satisfactory. In addition to Boston, the NavCom survey team visited the six other ports to conduct on-site surveys. Making only minor adjustments as experience was gained, all six ports were successfully surveyed. Literature surveys of the remaining sixteen ports were completed using pertinent documents, charts, and VNTSC trip reports. Based on these surveys, port zones and sub-zones were defined, and preliminary VTS designs and 10-year life-cycle costs were prepared for each port.

Table 1 is a list of all ports surveyed. Table 2 shows the number of watchstanders, watchsupervisors and radar sites recommended in the preliminary VTS design. Examination of these data reveals a strong correlation between the number of watchstanders and system cost. This dependency is due to the emphasis placed on using modern technology to obtain maximum performance while employing minimum personnel.

NavCom also was tasked with expanding or modifying the VTS design and costs for those ports where:

1. Expanded zone definitions had been developed by VNTSC.

2. USCG and VNTSC recommended supplemental surveillance capability.

3. Existing VTS equipments were in place.

Table 3 lists modified costs for each harbor based on changes made to the original VTS designs. The changes also are noted in the table.

Finally, a VTS design report was submitted for each harbor.

4.0 CONCLUSIONS

The experience gained from developing the required methodology, conducting on-site and literature-based port surveys, assessing VTS technology and designing preliminary VTS systems for 23 major ports in the U.S. has led to the following conclusions:

- The VTS designs which were prepared are preliminary in nature and are not sufficiently detailed to begin construction of operating VTS systems.

- Personnel expenses are the most significant factor in life-cycle costs of current VTS systems. These costs can be reduced significantly and system effectiveness can be increased by utilizing modern data integration and display techniques coupled with decision-aiding software. An examination of Table 2 indicates that a conservative estimate of $1M/year/watchstander applies to all ports studied regardless of the surveillance technology selected. Table 2 shows the average ten-year life-cycle costs are as follows ($ x 1000):

  - one watchstander port (13 zones)
    average $8,562

  - two watchstander port (2 zones)
    average $16,945

  - three watchstander port (2 zones)
    average $22,305

  - four watchstander port (3 zones)
    average $35,148

  These data show that a logical way to group ports is by the number of watchstanders and watchsupervisors required to operate a VTS effectively.

- A database management system is required to efficiently manage a modern port. This database also can make a major contribution in limiting the effects of an accident after it occurs.

- Modern VTS consoles which incorporate complete data integration and an interactive graphics capability require less manpower and are much more efficient than older VTS systems

- The most severe port management problem in the U.S. is interaction between channel-confined deep draft traffic and "local" traffic. With few exceptions, interactions between deep draft vessels do not present very severe problems.

- The use of surveillance sensors, whose output is not capable of computer integration with other sensor data, diminishes the ability to reduce manpower and increases the watchstander training levels required. The main sensor of this type in use today is closed circuit television (CCTV).

- In the area of Automatic Dependent Surveillance (ADS) systems, several conclusions were reached:

  - The most cost effective surveillance option, for troublesome local traffic such as ferries or hazardous material barges, is radar transponders.

  - The most practical ADS system for deep draft vessels within one VTS zone is a "carry-on" type of device whose operation can be verified and for which back-up communications with the pilot are available.

  - ADS position transponder devices are more applicable to "local" traffic of a significant size or cargo type than they are to deep draft traffic within a VTS zone. This is especially true for the Gulf of Mexico ports wherein Intercostal Waterways (ICW) traffic moves through all ports.

- The variation in management of each port will require specialized VTS implementation on a port by port basis.

- VTS acceptance and effectiveness can be greatly enhanced by "feedback" systems capable of providing integrated VTS data to vessel pilots and masters within the VTS zone.

- VTS implementation must include not only surveillance, but strict enforcement of local rules and procedures in order to be effective.

- The control center costs for a radar or ADS based system are approximately the same.

5.0 RECOMMENDATIONS

The following recommendations are based on experiences gained in this task:

- The VTS designs which were developed should be considered preliminary in nature. If VTS systems are to be designed and deployed in any of the 23 ports included in this study, then more detailed investigations, data collection and surveillance effectiveness measurements are necessary.

- Extensive testing of existing remote radar extractors/trackers is needed to verify their suitability for use in a modern VTS.

- Several specific issues that affect VTS designs for U.S. ports must be addressed. These include:

  - The management infrastructure in place at each port and the existing regulations, relationships, etc.

  - Concerns about factors other than the actual vessel traffic problems identified, e.g., political and local environmental pressures.

  - Plans for expansion or restructure of each port

  These issues need to be addressed in depth before a VTS system design can be finalized.

- The makeup and organization of a VTS database management system needs considerable study. Both national and local decisions must be identified along with the division between the national database portion and the local database portion of a complete database management system. Standard hardware and software options must be selected and serious consideration should be given to exploration of possible linkages with the automated cargo and manifest tracking systems under development by the U. S. Customs Service. A positive result from such a linkage would be better tracking of hazardous and polluting cargoes, with corresponding improvement in safety and incident response.

- The costing approach used in this study relied on an estimation methodology. It should be pointed out, therefore, that more work is required before this model can be used to determine actual system costs.

- The preliminary surveillance modules that have been defined need additional effort to adequately document their performance and costs.

- Before VTS systems are installed in U.S. ports, a systematic approach must be developed to make necessary harbor measurements prior to siting surveillance radars.

- The Intracoastal Waterway (ICW) between Mobile, Alabama and Corpus Christi, Texas should be treated as a separate vessel traffic management "Zone". A study should be conducted to examine the feasibility of combining: 1) vessel traffic management techniques, 2) the existing U. S. Army Corps of Engineers movement-and- cargo database and data collection program, and 3) improved communications and surveillance sensors. Goals of this study should include:

    - Enhancement of the tracking and movement of dangerous/ hazardous materials through the ICW, thereby improving the capabilities for preventing and responding to pollution incidents.

    - Incorporation of the tracking of ICW traffic into VTS information at points where traffic crosses, and/or co-mingles with, deep-draft traffic.

    - Exploitation of the potential offered by the database prepared by the Corps of Engineers.

- An advisory type VTS system should be designed to monitor "along track" position and channel boundary violations of deep draft vessels rather than cross track performance within narrow channels. Cross track performance monitoring requires very precise surveillance hardware and a data update rate adequate for vessel maneuvering time constraints.

- The use of closed circuit television (CCTV) type sensors should be kept to a minimum.

U.S. VTS ZONES STUDIED

1. Boston, Massachusetts
2. Puget Sound, Washington
3. Los Angeles/Long Beach, California
4. Santa Barbara, California
5. Port Arthur, Texas
6. New Orleans, Louisiana
7. Houston/Galveston, Texas
8. South Chesapeake Bay, Virginia
9. North Chesapeake Bay/Baltimore, Maryland
10. Corpus Christi, Texas
11. New York, New York
12. Long Island, New York
13. Philadelphia, Pennsylvania
14. San Francisco, California
15. Portland, Oregon
16. Cook Inlet/Anchorage, Alaska
17. Portland, Maine
18. Portsmouth, New Hampshire
19. Providence, Rhode Island
20. Wilmington, North Carolina
21. Jacksonville, Florida
22. Tampa, Florida
23. Mobile, Alabama

TABLE 1

SUMMARY OF RESULTS

PORT	W/S [1]	RADAR SITES	TOTAL (x $1000)
Boston, Massachusetts	1	2	9560
Puget Sound, Washington	4	12	23670 [2]
Los Angeles/Long Beach, California	2	2	15160
Santa Barbara, California	1	0	4296
Port Arthur/Lake Charles, Texas	2	4	18730
Houston/Galveston, Texas	5	12	35188
New Orleans, Louisiana	4	12	43031
Chesapeake Bay, Maryland	3	3	17741
Corpus Christi, Texas	1.5 [3]	2	11586
New York, New York	4	7	31739
Long Island Sound, New York	1	2	9668
Philadelphia, Pennsylvania	1	0	6489
San Francisco, California	3	6	26869
Portland, Oregon	1.5 [3]	1	11700
Cook Inlet, Alaska	1	2	11365
Portland, Maine	1	2	9248
Portsmouth, New Hampshire	1	1	7561
Providence, Rhode Island	1	2	8832
Wilmington, North Carolina	1	2	9191
Jacksonville, Florida	1	1	7876
Tampa, Florida	1	2	9680
Mobile, Alabama	1	1	9420
Baltimore, Maryland	1	1	8124

NOTES:
1. Watchstanders/supervisors.
2. Costs do not include new radars.
3. One watchstander, one supervisor/day worker.

TABLE 2

SUMMARY OF RESULTS
(Modified Costs)

PORT	W/S [1]	RADAR SITES	TOTAL (x $1000)
Boston, Massachusetts	1	2	9560
Puget Sound, Washington	4	12	30675 [2]
Los Angeles/Long Beach, California	2	4	15799 [2]
Santa Barbara, California	1	3	10405 [5]
Port Arthur/Lake Charles, Texas	2	4	18730
Houston/Galveston, Texas	5	12	35188
New Orleans, Louisiana	4	12	43031
Chesapeake Bay/Hampton Roads	4	6	27964 [4]
Corpus Christi, Texas	1.5 [6]	2	11586
New York, New York	4	7	28948 [3]
Long Island Sound, New York	1	3	10836 [5]
Philadelphia/Delaware Bay	2	4	16864 [4]
San Francisco, California	3	6	26017 [3]
Portland, Oregon	1.5 [6]	1	11700
Cook Inlet, Alaska	1	2	11365
Portland, Maine	1	2	9248
Portsmouth, New Hampshire	1	1	7561
Providence, Rhode Island	1	2	8832
Wilmington, North Carolina	1	2	9191
Jacksonville, Florida	1	1	7876
Tampa, Florida	1	2	9680
Mobile, Alabama	1	2	11384 [4]
Baltimore, Maryland	1.5 [6]	2	10502 [5]

NOTES:
1. Watchstanders/supervisors.
2. Use of existing radars is not included in cost.
3. Use of existing radars is included in cost.
4. Cost includes expanded VTS zone.
5. Cost includes changes made by VNTSC.
6. One watchstander, one supervisor/day worker.

TABLE 3

APPENDIX A

AN APPROACH TO CALCULATING VESSEL TRAFFIC SERVICES SYSTEM COSTS

To determine the total cost of establishing and operating a Vessel Traffic Services System several interactive variables must be examined. These are: 1) Procurement, 2) Engineering, and 3) Operations and Maintenance.

1. PROCUREMENT

Procurement includes the purchase of the physical infrastructure of the Vessel Traffic Service System as well as the necessary personnel. The major subsets to be acquired are:

a. The electronics equipment for the vessel traffic control center and remote sensor sites.

b. The support hardware for the electronics equipment. This includes consoles, equipment racks, emergency power, conventional power handling devices, special interfaces, cables, wires, etc.

c. Sites required for facilities and structures.

d. Physical structures such as towers, buildings, fences, etc.

e. Civil engineering services including road construction, building erection and site preparation.

f. Operating personnel.

2. ENGINEERING

Engineering includes systems design, integration, installation, testing, documentation and training.

a. System design starts with a conceptual statement of operator requirements for Vessel Traffic Services in a harbor. This is followed by a thorough survey of the harbor including analyses of its history of accidents and plans for future expansion or change. Identification of physical and traffic related problem areas is necessary to divide the harbor into sub-zones. These sub-zones represent areas where the identified problems are relatively constant. Appropriate VTS technology then can be selected for each sub-zone. Next, the technology is analyzed for overlapping service so that a minimum suite of remote sensing devices and preliminary sites can be chosen. The initial sensor site selection is verified with field measurements using portable sensors. Finally, a vessel traffic service center is designed based on the final sensor suite selected and the planned scheme for overall harbor control.

b. Integration involves the interfacing of various pieces of hardware and software modules so that they function as a system. This task requires:

- identification of the required interfaces,
- availability of the interface devices needed,
- determination of the adequacy of the software to be provided,
- detailed site integration involving specific interface details (pin out voltages, size, etc.), delivery schedules and specification of manufacturer assistance to be provided.

c. Testing a VTS system is necessary to verify individual equipment and system performance prior to commissioning. All system sensors and software capabilities must be verified for a number of scenarios.

d. Documentation includes verification of technical and operating manuals and the preparation of a "systems manual" if required.

e. Training involves detailed operational instruction for watchstanders and technical repair training for technicians.

3. OPERATIONS AND MAINTENANCE (O&M)

Operations and Maintenance costs are recurring expenses associated with operational and technical personnel, utilities, maintenance contracts, leased equipment and repair parts. These costs are a direct function of the VTS equipment and system design selected. The largest expenses are usually personnel salaries and benefits, and utilities. These costs are intrinsic and must be calculated when the system design is complete.

4. ESTIMATION OF VTS SYSTEM COSTS

An approach to first estimate costing of VTS systems has been developed using historical data from recent VTS system acquisitions. This estimate is based on calculation of a total cost for all electronic and support equipment selected in the preliminary design. This cost is normalized so that other major cost categories can be computed as a percentage of equipment cost. These percentages vary from system to system as a function of customer requirements and physical constraints. This process gives a reasonable first estimate of total system establishment, or non-recurring, costs. Table A-1 contains the results of interviews with designers, purchasers and operators of several current VTS systems. Operations and Maintenance recurring costs must be calculated separately based on design manpower requirements and other factors.

5. DATABASE MANAGEMENT SYSTEMS

An examination of IMO guidelines for VTS systems shows that half of the identified functions relate to the management of vessel and port data. Historically most VTS activities have focused on active or passive surveillance in an attempt to reduce the probability of accidents. Recently, the use of VTS to reduce the effects of an accident has begun to emerge as an equally important task. Along with this realization has come the knowledge that one of the most powerful tools of a modern VTS is a vessel and port database management system. This database can aid in the reduction of accident probability by matching planned maneuvers with harbor, channel and dock dimensions and by comparing current traffic patterns to known ferry schedules and other repetitive operations. It is in the area of limiting the effects of an accident, however, that a database becomes mandatory. The VTS can limit the effect of an accident by supplying position of the vessel, data on the cargo, and equipment and physical layout of the vessel. The VTS also can act as a communications center for rescue organizations. Database tracking of dangerous or hazardous cargo flow also allows extra surveillance of these vessels thereby reducing the probability of a serious accident. A complete database for a modern VTS should include:

- A ship file which contains the characteristics of all vessels including size, draft, construction, handling characteristics, internal systems and any other data of use to emergency personnel. This file also should contain an accident history for each vessel.

- A vessel cargo data file which contains recent trip records, cargo carried and ports of origin.

- A local vessel file which contains data on local tugs, barges and fishing vessels. This file also should have ferry schedules and records of any other local traffic of interest.

- A file of vessels expected in port with their estimated times of arrival.

- A file with complete data on all harbor facilities. These data are of use for harbor planning and for the facilitation of commerce. Normally, this file is used by port commissions to order port services and to direct vessels to appropriate piers. These directions need to be coordinated with the VTS service.

- A Geographic Information System (GIS). A port or harbor GIS can add significant capability to a VTS system by providing readily updatable geographic reference data for the entire area. Multi-layered electronic charts can be used as VTS displays to show changes such as new survey and dredging data as well as maintaining a complete audit trail of all chart and display updates.

Estimating the cost to develop an adequate database for each harbor is difficult without specific information on national decisions concerning data content, location and access. Nevertheless, an assessment has been made for each harbor to give an indication of the cost of hardware and software required to implement a local database.

VTS COST PLANNING

ITEM	WEIGHING FACTOR	VARIABILITY FACTORS
EQUIPMENT	100 (determine final equip cost and set = 100)	NUMBER OF VTC's NUMBER OF CONSOLES CONSOLE FEATURES NUMBER OF REMOTE SITES COMPLEXITY OF RADAR ANT's COMPLEXITY OF VHF COMMS USE OF MICROWAVE LINKS
MANAGEMENT, DESIGN, ENGINEERING, INTERACTION TESTING, INTEGRATION, DOCUMENTATION	50 - 75	LEVEL OF HARDWARE USED (less in simple sys') AMT OF CUSTOMER LEVEL OF EQ MANUF SUPPORT TURNKEY SYSTEM PROCUREMENT SYSTEM USED INTERFACE PROBLEMS SOFTWARE REQUIRED SYSTEM MANUAL REQUIRED
INSTALLATION, SITE INTEGRATION	10 - 25	REMOTE SITE ACCESS COMPLETE INSTALL/ASSIST EQUIP MANUF SUPPORT
SPARE PARTS TRAINING	5 - 10	LEVEL OF SPARES (DEPOT) LEVEL OF TRAINEES AMOUNT OF TRAINING
CIVIL COSTS	25 - 200	SITE ACQUISITION BUILDINGS TOWERS, ROADS, UTILITIES
DBMS	$300-500K	AMOUNT OF NON-RECURRING COSTS ASSIGNED TO EACH HARBOR OPERATING SYSTEM SELECTED FOR VTC CONSOLE

Table A-1

APPENDIX B

VTS SURVEY QUESTIONS

QUESTION CODING REFERENCE

C:	COMMERCIAL
TM:	TRAFFIC MANAGEMENT
N:	NAVIGATION
F:	FOLLOW-UP
E:	ENVIRONMENTAL

VTS SURVEY QUESTIONS

QUESTION # C-1

TYPES OF COMMUNICATIONS USED IN PRESENT OPERATIONS.

QUESTION # C-2

COMMUNICATIONS ARE WITH:

QUESTION # C-3

IS VHF-FM CHANNEL 13 (BRIDGE-TO-BRIDGE) COMMUNICATIONS EFFECTIVE IN TRAFFIC MANAGEMENT AND THE REDUCTION OF MARINE CASUALTY RISKS IN THE PORT COMPLEX?

QUESTION # C-4

WHAT CHANNEL 13 PROBLEMS NEED TO BE ADDRESSED?

QUESTION # C-5

COMMUNICATION PROBLEMS ON OTHER VHF-FM CHANNELS?

QUESTION # C-6

LOCATIONS WHERE VHF-FM COMMUNICATIONS ARE DIFFICULT?

QUESTION # C-7

TIMES WHEN EXISTING VHF-FM COMMUNICATIONS ARE INADEQUATE.

QUESTION # C-8

PENALTIES OR HAZARDS ACCRUING FROM INADEQUATE COMMUNICATIONS?

QUESTION # C-9

WHO ELSE OPERATES ON THE VHF-FM CHANNELS ASSIGNED TO YOU?

VTS SURVEY QUESTIONS

QUESTION # C-10
SUGGESTED IMPROVEMENTS NEEDED IN VHF-FM COMMUNICATIONS FOR PORT.

QUESTION # TM-1
AREAS OF TRAFFIC MANAGEMENT PROBLEMS OR CONCERNS.

QUESTION # TM-2
REASONS FOR ANY TRAFFIC MANAGEMENT PROBLEMS.

QUESTION # TM-3
ARE OPERATING PROCEDURES OR RULES FOR THE PORT ADEQUATE?

QUESTION # TM-4
HOW COULD THESE PROCEDURES BE IMPROVED?

QUESTION # TM-5
WHICH OF THE FOLLOWING FACTORS WOULD BEAR ON IMPROVED TRAFFIC MANAGEMENT AND SAFETY IN THE PORT IN ORDER OF IMPORTANCE BEGINNING WITH 1?

QUESTION # TM-6
WHO SHOULD BE IN CHARGE OF MOVING TRAFFIC THROUGH THE PORT?

QUESTION # TM-7
WHICH TOPOGRAPHICAL AREAS SHOULD BE EXAMINED TO IMPROVE TRAFFIC MANAGEMENT AND SAFETY IN THE PORT IN ORDER OF IMPORTANCE BEGINNING WITH 1?

QUESTION # TM-8
WHAT IS THE IMPACT OF FUTURE PORT DEVELOPMENT ON THESE AREAS.

VTS SURVEY QUESTIONS

==

QUESTION # TM-9

WHAT ARE THE DENSITIES AND COMPOSITION OF TRAFFIC IN THE PORT? SELECT VESSEL TYPE WITH HIGHEST VOLUME FOR CHOICE RESPONSE & DETAIL OTHER BELOW.

QUESTION # TM-10

WHAT ARE FUTURE TRENDS FOR TRAFFIC? SELECT VESSEL TYPE WITH HIGHEST VOLUME AND DETAIL OTHERS BELOW.

QUESTION # TM-11

WHAT TYPES OF MARINE CASUALTIES ARE MOST LIKELY TO OCCUR DUE TO TRAFFIC MANAGEMENT PROBLEMS?

QUESTION 3 TM-12

WHAT TYPE OF MARINE CASUALTIES WOULD HAVE THE MOST IMPACT ON PORT TRAFFIC AND OPERATIONS?

QUESTION # N-1

WHAT ARE THE MOST HAZARDOUS AREAS OF THE PORT (IN ORDER OF IMPORTANCE STARTING WITH 1) BECAUSE OF NAVIGATION ISSUES?

QUESTION # N-2

ARE THE FOLLOWING AIDS-TO-NAVIGATION ADEQUATE FOR THE PORT?

QUESTION # N-3

IDENTIFY SPECIFIC AREAS OF THE PORT WHERE SAFE NAVIGATION IS CRITICAL TO PREVENTING MARINE CASUALTIES. (NO MULTIPLE CHOICE: USE LONG ANSWER TEXT FIELD BELOW).

QUESTION # N-4

UNDER WHAT CONDITIONS WOULD THE PORT BE CLOSED TO TRAFFIC OR SERIOUSLY DELAYED DUE TO NAVIGATION FACTORS? (ENTER LONG TEXT BELOW).

QUESTION # N-5

HOW COULD THESE CONDITIONS BE IMPROVED? (ENTER LONG TEXT BELOW).

VTS SURVEY QUESTIONS

==

QUESTION # N-6

IN THE AREAS OF THE PORT HAVING THE LARGEST NAVIGATION RISKS WHAT ARE THE VESSEL POSITIONING REQUIREMENTS?

QUESTION # N-7

WHAT SPECIAL NAVIGATION REQUIREMENTS ARE NEEDED FOR OPERATIONS WITH DECREASED VISIBILITY?

QUESTION # N-8

ADDITIONAL FACTORS HAVING THE GREATEST IMPACT ON NAVIGATION WITHIN THE PORT IN ORDER OF IMPORTANCE (STARTING WITH 1).

QUESTION # F-1

IN TERMS OF MOST HAZARDOUS SITUATION IN THE PORT, DISCUSS:
\ - TRAFFIC MANAGEMENT IMPLICATIONS.
\ - POLITICAL, ECONOMIC AND ENVIRONMENTAL IMPACT.

QUESTION # F-2

DISCUSS SPECIFIC HAZARD AREAS AND CATALOG THEM BY DEGREE OF CONCERN AND REQUIREMENT FOR TRAFFIC MANAGEMENT.

QUESTION # F-3

DISCUSS WHAT, IF ANY TRAFFIC MANAGEMENT IS NEEDED IN THE PORT.

QUESTION # F-4

WHAT IS THE MOST NAVIGATION-SENSITIVE TRAFFIC MOVING IN THE PORT?

QUESTION # F-5

WHAT MARITIME TRAFFIC SITUATIONS IN THE PORT BOTHER YOU?

QUESTION # F-6

WHAT MARITIME TRAFFIC SITUATION IN THE PORT SHOULD BE OF CONCERN WITH RESPECT TO SAFETY, POLLUTION, TIMELINESS OF TRAFFIC MOVEMENT?

VTS SURVEY QUESTIONS

QUESTION # E-1

WHAT ARE THE MOST SENSITIVE ENVIRONMENTAL AREAS OF THE PORT COMPLEX?

QUESTION # E-2

DESCRIBE THE TYPE OF MARINE CASUALTY WHICH COULD LEAD TO SIGNIFICANT ENVIRONMENTAL INCIDENT IN THE PORT COMPLEX.

QUESTION # E-3

DESCRIBE THE MOST LIKELY MARINE CASUALTY FOR THIS PORT COMPLEX AND ITS IMPACT ON THE ENVIRONMENT.

QUESTION # E-4

WHAT CONDITIONS OF WEATHER, WIND, VISIBILITY, TIDE, ETC. WILL IMPACT AN ENVIRONMENTAL CASUALTY BE THE WORST?

QUESTION # E-5

WHAT FEATURES OF A VESSEL TRAFFIC MANAGEMENT SCHEME COULD RELIEVE, PREVENT, OR LESSEN THE PROBABILITY OF THE OCCUPANCE OF AN ENVIRONMENTALLY SENSITIVE MARINE CASUALTY?

SECTION 5.

VTS TECHNOLOGY SURVEY

Prepared For:

The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Prepared By:

NavCom Systems, Inc.
7203 Gateway Court, Bldg. 7251
Manassas, VA 22110
November 1990

5. VTS TECHNOLOGY SURVEY

NOTE: This section documents the NavCom Systems, Inc., survey of state-of-the-art VTS technology, performed in support of Section 7 of the Port Needs Study (Volume I), under Contract DTRS-57-88-C-00088 Technical Task Directive 13.

Table Of Contents

LIST OF FIGURES

APPENDICES

VESSEL TRAFFIC SERVICES (VTS) TECHNOLOGY SURVEY

1.0 INTRODUCTION

The purpose of Vessel Traffic Services is to monitor a harbor environment to insure compliance with established procedures and to advise vessels of potential dangers. This task is accomplished by watchstanders trained in the use of highly specialized equipment. The heart of the modern vessel traffic services system is the integrated display console. These consoles grew out of Automatic Radar Plotting Aid (ARPA) units and in many places ARPA type units are still being used. These units typically were built using special purpose software and hardware which is difficult to interface to modern bus organized systems and difficult to modify. These special purpose implementations are referred to as "closed architecture" designs. They usually require manufacturer support, especially when software or hardware changes are desired.

There are two methods of implementing Vessel Traffic Services classified by the type of surveillance being utilized, either independent or dependent. Independent surveillance employs sensors such as radar which require no cooperation from the vessel to obtain its position and velocity vector. Independent systems are implemented on several levels of complexity varying from a system with a single local radar sensor and a less complex display system to an extensive multisensor system using highly integrated flexible sectored displays with automatic monitoring functions. Dependent surveillance systems employ various techniques requiring vessel cooperation. This cooperation can vary from reporting the ships identity and location on voice radio to carrying special equipment that can be automatically interrogated from shore. Most existing VTS systems employ a combination of independent and dependent surveillance techniques.

This report first describes the major components of a modern VTS system and how they interact to provide the data necessary for control of a harbor environment. Each of these major components is then reviewed in terms of price, performance and availability. Finally, the manufacturers surveyed, contact personnel and pertinent company products are identified.

A summary of the Equipment Surveyed, Manufacturers, and Government Agencies contacted is contained in Appendices A, B, and C respectively. Appendix D represents a new concept for classifying VTS technology into "modules". These modules can then be utilized in preliminary VTS design efforts.

2.0 INDEPENDENT SURVEILLANCE

The elements of an independent surveillance VTS system shown in Fig 2-1 are: 1) unmanned remote sensor sites; 2) data transfer equipment; and 3) vessel traffic center incorporating integrated vessel traffic and communications consoles. Each of these components will be discussed as they relate to performing the VTS mission.

2.1 Unmanned Remote Sensor Sites

2.1.1. Remote Radar Site Configuration

The most common remote sensor used in a modern VTS system is shore based radar. The typical remote radar site is made up of a transmitter/receiver (T/R), an antenna/rotator unit, a radar/microwave interface and a microwave link. Ancillary equipment may include backup generators, voice/data telephone lines, fire fighting systems, remote maintenance monitoring and climate control equipment.

2.1.1.1 Radar Transmitter/Receiver (T/R)

A remote radar site usually is designed with two installed T/Rs. One T/R is designated as primary while the second serves as a backup. Most VTS radars are marine type units that operate either in X band (3cm) or S band (10 cm). The X band units are used for high definition applications. S band radar is used where rain clutter is a serious problem such as in tropical areas. In many installation both X and S band are used together to provide high definition and rain clutter reduction. If a radar antenna tower is required, the output power of the T/R unit must be carefully chosen. Waveguide power losses for a 100 foot tower can reach 75%. In cases where sea clutter is severe both frequency and polarity diversity are used. This technique provide improvement in clutter rejection and target detection. Other considerations in choosing a radar are operating frequency, power output, receiver noise, and remote control capability.

2.1.1.2 Radar Antenna/Rotator Unit

Antenna requirements are a complex mix of physical environment, target size to be tracked, range to be monitored, and bearing accuracy. Important antenna specifications are the horizontal and vertical beam widths and sidelobe/backlobe rejection characteristics. When choosing rotator units an important factor to remember is that the number of echoes from any single target should be sufficient for the processing software employed. In very high wind areas, radomes are used to provide protection for the antenna and rotator.

2.1.1.3 Ancillary Equipment

The major non-standard units that must be selected for a remote radar site include:

- Local radar control units. These devices allow for local control of a radar for maintenance purposes. They are generally accompanied by a Plan Position Indicator (PPI) unit.

- Radar communications interface. These devices encode the radar triggers, azimuth and synchronization data, then combine it with the raw video and modulate a microwave transmitter.

- Supervisory control interface. This device allows remote control of the radar units and in some cases provides remote maintenance monitoring data.

2.1.2 Other Remote Sensor Sites

The other types of remote sensing sites found in VTS systems include VHF/DF, meteorological and hydrological sensors, and Closed Circuit Television (CCTV) cameras. The VHF/DF and CCTV sites are normally used for vessel identification but occasionally CCTV technology is used to monitor traffic in a specific area where radar is not feasible. The various meteorological sensors monitor wind speed and direction, air temperature, visibility, and barometric pressure. Hydrologic sensors monitor water depth, current, and temperature.

2.2 Data Transfer Equipment

Current VTS systems transmit raw video data from remote radar and CCTV sites to the vessel traffic center over wideband microwave links. In some instances additional telephone lines are required for remote control.

2.3 Vessel Traffic Center (VTC)

A modern vessel traffic center employs one or more display consoles and communications consoles. The major sub-elements in the control console are: a) the graphics display, b) scan converter, c) target extractor/tracker, d) tactical display software, e) human interfaces, and f) recording equipment. The function of the various modules are:

2.3.1 Graphic Display

The graphic display in modern consoles are high-light level color displays. Most use 19" to 25" tubes with 1024 x 768 or 1280 x 1024 pixels on a non-interlaced, high definition raster. These displays with driver hardware are available from many manufacturers and cost between $3K and $10K.

2.3.2 Scan Converter

The function of the scan converter module is to convert the RHO-THETA display of a radar into X,Y coordinates appropriate for display on a high resolution graphics tube.

2.3.3 Target Extractor/Tracker

The target extractor/tracker module allows the console operator to either manually identify targets for automatic tracking and/or to set "guard zones" in which targets are automatically acquired and tracked. Most tracking algorithms generate a target identification and velocity vector as well as allowing operator entry of other target data to be displayed. The most difficult technical problem for these devices is the extraction or identification of targets in sea clutter. These extraction algorithms require calculation of average clutter levels of many azimuths because sea clutter is not usually omni-directional.

2.3.4 Tactical Display/Integration Software

This software performs the following functions:

- Site-to-site integration of all radar data
- Integration of all remote/local sensor data (data fusion)
- Sector-to-sector target handoff and display if more than one sector display is required
- Display graphics
- Processing/integrating wideband inputs (e.g. Radar, CCTV)
- Data base management
- Human interface management
- Act as Local Area Network file server
- External Input/Output
- Harbor monitoring and alarm strategies

2.3.5 Human Interfaces

There are many human interface devices on the market. Most VTC consoles contain one or a combination of:

- Track ball
- Keyboard
- Computer mouse
- Touch screen

2.3.6 Recording Equipment

A vessel traffic control center requires both video and audio recording equipment. These devices are used to record all voice communications and all operators visual displays. These recorders are used to analyze performance of the system and its operators and for playback in case of an accident. Modern time-lapse video cassette recorders and large capacity audio reel systems can be time-synchronized so that playback can provide both audio and video presentations in the exact time sequence they occurred.

3.0 DEPENDENT SURVEILLANCE IN VTS

3.1 General

Dependent surveillance is the process of obtaining position and/or other information from devices carried on board cooperative vehicles. A cooperative vehicle, or vessel in the case of VTS, is one which is carrying a specified device either by choice or by regulation. These devices can vary from radar transponders to more complex equipments able to furnish position, identification, and other desired data automatically when interrogated. The higher capability devices are normally comprised of a position sensor, a communications device and interfacing hardware and software. They are known as Automatic Dependent Surveillance (ADS) systems. Dependent surveillance is being proposed for VTS because it offers two potential advantages over existing radar based VTS systems. These are:

1) The ability to transfer of the major capital costs of VTS systems from the system operator to the system participants, and

2) the ability to extend surveillance to a much larger area than is currently possible if desired. The surveillance area is limited only by the position sensor and communications system capabilities.

The major disadvantages of dependent surveillance to a VTS system operator are:

1) All vessels of interest in the VTS zone and/or sub-zone must be cooperative and carry the surveillance device, and

2) The system is not fail safe. A failure of any part of the system is likely to result in an absence of information instead of an alarm. Such failures are not controllable by the VTS system operator.

3.2 Applicability to VTS

VTS systems are currently being designed and implemented in areas around ports called VTS zones. Within these zones there can be two types of vessels; 1) VTS participants and non-participants, and 2) cooperative and non-cooperative. These vessel types result in four possible vessel classes within a VTS zone. These are:

1. Participant/Cooperative. A vessel required to participate in the VTS system and carry a specified dependent surveillance device.

2. Participant/Non-cooperative. A vessel required to participate in the VTS system but not required to carry a specific dependent surveillance device.

3. Non-participant/Non-cooperative. A vessel neither required to participate in the VTS system nor carry a dependent surveillance device.

4. Non-participant/Cooperative. An unrealistic class of vessel since the carrying of a surveillance device by a vessel not required to participate in the VTS system is unlikely.

Only class 1, 2, and 3 vessels need to be addressed in any discussion of dependent surveillance within a VTS zone or sub-zone.

To implement a VTS system based only on dependent surveillance which meets the IMO recommendations, all vessels in the VTS zone over 20 meters must fall into the Participant/Cooperative class. This creates only two classes of vessels: 1) those over 20 meters are Class 1, Participant/Cooperative and, 2) all other small craft are considered Class 3, Non-participant/Non-cooperative. If a combination of independent and dependent systems is to be employed, each VTS zone must be analyzed to identify the ship interactions in each sub-zone. It must be determined if only one type of vessel, e.g., ocean-going ships, with ADS devices provides adequate surveillance. The amount of traffic is not a relevant factor; the interaction of ADS equipped and non-equipped vessels is of primary concern.

3.3 Areas of Interest within a Typical VTS Zone

3.3.1 Approaches and Outer Harbor Areas

These areas are generally less confined than inner harbor areas. They usually contain a portion of a traffic separation scheme, a precautionary area, and the harbor entrance channels. Most also contain at least one federal anchorage. The major concern in these areas is significant pollution occurring from incidents involving large ships or barges. Many of these incidents occur between large ships and local vessels that may not participate in the VTS system and from single vessel incidents caused by errors or mechanical failures. In the present VTS implementation in the U.S., there is no specific knowledge of, nor advisory service to vessels outside of the VTS zone other than the required 24 hour notice of arrival. In some harbors this knowledge can be used to manage the queue of vessels heading to the port by scheduling arrivals before they reach the VTS zone and by monitoring vessel performance in the traffic separation schemes. It is in these applications that dependent surveillance may have its greatest impact since one class of vessel is monitored over a large area with no severe penalty for data loss. In the outer area of any VTS zone the value of ADS systems is dependent on several questions. These are:

1. Are all larger ships entering the VTS zone equipped with a standard ADS device capable of being queried by the VTC or must some local type of ADS device be carried aboard by the harbor pilot? Normally there is a considerable distance between the VTS zone boundaries and the pilot boarding station.

2. Are there any federal anchorages in the outer harbor? These areas must be actively managed by the COTP. If the anchorage cannot be visually observed a fail safe independent surveillance system is required.

3. Are there large areas in the VTS zone where the classes of interacting vessels are limited, e.g. off-shore precautionary areas or traffic separation schemes? If there are large areas which would require extensive radar systems, ADS could be of use. The requirement for all vessels of interest to be equipped still exists.

3.3.2 Inner Harbors/Rivers

These areas normally exhibit a combination of all classes of vessels in waters that are usually "confined" for larger vessels. Port surveys show that the failure of local vessels to give way to larger, channel-confined vessels is the most consistently dangerous problem in these waters. For ADS to be effective all vessels must be ranked Class 1 (Cooperative/Participants). In the majority of harbors this means that all vessels above a minimum size or in a specialized service must be equipped with dependent surveillance devices. If these vessels travel between two or more VTS zones, this equipment needs to be standardized.

3.4 Implementation of Dependent Surveillance

3.4.1 Regulatory Impact

If an ADS system is to be effective, it is required that certain vessels carry the selected equipment when they are in the VTS zone and/or other areas of interest. Currently, vessels in international trade are required to carry radio communications equipment which complies with the requirements of the Global Maritime Distress and Safety Systems (GMDSS). The GMDSS carriage requirements are being implemented in stages with full implementation due by 1999. It is prudent to consider these requirements when formulating any ADS concept in order to minimize international problems and equipment carriage. One of the required capabilities under GMDSS is Digital Selective Calling (DSC) for all ships over 300 gross tons. This DSC capability is to be implemented in two ways: 1) ship to ship, short range to use VHF or MF and 2) long range either HF or satellite. Since this DSC capability provides the polling capability needed for dependent systems and since it is already an internationally recognized requirement, it should be included in any ADS design.

3.4.2 VTS Dependent Surveillance Hardware

The two types of devices that have been proposed for VTS systems are active radar transponders and position transponders.

3.4.2.1 Radar Transponders

This type of device is required on all commercial aircraft to enhance radar acquisition and to aid ground controllers in obtaining positive identification on all radar targets. At the present time there is no international or national standard for such a device on vessels. There are some experiments underway in Europe to examine the effectiveness of this type of device.

3.4.2.2 Position Transponders (ADS)

These devices are composed of a position sensor and a communications device. The positional accuracy of these devices is equivalent to that of the navigation system being used and the range is a function of the communications link utilized.

A. Position Sensors. The major navigation component systems proposed as position sensors for ADS applications are:

1) Loran-C. This system is currently the U.S. government furnished radionavigation system for the Coastal Confluence Zone of the United States. Its accuracy is 1/4 nm (2 drms) throughout this region. All VTS zones in the U.S. are covered by Loran-C. A Loran-C receiver costs between $500 and $1000.

2) Differential Loran-C. This system involves monitoring the Loran-C grid in the VTS zone and correcting for grid instability and bias errors. Since there are many types of Loran-C receivers on the market and the time difference to Latitude/Longitude conversion algorithms are not standard, this type of system only improves accuracy if Time Difference (TD) numbers are transmitted from cooperating vessels. Accuracy of 50 meters or better within typical VTS zones is achievable. If properly instrumented, correction information can also be transmitted to participating vessels to improve their navigation solution. This type of system must be implemented very carefully taking into account the differing receiver processing and the attendant liability involved in broadcasting corrections. Local area calibration of the Loran-C grid within the VTS zone followed by continuous monitoring of the

grid can achieve the same accuracy results. The differential loran addition need not increase cost unless position upgrade is to be furnished to the vessels.

3) GPS. The DOD GPS system will provide 100 meters (2 drms) worldwide to civil users in the 1990's after it has become operational and achieves the status of a government furnished radionavigation system for civil users.

4) Differential GPS. Same status as (3) above. Requires monitor stations every 200 to 400 miles and data update rates of several per minute to achieve the 5 to 10 meters advertised when selective availability is in use. Within a VTS zone only one monitor station is required. Costs increase if position upgrade information is also furnished to the vessel.

5) Radio Determination Satellite Systems. A number of commercial satellite communications services will soon be furnishing both communications and positioning service over the CONUS and Coastal Confluence Zone (CCZ) areas. The accuracy of this service is reported to be better than 50 meters.

B) Communications Systems. There are many communications systems capable of being utilized in an ADS system. These communications systems include cellular telephone, short range VHF band systems for use within one VTS zone and satellite systems capable of providing U.S. and worldwide coverage. Given coverage areas, data rate and other pertinent design information, communications systems can readily be selected for any ADS system concept.

3.5 Near Future Technology Applicable to ADS Use in VTS Systems

3.5.1 Radionavigation

The only new radionavigation system coming online in the next few years is GPS. This system will provide 100 meters (2 drms) worldwide for civil users. Differential techniques can be employed to achieve accuracies in the 5 to 10 meter (2 drms) range. Use of this system will enable vessels to be tracked over wider areas than is now possible. Using GPS in lieu of Loran-C as a position sensor in an ADS system does not decrease the present costs either to the VTS operator or participating vessels.

3.5.2 Communications

There are several wide area satellite based communications systems proposed for the near future. Of these several promise the capability of low power mobile communications which is applicable to VTS systems. Examples are:

o IRIDIUM -- A Motorola proposal to cover the globe with low altitude satellites (77 satellites in 11 polar orbit planes) which can communicate with each other, with ground telephone terminals, and with individual users. National and international frequency allocation problems will likely delay this system into the next century.

o American Mobile Satellite Consortium (AMSC) -- This consortium is made up of eight major companies. The purpose of AMSC is to provide nationwide mobile telephone service via satellite. Field testing will begin in late 1990 utilizing leased space on INMARSAT's satellites. A dedicated satellite is due for launch in the fourth quarter of 1993. This high power, spot beam satellite design is aimed at allowing simple mobile telephone communications nationwide with a minimum of frequency usage.

4.0 INDEPENDENT SURVEILLANCE TECHNOLOGY

4.1 New Developments

There are two new technical developments that are causing major changes in VTS design. These are remote scan conversion and remote target extraction and tracking. The impacts of these developments are as follows:

4.1.1 Remoting of Scan Converters and/or Target Extractors and Trackers

Remote operation of scan converters and/or target extractor/trackers eradicates the need for a wide band microwave link to send radar data to the VTC. There is a great deal of interest in implementing and operating these systems because it allows the use of inexpensive telephone lines. Most of the current hardware on the market require further proof-of-performance testing and are divided into two major subcategories:

a) Remote Target Extraction/Target Tracking. These devices extract radar targets from background clutter and send target information only to the VTC. The VTC watchstander is presented with target data only and cannot view the raw video data from which the targets are extracted.

b) Remote Scan Conversion and Target Extraction. In this implementation, scan conversion and target extraction are done in parallel at the remote radar site. The output of these two devices is then multiplexed and transmitted over a telephone line at relatively high baud rates, e.g., 9600 baud. The VTS watchstander is then presented with both radar video in X, Y format and delayed in time from 3 to 15 seconds, depending on the scan conversion techniques and real time target information used.

4.1.2 VTS System Architecture

In the past several years new "open" architecture systems have appeared on the market. These systems are built around a general purpose computer with a standard bus organization and utilize both a high order programming language and a widely used operating system. These consoles can be connected to the other elements in a VTS system via a Local Area Network (LAN). Wide band information that comes from radar and CCTV sensors should not be added to the LAN because these data could overload the bus and interfere with normal communications. This type of data should be handled by separate high capacity bus systems within the Integration unit. This will allow only the necessary processed data to be sent on the LAN bus. This implementation allows easy handling of input/output data over telephone lines and extensive expansion of both local and remote sensors. Modifications such as interfacing the United States Coast Guard standard terminal to the vessel traffic console or adding automatic dependent surveillance capability are not difficult to implement. This open architecture allows upgrades with available board level products. This type of design allows the entire VTS system to be implemented on a LAN with all the attendant flexibility and remote telephone modem access. Such a system is diagrammed in Figure 2-2.

4.2 Radar

4.2.1. Radar Transmitter/Receiver (T/R)

This survey of existing market indicates that no recent major technical advances in marine radar T/R's have occurred, most units available fall into the following classes:

a. X Band (3cm) 20kW to 250 kW
   Price Range: $10,000.00 to $200,000.00
b. S Band (10cm) 20 kW to 100 kW
   Price Range: $15,000.00 to $100,000.00

For VTS planning purposes a cost of $1000 per kW is a good estimate for the radar. The cost of the selected radar is driven by desired power output. A recent development in the German VTS System Radars is achieving improved sea clutter rejection by employed frequency and polarity diversity. The two installed T/R's operate simultaneously on frequencies about 200 mhz apart. The polarity of the transmissions is also switched between horizontal, vertical and circular. Signal processing hardware & software is employed to select the best clutter free graphic presentation. Improvements of 4db in signal clutter and 2db in target false alarm rate have been achieved. The signal processing and antenna required are significantly more costly than conventional installations. In general, costs of remote radar sites including buildings, towers, installation and other ancillary equipment usually dwarf the actual radar T/R purchase costs.

Manufacturers of radar transmitter/receivers surveyed included. Raytheon, Sperry, RACAL-Marine, Canadian-Marconi, Krupp-Atlas, Salesmar and Telefunken System Technik.

4.2.2 Radar Antennas/Turning Units

Unlike radar T/Rs there has been and continues to be extensive development work in radar antennas for shore based surveillance sites. The cost of these devices is an inverse exponential function of horizontal and vertical beam width and sidelobe/backlobe rejection characteristics. In general smaller beam widths mean a larger antenna and a more expensive turning unit. A new high performance linear array antenna with electronic polarization control is now operating at several European radar sites. Unlike the radar T/R, the antenna/turning unit selection can represent a sizeable portion of the cost of a remote radar site. Expensive antennas are needed where the following conditions exist:

a. Excellent bearing resolution is required.
b. Urban or congested areas cause false echoes due to reflections.
c. Heavy rains, severe sea clutter or other interference is a significant problem.
d. Radar data processing used requires exceptional antenna performance.

The price ranges of current antennas are as follows:

5′ to 12′ antennas:	\$5K to \$10K
18′ to 24 ′ antennas:	\$30K to \$60K
18′ and larger high performance antennas:	\$250K to \$1M
High performance co-located S/X antennas:	\$150K to \$350K

Manufacturers surveyed included: Raytheon, RACAL Marine, Sperry, Canadian Marconi, Krupp-Atlas, Salesmar, Telefunken System Technik, and Christiaan Huygens laboratorium B.V.

4.3 Very High Frequency-Direction Finder (VHF-DF) Sites

In large VTS systems a common remote sensor is VHF/DF. This equipment is used to obtain independent position information on a vessel when it is transmitting on voice radio. Each VHF/DF site gives one line-of-position. To obtain an unambiguous position fix on a vessel, two sites are required. In most instances, correlation of the radar return and the VHF/DF information provides positive identification of the vessel.

The price range of modern computer-based remote controllable direction finders varies from \$50K to \$100K. The major reason for cost variations is frequency range and antenna complexity. Increased antenna complexity is required where both UHF and VHF coverage is desired or when a wide antenna aperture is required. Wide aperture antennas are necessary to improve the bearing accuracy of the DF measurement. These costs are a minor part of a remote DF installation if it cannot be co-located with an existing facility. Modern units can operate with other computer-based systems such as vessel traffic center consoles and can be engineered to present their data on an integrated graphic display. The data and remote control signals can be sent over standard telephone lines. Manufacturers surveyed included: Servo Corp. of America and Rhode & Schwarz.

4.4 CCTV Sites

Many existing VTS systems implement CCTV sensors to monitor small areas where radar data is not sufficient. CCTV is the only surveillance technology in use that does not lend itself to modern data integration and the reduction of manpower by increased technology. Each CCTV site requires a separate monitor and the data presented must be viewed and interpreted by a watchstander.

Continuous technological progress is being made in the field of remote low light level CCTV hardware. The three notable areas are cameras, control hardware/software and video transmission.

o Cameras. Modern high quality, low light level cameras fall into two major categories: intensified and non-intensified. Intensified cameras are capable of producing functional pictures with a scene illumination in 0.001 lux range. Their prices vary from $10,000 to $15,000. Non-intensified cameras can produce pictures with scene illumination in the 0.01 lux range and range in price from $1,000 to $3,000. Modern cameras have a full range of remote control capabilities including focus, iris , and zoom.

o Control Hardware/software. Microprocessor-based camera control systems are available that provide and extremely wide range of semi-automatic control. These systems are able to control over 100 camera sites, cycle selected cameras through a programmable sequence of preset scenes with pre-selected dwell times as well as to independently control all remote camera functions. Images are routed to pre-selected monitors. These systems provide complete programmable surveillance image sequences to a VTC. These units cost between $10,000 and $20,000, depending on the capabilities desired.

o Video Transmission. The options for transmitting video images are increasing rapidly. At the present time only three major options will be considered. These are microwave, fiber optics and video compression for transmission over telephone lines. Microwave systems for transmission of wideband, real time video images cost about $1,000 for a one hop installation. Fiber optic lines can be used to transmit wideband video for distances of up to three miles. Distances of six miles can be achieved with the addition of in-line amplifiers. A three mile run of fiber optic cable costs approximately $30,000 installed. A six mile run with amplifiers costs approximately $65,000 installed. Various video compression devices are coming on the market. They are capable of sending a delayed "snapshot" of a video image over ordinary telephone lines. Current prices range from $6,000 to $40,000 depending on time delay and picture quality desired.

5.0 ADS TECHNOLOGY

5.1 General

A survey of applicable equipment quickly shows that a large number of acceptable sensor and transmissions systems combinations are on the market. Off-the-shelf systems are reviewed to provide data on the current range of costs and performance and a discussion of expected trends is included.

5.2 Off-the-Shelf Vehicle Tracking Systems

The following list represents a cross-section of the vehicle tracking systems available today. The position reference for all of them is currently Loran-C or Radio Determination Satellite Systems (RDSS). In the future they may be upgraded to GPS.

5.2.1 GEOSTAR/Loran-C

GEOSTAR is a satellite based communications network which presently provides coverage of CONUS, the Caribbean and Alaska. The company sells a GEOSTAR communications terminal which includes an integrated Loran-C receiver, keyboard display unit, antenna, external sensor input capability and backup power. Use of this terminal allows vehicle tracking and data communications. The vehicle data is sent at pre-determined, programmable intervals to a GEOSTAR central station in Washington, D.C. and in Denver, CO). A fleet manager must purchase a base station that communicates with the GEOSTAR Central Station to extract data on the vehicles of interest. Data can also be sent to selected vehicles. When fully implemented this system will also provide an RDSS capable of providing positioning information of 50 meters or better independent of any other radionavigation system. The system costs are as follows:

A) Vehicle Costs:	
GEOSTAR Terminal	$3,000
GEOSTAR Basic Monthly Charge/Terminal (including 900 msg.)	45
Additional message charges, each	00.035
B) Fleet Management Costs:	
Base Station (each)	$8,000
Comms link to GEOSTAR $1.00/mi/month (1500 miles + backup)	20,000

The output of this system must be integrated into the existing VTS data and display. This task is variable depending on the VTC equipment in use. GEOSTAR currently tracks about 4000 vehicles on a daily basis and has near term expansion potential to over 20,000.

5.2.2 Omnitracs

This satellite based KU band communications system is owned and operated by Qualcomm Inc., San Diego, CA. It is operating throughout the United States, Canada, Western Europe and Japan. In the United States position information of tracked vehicles is based on a Loran-C sensor and/or an RDSS capability referred to as QASPR (Qualcomm Automatic Satellite Position Reporting). Currently over 10,000 vehicles are tracked in the U.S. The QASPR position accuracy is 1000 feet. The system is capable of two way data communications between mobile vehicles and the Qualcomm Computer in San Diego. A fleet manager must purchase Qualcomm software that runs on an IBM Personal Computer. This software communicates with the Qualcomm central computer to transmit or receive data from its vehicles. System costs are as follows:

A) Vehicle Costs:	
Mobile Terminal	$4,500
Monthly Service Charge (including 1 position/unit/hr.	35
Additional Messages	0.05/msg
B) Management Costs:	
Omni Tracs "Premise" Software	$3,000
IBM PS-2, Pro-printer & Modem	6,000
Telephone Connection Costs $1.00/mi/month (1,500 miles + backup)	20,000

5.2.3 Coverage Plus

Coverage Plus is a vehicle tracking and communications system from Motorola Inc. This two-way voice/data/position system is based on Motorola's "Privacy Plus" Trunked Specialized Mobile Radio (SMR) Systems. The 500+ SMR sites operating in the 800 MHZ band have been linked together using a packet data network to provide a nationwide real time voice data communications path among vehicle dispatchers, the Motorola hub in Chicago and SMR sites. The dispatcher terminal is a personal computer that is not linked to a mainframe computer but offers a stand alone capability linked to the Coverage Plus network. In addition to data and voice communication, vehicle location is offered in two levels. At the first level the vehicle zone location or SMR in use is furnished. For more precise location, a Loran-C vehicle option is available. Facsimile and on-board computation is now being added. This system, as presently operating, is impractical for application to VTS zones. It is unnecessary to send data to a central computer in Chicago if a VHF system is being used in a VTS zone. If, however, VTS becomes a coastwide system, this technology could be considered. For VTS application the vehicle portion of this system is tied to a local VHF facility capable of covering the entire VTS zone. System costs are:

A) Vehicle Costs

Vehicle terminal and Loran-C	$3,700
Basic monthly service charge including 600 locations/month	35
MSG charge $0.05/240 char test msg + $0.50/min $0.05/location	

B) Management Equipment Costs:

Base Station--VHF transmitting & receiving equipment & an interface capable of extracting digital location & identification information	20,000

5.2.4 "Load-Track" System

This tracking system sold by Pegasus Message Corp., Herndon, Virginia is based on Loran-C sensors and VHF meteor burst data communications system. The mobile unit consists of a VHF radio with an RF transmit power over 200 watts, a VHF receiver, a Loran-C receiver and a microprocessor controller. The dispatcher terminal is a PC based system connected to the Pegasus Network Control Center (NCC) in Virginia. The NCC communicates directly with systems master transmitting stations using dedicated satellite links. Currently most of the Eastern half of CONUS is covered by this service with nationwide coverage planned by the end of 1991. Meteor burst communications is not "continuous" and depends on the reflection of short messages off meteor trails. This can create delays in sending or receiving messages. These delays are typically 5 to 10 minutes but can occasionally reach one hour. In VTS use this delay is not acceptable in confined waters with no back up communications system. Costs for this system are:

A) Vehicle Costs:

Vehicle Terminal	$2,000
Monthly access (24msg/day)	35
Add msg fees	0.05 msg

B) Terminal Costs:

Base station costs vary depending on volume of traffic. It can be PC/based up to main frame	3,000-5,000

5.2.5 METS, Inc.

The METS vehicle tracking system is made up of a computer based vehicle unit called a Tracker and a Central Station Management Computer. These units are independent of communications technology and can operate with UHF/VHF, cellular telephone, satellite, etc. The tracker module contains a Loran-C receiver and dead reckoning capability for position information. It can also calculate and transmit a large amount of vehicle data as well as accept other manual or automatic data inputs. Several communications technologies can be managed. It is designed for board level upgrade. The tracker unit can be individually configured to provide the capability desired. The Central Station Computer provides both map graphics and data readout. The map output is based on layered digital mapping which consists of a Geographic Information System and an interactive data base. The system is capable of accepting GPS information when it is available. METS currently is installing and/or testing vehicle tracking systems in Baltimore, Seattle, and Los Angeles. System costs are:

A) Vehicle Costs

Mobile Terminal	$2,500
Monthly Charge (Cellular phone)	45
Data Message Cost (cell. phone) $0.10/data msg.	

B) Management Costs

Base Terminal--capable of communicating with vehicles & furnishing digital data representing position and ID	$10,000
Monthly Charge (Cellular phone)	45

5.2.6 VTRAC Vehicle Tracking System

VTRAC is a vehicle tracking system built by Trimble Navigation. The system is composed of a vehicle unit and a base terminal and can work with any communications system using either Loran-C, GPS or differential GPS as a location sensor. The VTRAC base workstation is GP computer based and can be configured with digital maps, display vehicle position and other data, calculate range and bearing between vessels and provide interactive graphics capability. The vehicle unit can also receive differential GPS corrections and display corrected positions. Trimble does not as yet have a commercial tracking system in operation.

A) Vehicle Costs

Mobile Terminal & modem (Loran-C/GPS)	$2,700
Maintenance Contract	500
VHF Radio	500
Installation	500

B) VTC Costs

Base Terminal	5,000
Maintenance	500

5.2.7 II Morrow Vehicle Tracking System

The II Morrow vehicle tracking system is a Loran-C based system which monitors the location and movement of a fleet of vehicles from a command center. The system is used primarily with VHF/UHF radio but can be used with any communications system. This system is designed for polling of vehicles from the base station. Vehicles respond with a transmission giving Loran-C location and ID. The control console provides digital maps, map selection, vehicle tracks and location on maps and vehicle data analyses. The vehicle unit can also be furnished as a portable battery operated unit for harbor pilots to carry onboard ships. II Morrow currently has sold systems that track 1400 vehicles owned by 40 different clients.

A) Vehicle Costs

Vehicle Terminal - Loran-C	$1,260
Installation	250
Maintenance Contract	250
UHF/VHF Radio	500

B) Fleet Terminal

Base Station - capable of communicating with vehicles & furnishing digital data representing position & ID	$3,000

5.3 ADS System Costs

5.3.1 General

Certain assumptions must be made to estimate VTS system costs. These are:

1. All of the Vessel Traffic Center (VTC) data integration, manipulation and display capability, including a data base management system, remains the same as for an active system. The same VTC consoles and communications consoles are required.

2. Recurring manpower costs are identical to active surveillance type systems since they are based upon VTC workload not on the data collection system.

3. The same ADS devices will function in all VTS zones in the United States.

4. A fleet of 500 vessels will be equipped for each VTS zone. This number is based on all vessels over 20 meters being required to participate in the VTS.

5. The average underway time in a VTS zone for the 500 vessels is chosen as 10%. The following examples support this choice:

a. The Alaskan pipeline (TAPS) tankers - twelve day turnaround with approximately 1.5 days in VTS zones (13%)

b. "TOTE" ships that transit from Tacoma, Washington to Cook Inlet, Alaska - seven day round-trip cruise with approximately one day in VTS zones (14%)

c. Puget Sound salmon fishing boats - 60% at the dock; 30% in Alaska; 10% in Puget Sound VTS zone

d. Tugs/barges in major ports - underway approximately 80-90% of the time. Estimated moving barges in VTS zones one-quarter of that time (20%)

e. Ferries - underway in VTS zones approximately 80% of the time

g. Boston fishing vessels - underway 50% of the year; one-half of that time in VTS zones (25%)

h. A container ship between New York and Rotterdam -- spends approximately twelve hours every ten days underway in a VTS zone (5%)

i. Recreational boats over 20 meters -- underway in a VTS zone approximately 1% of the time

6. The vessel position update rate within the VTS zone will be 10 seconds. This figure is based on the safety of navigation requirement for large ships and tows in a harbor environment from the Federal Radionavigation Plan.

7. The average number of messages required to be sent by a vessel in a year is then 6 msg/min x 60 min/hr x 24 hr/day x 365 day/yr x .1 (% in zone) =
315,360 messages/year

8. The ADS system has a ten year life cycle.

9. Cost of ADS vessel terminals and monthly charges will be paid by vessel owners.

10. Base stations and related communications costs will be paid by the government.

5.3.2 Existing Vehicle Tracking System Costs in an ADS/VTS System

5.3.2.1 GEOSTAR

VTC COSTS		
Non-recurring		
2 Base Terminals		$ 16,000
Installation		1,000
Integration w/VTC console		25,000
	TOTAL:	$ 42,000
Recurring		
Comms link to GEOSTAR		20,000
Maintenance contract		10,000
	TOTAL:	$ 30,000
VESSEL COSTS		
Non-recurring		
2 Terminals		$ 6,000
Installation		1,000
	TOTAL:	$ 7,000
Recurring		
Maintenance Contract		$ 500
Monthly Charges @ $45/unit		1,080
Message Charges @ $0.035/message		11,038
	TOTAL:	$ 12,618

5.3.2.2 OMNITRACS

VTC COSTS		
Non-recurring		
2 Base Terminals		$ 18,000
Installation		2,000
Integration w. VTC consoles		25,000
	TOTAL:	$ 45,000
Recurring		
Comms link to Qualcom, Inc.-- $1.00/mi/month + backup (1,500 miles)		$ 20,000
Maintenance		1,000
	TOTAL:	$ 21,000
VESSEL COSTS		
Non-recurring		
2 Terminals		$ 9,000
Installation		250
	TOTAL:	$ 9,250
Recurring		
Maintenance		$ 500
Monthly Charges @ $35/terminal		840
Additional Messages $0.35/message		11,038
	TOTAL:	$ 12,378

5.3.2.3 COVERAGE PLUS

VTC COSTS

Non-recurring		
2 Base Terminals/VHF facility		$20,000
Installation		5,000
Integration w. VTC consoles		$25,000
	TOTAL:	$50,000
Recurring		$ 2,000
Maintenance		

VESSEL COSTS

Non-recurring		
2 Terminals		$ 7,400
Installation		250
	TOTAL:	$ 7,650
Recurring		
Maintenance		$ 500

5.3.2.4 METS, Inc.

Since this system is independent of the communications system used, it was examined with both a cellular phone system and a VHF system.

A. Utilizing cellular telephone communications

VTC COSTS

Non-recurring		
2 Base Terminals		$20,000
Installation		2,000
Integration w. VTC consoles		25,000
	TOTAL:	$47,000
Recurring		
Maintenance		$ 500
Cellular Phones--4 ea. @ $45/month		2,160
	TOTAL:	$ 2,660

VESSEL COSTS

Non-recurring		
2 "TRACKER" Vehicle Computer Units		$ 5,000
Installation		500
	TOTAL:	$ 5,500
Recurring		
Maintenance		$ 500
Monthly Charges (cellular phones)		
2 @ $45/month		540
Message Charges @ $0.10/data message		31,536
	TOTAL:	$32,576

B. Utilizing VHF communications system

VTC COSTS

Non-recurring

2 Base Terminals		$20,000
Installation		2,000
Integration		25,000
Comms console modification + 1 add'l. VHF radio in ea.sector		25,000
	TOTAL:	$72,000

Recurring

Maintenance of additional comms/per year		$ 1,000
	TOTAL:	$ 1,000

VESSEL COSTS

Non-recurring

Terminal (Loran-C, VHF, Interface--2 ea.)		$ 4,000
Installation		250
	TOTAL:	$ 4,250

Recurring

Maintenance		$ 500
	TOTAL:	$ 500

5.3.2.5 TRIMBLE VTRAC

VTC COSTS

Non-recurring

2 Base Terminals		$10,000
Installation		1,000
Integration w. VTC console		25,000
Comms console modification + 1 add'l. VHF radio in ea.sector		25,000
	TOTAL:	$61,000

Recurring

Maintenance of additional comms/per year		$ 1,000
	TOTAL:	$ 1,000

VESSEL COSTS

Non-recurring

2 Terminals		5,400
Installation		500
2 VHF Radios		1,000
	TOTAL:	$ 6,900

Recurring

Maintenance		$ 500
	TOTAL:	$ 500

5.3.2.6 II MORROW Vehicle Tracking System with VHF Communications

VTS COSTS		
Non-recurring		
2 Base Terminals		$ 6,000
Installation		2,000
Integration		25,000
Comms console mods, + 1 additional radio in each sector		25,000
	TOTAL:	$58,000
Recurring		
Maintenance on additional comms		$ 1,000
	TOTAL:	$ 1,000
VESSEL COSTS		
Non-recurring		
2 Terminals		$ 2,520
Installation		250
2 VHF radio		1,000
	TOTAL:	$ 3,770
Recurring		
Maintenance contract		$ 250
	TOTAL:	$ 250

5.3.2.7 Costs Summary

Table 3-1 shows that:

o when applied across the spectrum of vessels in a VTS zone, ADS becomes prohibitively expensive to users if message charges are assigned to them;

o if the government assumes these message charges the cost of an ADS system can rapidly exceed a radar based system;

o the recurring and non-recurring cost of a vessel traffic center is virtually identical with either type of surveillance since the manpower levels are the same and the console hardware and software is identical;

o the most viable ADS stand alone system for a VTS zone is one without message charges, e.g., a local area VHF based system. This result is in compliance with the international requirement for digital selective calling on ships and also allows simple portable or "carry on" devices.

6.0 VESSEL TRAFFIC CENTER TECHNOLOGY

The heart of a modern VTS is the vessel traffic center (VTC). It is in this center that all available information is collected and displayed. Decisions made utilizing this information are then disseminated over communication networks. The vessel traffic center is also the communications control center. The major components of a vessel traffic center are the VTS operations console, the supervisory control and date acquisition system, and the communications console.

6.1 VTC Operations Console

Modern operations consoles present an integrated display of all information gathered by remote and local sensors. There are many integrated consoles on the market today. These units vary from modified ARPA units to computer based special purpose systems designed for the VTS application. Prices on these consoles vary from $100K to $400K depending on the level of integration and features furnished. Following is a sampling of the most current consoles available.

6.1.1 Raytheon Marine Co.

Pathfinder/ST, ARPA 34, VTS Console Display is an ARPA-based console that processes information from only one radar at a time. This console has a high-light level, raster scan, green display. The design of this console is based on a special purpose closed architecture system. It is capable of automatic acquisition and tracking of up to forty targets. Target velocity, track history, and other pertinent data are provided. Navigation lines and automatic acquisition guard zones may be programmed by the VTS watchstander. Off-centering capability of up to 70% is provided. Human interface is by tracker ball. This unit will be installed in New York VTS in the summer of 1990.

6.1.2 Canadian Marconi

Raster Scan Display CMR-809 is a high-light level, color, raster scan display. It provides all of the features of an ARPA unit except automatic target acquisition and tracking. This unit has a "grease pencil" tracker that will calculate course and speed as long as the operator marks the target at regular intervals. Map overlay capability is programmed into the graphics package. A zoom capability of 8-to-1 is combined with center offset capability. An open architecture 16-bit VME bus is used in this design. The display can handle only the input from one radar at a time. Human interface is by keyboard and tracker ball. The latest unit is installed in the VTC at Placentia Bay, Newfoundland.

6.1.3 Norcontrol

VTS Operators Workstation VOC 90 is a high-light level, raster scan, color display. The design is semi-closed architecture consisting of a special purpose computer system entered with LAN and RS-232 Interfaces furnished. The display graphics software provides a synthetic map display with color landfill capability. This console is a high level, operator interactive integrated system capable of processing data from several radars and geographically sectoring data with hand-off to other consoles. Complete off-centering and zoom capability exists. Automatic acquisition and track is provided along with the ability to enter vessel data for each target tracked. Vessel velocity vectors and tracking history may be displayed. The software includes the ability to maintain a complete vessel data base, extensive programmable alarm capability on each target tracked and also provides many harbor monitoring functions. Human interface includes keyboard, an extensive set of special function keys and a tracker ball. The unit is installed in Quebec City, Quebec, Canada.

6.1.4 Krupp-Atlas Electronic

Atlas MITC-9000 VTS Console is a high-light level, raster scan, color display. The display graphics software provides a full synthetic map capability with color landfill including displays of all harbor berths. This console is an open architecture bus organized design based on Hewlett-Packard general purpose computers running on the UNIX operating system and programmed in the C-language. This design is fully LAN compatible. A standardized building block implementation is provided which allows desired functions and capabilities to be added as needed. This console is a high-level operator-interactive integrated design, capable of processing data from several radars and other sensors, geographically sectoring the data and managing hand-off to other consoles. Automatic acquisition and tracking of targets along with extensive off-centering and zoom capabilities are incorporated. Vessel velocity vector and track history can be shown. It has the ability to maintain a complete vessel data base, extensive programmable alarm capability on each target tracked and also provides many harbor monitoring functions. Human interface includes a keyboard and tracker ball. This unit is installed in Melbourne, Australia.

6.1.5 Radar Digital Systems

Vessel Traffic Data Management System VTMS-87 and VTMS-91 are a high-light level, raster scan, color displays. The display graphics software provides a full synthetic map capability with color landfill. This console is an open architecture VME bus organized design capable of operating on an LAN. This is a high-level operator interactive console capable of integrating data from several radars, geographically sectoring data, and managing target hand-off between sectors. Automatic target acquisition and tracking are provided. Target velocity vectors and track history are available. The unit is offset and zoom capable and a large amount of target data plus extensive alarm capability is provided for all tracked targets. Harbor monitor functions and an extensive ship data base system are incorporated. This system has been offered for consideration against the recent Shanghai VTS bid requests.

6.1.6 Sperry Marine

Vessel Traffic System Console is a high-light level, raster scan, color display. The console is an open architecture general purpose computer (386) based, token-ring organized system. The console is a high-level operator interactive display system with synthetic map overlays and color landfill capability. The integrated data software system is capable of handling multiple radar and other sensor inputs. It provides geographical sectoring and target data hand-off between sectors. Automatic target acquisition and tracking is provided along with complete target data including velocity vectors and track history. Harbor surveillance and target alarm features are also included. Full offset and zoom functions are provided for the operator. An interactive ship data management system is furnished. This system is designed around a remote data unit (RDU) that automatically acquires and tracks up to 200 targets. These target tracks are then sent to the vessel traffic console via a narrow band link. Raw radar video is not normally sent to the vessel traffic center. Human interface for this console includes a touch screen system and a keyboard. This unit is installed in Milford Haven, Wales, U.K.

6.1.7 Hughes Aircraft Co.

AMD-44 is a high light level, raster scan color display. The display graphics software provides full synthetic map capability. The console is an open architecture bus organized design based on the 68,000 family of micro processors. The design incorporates a LAN for the distribution of integrated data and special circuitry for processing radar video from up to 16 radars. The graphics package includes proprietary graphics hardware and software driving the largest display tube on the market, a Sony 20" X 20" color tube. The console is a high level operator-interactive design producing a fully integrated multi-sensor display. The software is fully capable of sectoring data and managing sector hand off. Hughes also provides a high level remote target extractor/tracker and provides tracked target information to the vessel traffic center console over telephone lines. This extractor/tracker can also be implemented locally in the vessel traffic center if raw video transmission is desired. Complete database management and on screen target data are also provided. Provision has been made for the incorporation of TV video insert screens on the VTS display. Harbor management, surveillance, and alarm functions are available. Human interface is by keyboard and a tracker ball. The system is not currently installed in an operating VTS, but has been bid against the Shanghai Harbor specification.

6.1.8 Telefunken System Technik

This is a high light level, raster scan, color display. The display graphics software is capable of full synthetic map display with color landfill. The console is an open architecture design based on the 68,000 series microprocessor. The design incorporates a high-capacity bus for video data and a LAN bus for data distribution. The major building blocks are the target extraction/tracking modules (operable either locally or remotely), a main data processor that integrates all radar and other sensor data and a ship data management system containing a complete data base. Displays available include raw and/or processed video, a traffic extrapolation way-time graph and a data screen. This is a high level operator interactive system capable of integrating data from up to 16 radars, geographically sectoring data, and managing target hand-off between consoles or vessel traffic centers. Target data including track history, Identification and velocity vectors are provided. Harbor surveillance functions can be easily programmed for a complete set of alarms. This console system is installed in Wilhelmshaven, Germany and will soon be installed throughout the Elbe River system. By 1991 all of the German North Sea coastline will employ Telefunken System Technik equipment.

6.2 Supervisory Control and Data Acquisition (SCADA)

These equipments provide remote control of radar and other sensors and also provide remote maintenance and security monitoring for all system components. Data can be sent by all transmission media. Judicious use of this system can reduce manpower and increase maintenance effectiveness. The cost of these systems is highly dependent on the amount of data being monitored and the transmission medium used. Suppliers surveyed include Bristol Babcock and Motorola.

6.3 Communications Console

Modern vessel traffic control centers need an extensive UHF-VHF radio communications network. This network must be very flexible and frequency selection and remote station selection. The ability to guard selected frequencies, transmit on any channel at any location in the system and monitor radio performance constitutes half of the function of existing VTS systems. Modern centralized equipment is available off the shelf to provide all of the local and remote communications flexibility necessary for a VTS center. These systems can be easily implemented in a variety of levels based on system need. Prices for the central control console and electronics vary from $50K to $100K for a 1 to 2 operator system and from $150K to $200K for a more complex 3 to 4 operator VTS control center.

6.4 Additional Vessel Traffic Center Features

6.4.1 Remote Target Extraction/Tracking

These devices are now being sold by Sperry Marine, Hughes, Norcontrol and Telefunken. They only provide tracked targets and target information from a radar site. These devices cost approximately $100,000 and their features are as follows:

A. Sperry Marine's Radar Data Unit (RDU). This device operates at a remote radar site and furnishes tracked target data including location, identifier code, course, and speed to the control center console. This device masks land returns, integrates all other returns over a portion of the radar beam width, sets a threshold for background noise, and sends all targets above this threshold to a scan-to-scan integrator. Target shape is measured and a centroid is determined. This centroid is used as a target location. All targets are assigned identity codes and put in the automatic track mode. This target data can then be sent over a 9600 baud telephone line. Raw video data is not provided to the control center console by this system.

B. Hughes Radar Video processor. This device extracts and tracks up to 1000 targets at the remote radar site. The extractor/tracker is based on technology developed for DOD systems by Hughes. Target tracks are transmitted over land lines. One second is required per image over a 56kbit/sec digital phone network. With a 9.6kbit/sec modem a image takes 6 seconds to transmit. This device performs threshold detection, scan-to-scan correlation, target track generation and target shape calculation. When this system is used raw video is not sent to the control center.

C. Norcontrol Model RE-90 Remote Extractor. This device is based on the tested extractor/tracker technology employed in Norcontrol's vessel traffic center consoles. It provides extracted plots, target tracks and the results from buoy or other fixed object surveillance. This data is capable of being transmitted over one or more narrow band links. The RE-90 can provide 200 simultaneous tracks and data on 200 fixed or monitored objects. If this device is used at a remote radar site, target track data can be sent to the control center over a standard telephone line. Raw video data is not sent to the control center.

D. Telefunken System Technik - The ship target processor (STP) and Target Tracking Processor (TTP) modules manufactured by Telefunken are capable of remote operation. The STP is a target extractor with a video mask adjustable to areas of interest (guard zones), scan to scan correlation, and an adaptive area clutter threshold. Target extraction is accomplished with signal processing including a multi-level sliding window detector, a signal maximum detector and a signal quality evaluator. The TTD is an automatic tracker that contains adaptive parameters to account for target size and maneuvers. It also has the ability to predict tracks in cases of lost radar return and to resolve merged targets. Each TTR unit can track up to 200 tracks of which 100 can be labelled.

6.4.2 Remote Scan Conversion

There is only one device of this type on the market. This device is called a Teledisco and is manufactured by INA, a Dutch subsidiary of Racal Marine. The system is made up of a receiver and a transmitter that can be interfaced to most modern marine radars. The transmitter does signal processing, digitizing, masking, compression, and transmission of radar data. The receiver interfaces this compressed data to a standard color monitor. The system can operate over narrow band links or telephone lines. It adapts automatically to line quality. The same link or telephone line is used for remote radar control. This capability is currently being sold by Racal Marine. The price is approximately $20,000.

6.4.3 Remote Scan Conversion in Parallel with Remote Target Extraction/tracking

These devices are currently being sold by Radar Digital Systems and Krupp-Atlas. These units cost from $100K to $200K. Their features are as follows:

A. Radar Digital Systems Model VTMS-91 Remote Display and Control System. This device is the heart of Radar Digital's vessel traffic center console. Its open architecture design allows the scan conversion and target extractor/tracker functions to be operated remotely at the radar site with the addition of signal processing and interface cards. When operating remotely, this device provides the complete radar surveillance image including actively tracked targets and target data. Radar images are compressed and transmitted over telephone lines. The scan converted video is delayed less than ten seconds and the target track data is provided in real time. At the control site the radar surveillance images are re-created and graphic overlays are added. Remote control of the radar system can also be accomplished.

B. Krupp-Atlas Radar Processing Cabinet. This system allows remote operation of some of the functions normally provided in the vessel traffic center console. These functions are scan conversion, target extraction/tracking, and a radar land blanker map capability. Up to four independent, operator definable video extraction windows (scan converters) are available. These windows are adjustable in size and location. Automatic target extraction/tracking can provide up to 500 tracked targets per radar head. This system can be configured to present a choice of three levels of data to the control center console. These are:

- Tracks and radar control data requiring 2400 to 19,200 baud
- Video, tracks and radar control data (four video channels in real time) requiring from 384kbits/sec to 2mbits/sec
- Radar plots (returns) only requiring 4800 to 38,400 baud

All of the link requirements can be reduced if real time data is not required. This system allows complete remote radar control including calibration in range and bearing. The watchstander using this system has the option of looking at real time video and/or target plots. This device is designated to work with the Krupp console.

CURRENT VTS SYSTEM ARCHITECTURE

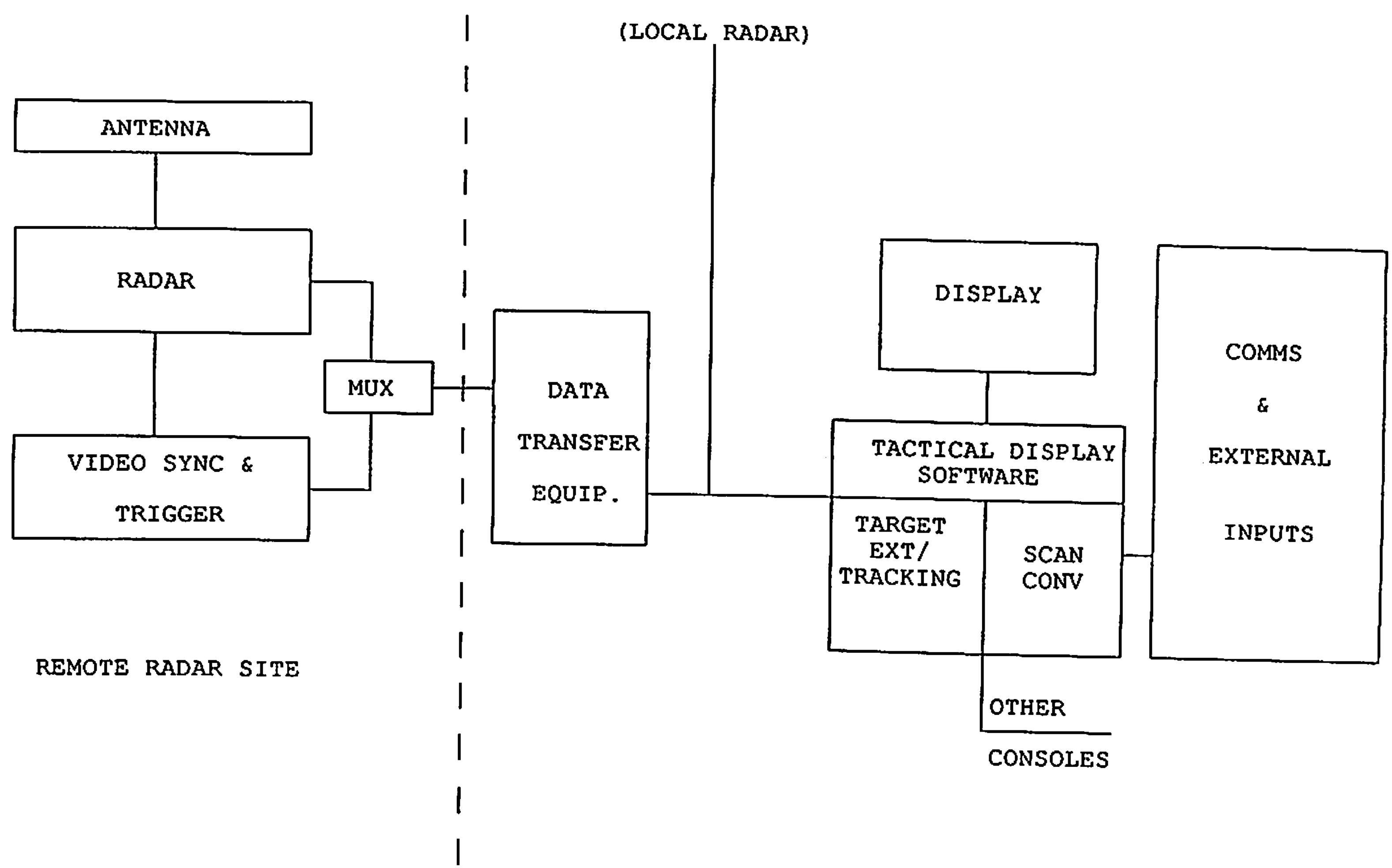


FIGURE 2-1

NEW VTS SYSTEM ARCHITECTURE

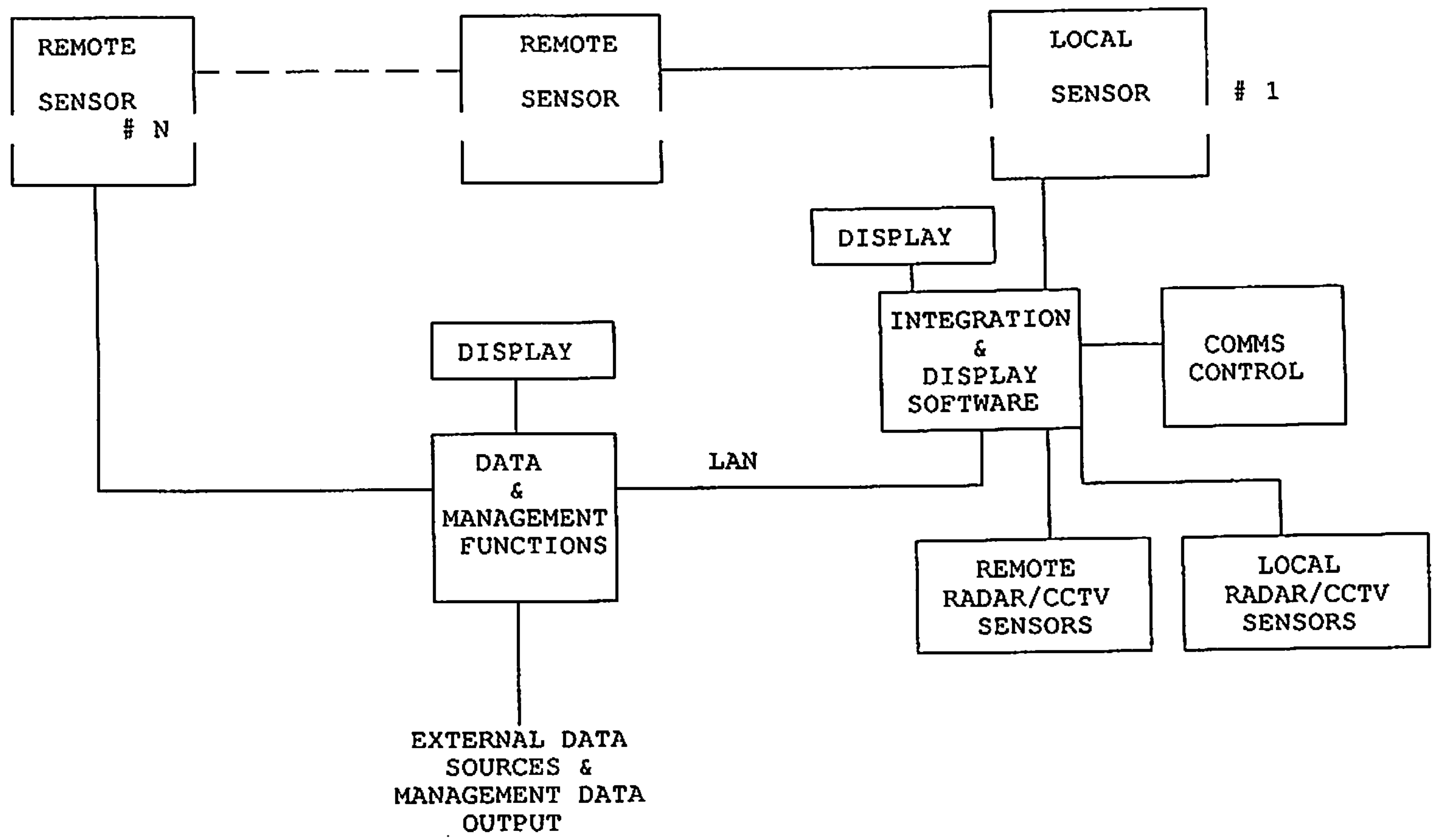


FIGURE 2-2

VTS SURVEILLANCE HARDWARE COSTS
FIG 3-1

PERFORMANCE COSTS							
SYSTEMS	VTC COSTS (1)		VESSEL COSTS				LIFE CYCLE SYSTEM HARDWARE COSTS FOR SURVEILLANCE SENSORS A+B+D+F
			NON - RECURRING		RECURRING		
	NON RECURRING	RECURRING (10 YRS)	PER VESSEL	500 VESSELS	PER VESSEL/YR	500 VESSELS 10 YEARS	
GEOSTAR	42,000	300,000	7000	3,500,000	12,600	63,000,000	$66,842,000
COVERAGE PLUS	50,000	20,000	7,650	3,800,000	500	2,500,000	$6,370,000
METS (CELLUAR PHONE)	47,000	26,600	5,500	2,750,000	32,500	62,500,000	$65,323,600
METS (VHF)	72,000	10,000	4,250	2,125,000	500	2,500,000	$4,707,000
OMNITRACS	45,000	300,000	9,250	4,625,000	12,400	62,000,000	$66,970,000
VTRAC (VHF)	61,000	10,000	6,900	3,450,000	500	2,500,000	$6,021,000
II MORROW (VHF)	58,000	10,000	3,770	1,885,000	250	1,250,000	$3,203,000
	A	B	C	D	E	F	A + B + D + F

"LOAD TRACK" N/A TO VTS

NOTE (1) - DOES NOT INCLUDE HARDWARE COMMON TO ALL SYSTEMS I.E. VTC CONSOLES, VHF COMM SYSTEM ETC

APPENDIX A

SUMMARY OF EQUIPMENT SURVEYED

SUMMARY OF EQUIPMENT SURVEYED

COMPONENT	SUPPLIERS SURVEYED	EQUIPMENT PRICE DATA	COMMENTS
Radar X & S Band	Sperry Raytheon, Telefunken Sys Tech Canadian Marconi Krupp-Atlas Salesmar Racal Marine,	Conserative Price Approx $1000/KW of power ourput	No recent significant technical advances. Several avialable through DOD supply or on GSA Schedule.
Radar Antrennas (S/X Band)	Sperry Raytheon, Racal Marine, Canadian Marconi Krupp-Atlas Salesmar Telefunken Sys Tech Christiaan Huygens	5' - 10' = $5K - $10K 18' - 24' = $30K - $60K 18' & up - special perform $250K to $1M Co-located S/X (hi-perform) $150K to $350K	Special high performance antennas sold by Christiaan Huygens
UHF-VHF/DF	Servo Rhode and Schwarz	$50K to $100K per site	Price varies by desired Freguency Range and Antenna.
Vessel Traffic Center Consoles	Raytheon, Telefunken Sys Tech Canadian Marconi Krupp-Atlas Norcontrol Hughes Aircraft Sperry Marine Radar Digital Systems	$100K to $500K	The devices vary widely in capability and price. They should be selected based on a careful analysis of harbor performance needed.
Communicatios Consoles	Motorola	1 t 2 operator system (consoles) $50K to $100K 3 to 4 operator system (consoles) $150K to $200K Remote VHF Radios $8K to $10K	Central control system and consoles must be designed to meet the needs of the planned VTS system.
CCTV	CTA	Video Compression for telephone lines 1 frame/15 sec is $45K	

Component	Supplies Surveyed	Equipment Price Data	Comments
Vehicle Tracking Systems	Motorola Mets Pegasus II Morrow Geostar Qualcomm Trimble	Price Varies Significantly Based on Technology (See Report)	
CCTV	CTA Panasonic Burle IND. COHU INC. American Dynamics	Low Light Level Cameras Range From $2k - $10k	Surveillance site costs are heavily dependent on remote capabilities and video data communications chosen

APPENDIX B

MANUFACTURERS CONTACTED

MANUFACTURERS CONTACTED

MANUFACTURER	PRODUCTS	CONTACTS
TELEFUNKEN SYSTEM TECHNIK (formerly AEG)	VTS Design and System Integration Vessel Traffic Center Consoles Radar Antennas Radar Remote Target Extraction/Tracking	Gary Von Kampen (U.S. Agent) 703-526-3500 703-526-2249 (FAX) Richard Zarl 0731-391-3393 (FAX)
BRISTOL BABCOCK Waterbury, CT	Supervisory Control & Data Acquisition Systems (SCADA)	Kevin Finnan Director of Marketing 203-575-3000 203-575-3170 (FAX)
CANADIAN MARCONI Ottawa, Ontario, Canada	RADAR Vessel Traffic Center Consoles	Aldo Bartolomei (U.S. Agent) 301-262-1212 301-464-8910 (FAX) John Williams Design Engineer 613-592-6500
CHRISTIAN HUYGENS LABORATORIUM, B.V. Noordwijk, Holland	Radar Antennas Feasibility Studies for VTS Systems Specifications for VTS Systems VTS Design Radar Site Surveys	Ronald Blommendaal 31-1719-20625 (FAX)

MANUFACTURERS CONTACTED

MANUFACTURER	PRODUCTS	CONTACTS
CTA, Inc. Rockville, MD	CCTV Video Compression Equipment	Dave Johnson 301-816-1200
ENGINEERING & MANAGEMENT INFORMATION, LTD Orleans, Ontario, Canada	VTS System Design	Simon Naipaul, President 613-830-0292
Hughes Aircraft 1100 Wilson Blvd Arlington, VA	Vessel Tracking Center Consoles Remote Radar Extractor/Tracker	W. Eric Leighty, Marketing 703-284-4254 Tom Witten Schlaeger, Product Mgr. 714-732-1468
KRUPP-ATLAS Bremen, W. Germany	VTS Design & Integration Vessel Traffic Center Consoles RADAR Remote Scan Conversion Remote Target Extraction/Tracking	Paul Bligh (U.S. Agent) 01-388-1500 01-388-5781 (FAX) Helmut Janeba/Jurgen Meine Bremen, W. Germany 421-457-2686 421-457-3449 (FAX)
Motorola, Inc. 1701 McCormick Drive Landover, MD	UHF/VHF Radios/Antennas Communications Consoles/ Control Systems SCADA Systems Time Lapse Video Recording Microwave Equipment	Jack Kasalonis 301-796-6225 301-796-6229 (FAX)

MANUFACTURERS CONTACTED

MANUFACTURER	PRODUCTS	CONTACTS
NORCONTROL, Survelllance Systems, A.S. Horten, Norway	VTS Design & Integration Vessel Traffic Center Consoles Remote Target Extraction/Tracking	Lou D'Arco Radio Holland (U.S. Agent) 804-431-2975 804-431-3676 (FAX)
RACAL MARINE New Malden, U. K.	Radar ARPA Units Remote Target Extractors Remote Scan Conversion	Carl Andren (U.S. Agent) 202-331-9097 202-296-5457 (FAX) Alan Thompson, Reg. Director 504-454-6193 504-877-1148 (FAX) Steven Wigmore VTS Product Manager 44-81-924-2464 44-81-924-6630 (FAX) Arjan Gerretsen INA Rotterdam 010-433-0711 010-433-0831 (FAX)

MANUFACTURERS CONTACTED

MANUFACTURER	PRODUCTS	CONTACTS
RAYTHEON MARINE CO. Hudson, N.H.	RADAR ARPA UNITS ARPA Base VTC Consoles	William Viega Manager Govt. Programs 630-881-4717 Robert Schwartz 603-881-4717
SPERRY MARINE Charlottesville, VA	RADAR VTC Consoles VTS Design/Integration Remote RADAR Processing	T. E. Braithwaite Program Manager VTS 804-974-2654
SALESMAR INT. Italy	RADAR VTC Consoles VTS Design/Integration	Tom Finneran (U.S. Agent) Mackay Marine 201-527-0300 Massime Alfieri Copenhagan, Denmark 453-126-0299
RADAR DIGITAL SYSTEMS Auburn, CA	VTS Consoles Remote RADAR Processing	Richard Fay President 916-885-2203
SERVO CORP. OF AMERICA HICKSVILLE, NY	VHF/DF	George F. Tubley Director Of Marketing 516-938-9700
RHODE AND SCHWARZ LANHAM, MD	VHF/DF UHF-VHF Radio	Terry Palmer Marketing 301-459-8800

MANUFACTURERS CONTACTED

MANUFACTURER	PRODUCTS	CONTACTS
FURUNO ELECTRIC CO. South San Francisco, CA	Depth Sounder Current Meters	Rose Henry Sales 415-873-9393
R.M. YOUNG CO. Tranverse City, MI	Meteorological Instruments	616-946-3980
JOHN E. CHANCE ASSOCIATES, INC. Lafayette, LA	Radiolocation (Starfix) Surveying	Thomas S. Chance Vice President 318-237-1300
COHU, INC. San Diego, CA	CCTV	Scott Fearn Marketing 619-277-6700
BURLE INDUSTRIES Lancaster, PA	CCTV	Mr. Burkheimer 717-295-6000
PANASONIC Secaucus, NJ	CCTV	Frank Abrams 201-348-7860
AMERICAN DYNAMICS Orangeburg, NY	CCTV Switching And Control Systems	Larry Wanuig Marketing 914-365-1000
AMERICAN MOBILE SATELLITE CORP. Wash., DC	Satellite Communications	Ms. Kelly 202-331-5858
II MORROW, INC. Salem, OR	Vehicle Tracking System	James Bailey Fleet Manag. Systems 503-581-8101

MANUFACTURERS CONTACTED

MANUFACTURER	PRODUCTS	CONTACTS
MOTOROLA, INC. Schaumburg, IL Chandler, AZ	"Coverage Plus" Vehicle Tracking System "Iridium" Satellite Communications System	David Hume 708-576-5719 James Foley Satellite Comms. Bus. Mgr. 602-732-3313
DUALCOMM San Diego, CA	"Omnitracs" Vehicle Tracking System	Tom Lancaster Marketing 619-587-1121 x335
METS, INC. Indianapolis, IN	Mets Vehicle Tracking System	James Winkle Public Relations 317-573-2200
PEGASUS, INC. Herndon, VA	Vehicle Tracking System	Joe Mitchelli Marketing 703-471-9300
GEOSTAR, INC. Wash., DC	Vehicle Tracking System RDSS	Brent Taylor Govt. Marketing 202-778-6075
TRIMBLE NAVIGATION Sunnyvale, CA	LORAN-C/GPS Receivers Vehicle Tracking System	Ann Ciganer Marketing 408-730-2900

APPENDIX C

GOVERNMENT AGENCIES CONTACTED

GOVERNMENT AGENCIES CONTACTED

AGENCY	CONTACTS
Canadian Coast Guard Ottawa, Ontario, Canada	Bert Tepper, Acting Chief, Guidance Systems Telecommunications & Electronics 613-998-1539 613-998-9258 (FAX) R. R. Beauchesne, Sr. Specialist Engineer Radar & Display, T & E 613-998-1550 613-995-4700 (FAX) Lee Barker 613-990-3031
U. S. Coast Guard	D. Wayne Rardon, U. S. Coast Guard Headquarters (G-TES-3) 202-267-1201

APPENDIX D
SURVEILLANCE TECHNOLOGY IN VTS

1.0 GENERAL

Many types of surveillance sensors are employed or proposed for use in VTS systems. To simplify VTS design and analysis, the various types of sensors have been divided into several levels of performance and cost called Surveillance Modules. This Appendix describes these modules and provides data on the cost and performance of each one. It is emphasized that the costs and performance pertain only to the hardware which makes up each module. A complete VTS system requires more equipment than the sum of the surveillance modules utilized, e.g., VTC control and communications consoles, recording equipment, utility costs, etc. The major categories of modules are Radar, Automatic Dependent Surveillance (ADS) and Miscellaneous.

2.0 RADAR TECHNOLOGY IN VTS

For the purposes of this report, radar systems are based on the assumptions that they:

- o have the ability to detect vessels that are typical to the area monitored at the ranges expected,
- o have the ability to remove most sea clutter and extraneous target data,
- o have the ability to eliminate interference by shipboard radars,
- o have a very high degree of reliability,
- o have the ability to detect the design size target on three out of five scans,
- o have the ability to display that target continuously, i.e. scan-to-scan integration,
- o have a display capability which enhances the radar resolution.

Selection of appropriate generic levels of radar performance depends on identifying the major variables in radar equipment that affect radar performance. These are: power output, noise figures, operating frequency, radar video processing, and radar antenna.

2.1 POWER OUTPUT

The difference in cost between low power and high power radar transmitter/receivers is negligible with respect to total VTS system costs. Since high power (50kw) output is cost efficient and causes no technical problems, high power radar transmitters should be installed universally regardless of target size or range requirements. An added benefit to this choice is standardization of equipment and training needs. Output power therefore is not a performance parameter.

2.2 NOISE FIGURE

Since a common radar is used, it is assumed that the noise figure of the receiver is capable of meeting the most severe requirement.

2.3 OPERATING FREQUENCY

The common shore-based VTS radars in use are X or S band. X band radar is higher frequency than S band. Since the beamwidth in radians of a radar antenna is approximately the reciprocal of its dimension in the plane of interest expressed in wavelength units, the vertical and horizontal beamwidth of any antenna is approximately three times wider at S band than at X band.
X band antennas can therefore be obtained with narrower beamwidths and can have finer azimuth resolution than S band. S band radar, however, offers superior detection of targets in heavy rains. The required azimuth resolution and bad weather performance must be considered when selecting the frequency band. Vessel traffic systems presently in operation have X, S and X/S co-located radar sites based on local conditions. Operating frequency is clearly a variable performance parameter.

2.4 RADAR MEASUREMENTS

2.4.1 RANGE MEASUREMENTS

The range measurement capability of a radar is a function of the pulse width of the transmitted pulses. Modern X and S band radar manufacturers specify that the minimum pulse width is 50 ns.
The resolution cell of a radar is approximated by

$$\frac{C \times T}{2} \quad \text{where } C = \text{speed of light}, \quad T = \text{pulse width}$$

For a modern radar this relationship gives a range measurement accuracy of ± 7.5 meters. For design purposes this accuracy is assumed to be ± 25 feet. The discrimination ability of a radar is defined as the minimum distance required between targets in order for both of them to be detected. Discrimination is a function of the radar itself and the display in use. A typical Plan Position Indicator (PPI) display has 4000 pixels along one radius. When used on a 6 nm scale each pixel represents .0015 nm (approximately 3 meters). On a modern 1024 x 1024 raster scan display, one-half of the display is 512 pixels (minimum) and each pixel represents approximately 22 meters. Since every other pixel must be unlit, the display resolution ranges from 22 to 44 meters with varying probabilities. The display resolution is used as the system resolution because the resolution of the raster scan display is not as good as the radar. To define radar module performance, target discrimination is assumed to be 35 meters.

2.4.2 AZIMUTH MEASUREMENTS

The azimuthal measurement capability of a radar is a function of the beamwidth of the antenna in use. One beamwidth is considered the smallest azimuthal definition possible. The beamwidth in degrees is converted to circumferential distance as follows: (assumed range is 6 nm)

(2 PI/360) (6 nm) (BW) (1852) = Azimuth resolution in meters

The azimuthal resolution of a radar is normally much worse than the range resolution due to antenna characteristics.

2.5 RADAR VIDEO PROCESSING

Radar video processing is the processing of radar video at the radar site. This can include remote target extraction, automatic target tracking, video scan conversion, and video processing to allow radar data to be sent over narrow band systems. For the purposes of this design effort, radar video processing includes all of these functions. It is also assumed that all radar sites, regardless of intended performance, has the same video processing equipment. The equipment selected must meet the most stringent requirements and is used in all locations. Special cases exist where sea clutter is a severe problem or where very dense traffic must be differentiated in very narrow waterways. This can require additional processing to reduce clutter effects. Radar video processing is not, therefore, a variable performance parameter.

2.6 RADAR ANTENNA

The performance of a shore based X band marine radar can be significantly altered by the antenna selection. Exceptional performance antennas are large and cost over 100 times more than the average performance antennas. There are three general antenna classes: exceptional performance, high performance and average performance.

a. Exceptional Performance Antennas. These are large size (25+ feet) antennas with very narrow beamwidths vertically and horizontally that provide a very small resolution cell with outstanding sidelobe and backlobe rejection characteristics are obtained. These antennas cost from $250K to $1M.

b. High Performance Antennas. These medium size (18-feet) antennas have very narrow horizontal and vertical beamwidths and good sidelobe/backlobe rejection characteristics. These antennas cost approximately $30K to $100 K.

c. Average Performance Antennas. These antennas are 12-feet in length, have relatively wide horizontal and vertical beamwidths and fair to poor sidelobe/backlobe rejection. If not furnished with the transmitter, they cost approximately $10K.

Additional costs may accrue on all types of antennas where high wind conditions dictate special turning units and/or radomes.

2.7 RADAR MODULES

To execute VTS designs, it is prudent to keep in mind the IMO recommendation that all vessels 20-meters or more in length participate in VTS systems. To incorporate this recommended minimum vessel size and match it to the hardware information discussed above, three surveillance modules of radar implementation have been selected. The electronics equipment in each module is redundant to provide a very high level of availability. These modules are:

MODULE 1. Average Performance -- a 20-meter vessel can be detected at the radar horizon in a relatively open area with average sea clutter (sea state = 1, radar cross section = 10 square meters)
Horizontal Beamwidth is assumed to be 0.7 degrees
AZ Resolution @ 6 nm = (2pi/360)(6nm)(0.7)(1852) = 135.8 meters
Range accuracy @ 6 nm = 8 meters
Discrimination = 35 meters

X BAND RADAR
12-foot antenna

MODULE 2. Average performance -- a 20-meter vessel can be detected at the radar horizon in a relatively open area with average sea clutter (sea state = 1, radar cross section = 10 square meters.
Horizontal Beamwidth is assumed to be 2 degrees.
AZ Resolution @ 6 nm = (2PI/360) 2)(6nm)(1852) = 388 meters
Range accuracy @ 6 nm = 8 meters
Discrimination @ 6 nm = 35 meters
Enhanced performance in heavy rain over Module 1.

S BAND RADAR
12-foot antenna

MODULE 3. High Performance - a 5 to 20 meter vessel can be detected at 6 miles in relatively open areas (sea state = 1, radar cross section = 5 square meters) or where ships and smaller targets must be tracked in relatively narrow channels (approximately 300+ feet).
Horizontal Beamwidth is assumed to be 0.5 degrees.
AZ Resolution @ 6 nm = 97 meters
Range accuracy @ 6 nm = 8 meters
Discrimination @ 6 nm = 35 meters

X BAND RADAR
18-foot antenna

MODULE 4. High Performance - a 5 to 20 meter vessel can be detected at 6 miles in relatively open areas (sea state = 1, radar cross section = 5 square meters) or where ships and smaller targets must be tracked in relatively narrow channels (approximately 300+ feet).

Horizontal Beam width is assumed to be 1.4 degrees.
AZ Resolution @ 6 nm = 271.5 meters
Range accuracy @ 6 nm = 8 meters
Discrimination @ 6 nm = 35 meters
Enhanced performance over Module 3 in heavy rain

S BAND RADAR
18-foot antenna

MODULE 5. Special Purpose - detect the same targets as Module 3 but is also able to track these targets in narrowly confined waterways with obstructions on either or both sides due to the outstanding side/backlobe rejection characteristics.
Horizontal Beamwidth is assumed to be .5 degrees.
AZ Resolution @ 6 nm = 97 meters
Range accuracy @ 6 nm = 8 meters
Discrimination @ 6 nm = 35 meters

X BAND RADAR
Large size, exceptional performance antenna
Low noise installation (special waveguides, etc.)

MODULE 6. Special Purpose -- detect the same targets as Module 4 but is also able to track these targets in narrowly confined waterways with obstructions on either or both sides due to the outstanding side/backlobe rejection characteristics.
Horizontal Beamwidth is assumed to be 1.4 degrees.
AZ Resolution @ 6 nm = 271.5 meters
Range accuracy @ 6 nm = 8 meters
Discrimination @ 6 nm = 35 meters
Enhanced performance over Module 5 in heavy rain

S BAND RADAR
Large size, exceptional performance antenna
Low noise installation (special waveguides, etc.)

2.8 RADAR SURVEILLANCE MODULE HARDWARE COSTS

The following are the current market costs of the radar surveillance modules. Recurring costs are estimated at 10%/year for each module.

MODULE 1, MODULE 2

2 radar T/Rs (50-75 kW)	$ 50K
Radar ancillary hardware	50
Antenna/turning unit-12 feet	10
Radar video processing--2 units	200
TOTAL:	$310K

MODULE 3, MODULE 4

2 radar T/Rs (50-75 kW)	$ 50K
Radar ancillary hardware	50
Antenna/turning unit - 18 feet	100
Radar video processing - 2 units	200
TOTAL:	$400K

MODULE 5, MODULE 6

2 radar T/Rs (50-75 kW)	$ 50K
Radar ancillary hardware (low noise)	100
Antenna/turning unit - 27 feet	300
Radar video processing - 2 units	200
TOTAL:	$650K

3.0 AUTOMATIC DEPENDENT SURVEILLANCE (ADS) TECHNOLOGY IN VTS

For a complete discussion of ADS technology in VTS systems see Section 3.0 of the VTS Technology Survey.

For the purposes of this report, ADS systems are based on the assumptions that they:

o conform to a national standard so that the data is useful in whatever port or VTS the vessel may be operating. This standard must also include a required minimum of data,

o have, as a data minimum, earth referenced position and vessel identification

o be manufactured to a standard of reliability consistent with the VTS requirements.

Selection of appropriate generic levels of ADS performance depends on identifying the major variables possible in ADS type equipment that affect performance. These are transponder type, accuracy, range, interrogation/response methodology and data transmitted.

3.1 TRANSPONDER TYPE

There are two types of transponders considered for VTS applications: radar transponders and position transponders. Radar transponders respond to radar pulses by sending a transmission that enhances acquisition and provides vehicle identification. Position transponders are devices composed of a location sensor, communications device, and some interfacing circuitry that can transmit the vehicle position and other data to a control center. Transponder type is obviously an important performance parameter.

3.2 ACCURACY

Positional accuracy in the case of radar transponders is a function of the radar in use and not an ADS variable. Positional accuracy in the case of position type transponders is clearly an ADS variable as it governs the choices of acceptable position sensor. Two levels of accuracy are considered acceptable. These are 1) very high accuracy -- 25 to 65 feet (2drms) and, 2) high accuracy -- .25 nm (2drms).

3.3 RANGE

The range of effectiveness of radar transponder devices is a function of their design and the local radar sensitivity. Variation is not considered great enough to make it a variable. The effective range of positional transponders is a function of both the position sensor and communication systems in use. This range can vary greatly and is therefore a valid ADS variable. Three range choices for positional transponders have been chosen. These are large ocean sized areas, intermediate or coastal sized areas and small or VTS zone sized areas.

3.4 INTERROGATION/RESPONSE METHODOLOGY

The technical mechanics and methodology of the interrogation and response for positional type ADS devices must be standard so that these devices are useful in more than one VTS zone. Without this standardization vessels carry different devices for each zone or are restricted to one zone. This parameter is not considered a variable.

3.5 DATA TRANSMITTED

It is obvious that positional type transponders can easily transmit a great deal of data by interfacing other sensors and/or input devices to them. In a VTS scenario only two pieces of information are considered to be mandatory at the initial level of implementation. These are position and vessel identification. An argument can be made to include vessel heading data in the minimum suite if "crabbing" of vessels in narrow channels is of concern to the control center. In a tug/barge case it is also highly desirable to know if the tug is moving barges or not. In the fishing vessel case the status of fishing activity would be pertinent especially if large nets are deployed. Since these variations are so large, it must be assumed that a careful national standard will exist that will allow these devices to be easily expandable to meet the many differing needs. For this exercise the data transmitted is not considered a variable.

3.6 ADS MODULES

The two levels of accuracy and three levels of range lead to six possible choices for positional type devices. Of these six the large area, very high accuracy choice is not considered realistic. The remaining five positional type devices plus one radar transponder device leads to six ADS types as follows:

- Type 1 -- Radar Transponder

- Type 2 -- Positional Transponder, large area, high accuracy

- Type 3 -- Positional Transponder, intermediate area, very high accuracy

- Type 4 -- Positional Transponder, Intermediate area, high accuracy

- Type 5 -- Positional Transponder, Small area, very high accuracy

- Type 6 -- Positional Transponder, Small area, high accuracy

Since surveillance requirements and performance are being considered only within one VTS zone, it is not logical to consider large or intermediate area systems. These have much lower data rates and wider area communications requirements than surveillance systems designed to service only one zone (see discussion in Section 3.0, VTS Technology Survey). Accordingly, only ADS Types 1, 5, and 6 will be used as ADS modules. The ADS modules then, become:

MODULE 7 -- ACTIVE RADAR TRANSPONDER (Type 1)

This device is similar to the radar transponders carried aboard aircraft but must respond to all land based VTS radar frequencies. The device enhances the radar return and provides positive vessel identification. The accuracy provided by this device would be the same as that of the surveillance radar in use.

MODULE 8 - POSITIONAL TRANSPONDER, SMALL AREA, VERY HIGH ACCURACY (Type 5)
This device is assumed to be a differential GPS (DGPS) receiver, coupled with a VHF communications system. The performance of this device is assumed to be:
Range -- Line of Sight (LOS) from the VHF facilities
Accuracy -- 5 to 10 meters (2 drms)
Relative Accuracy -- 5 to 10 meters (2 drms). Relative accuracy is defined as the accuracy of measurement between vessels.
Positive Vessel Identification -- Yes, if required in the vessel ADS device

MODULE 9 - POSITIONAL TRANSPONDER, SMALL AREA, HIGH ACCURACY (Type 6)

This device is assumed to be a Loran-C receiver coupled to a VHF communications system. The performance of this device is assumed to be:
Range -- Line of Sight (LOS) from the VHF facilities
Accuracy -- 0.25 nm (2 drms). This accuracy can be increased to at least 0.03 nm by very careful local calibration of the VTS zone coupled with active monitoring of the Loran-C grid with a monitor station located in the VTS zone.
Relative Accuracy -- Better than 0.05 nm. Relative accuracy is equal to the repeatable accuracy of the Loran-C system.
Positive Vessel Identification -- Yes, if required in the vessel ADS device

3.7 ADS MODULE HARDWARE COSTS

MODULE 7

	Non-recurring	Recurring (10 yr.)
VTS Costs	N/A	N/A
Vessel Costs		
Transponder	$1,500	
Maintenance @ $100/yr.		$1,000

MODULE 8

	Non-recurring	Recurring (10 yr.)
VTS Costs		
DGPS Base Station	$72,000	
Maint/comms		$100,000
Integration	25,000	
TOTAL:	$97,000	$100,000

Vessel Costs		
2 ea VHF/DGPS terms.	$ 8,000	
Installation	1,000	
Maintenance @ $500/yr.		$ 5,000
TOTAL:	$ 9,000	$ 5,000

MODULE 9

	Non-recurring	Recurring (10 yr.)
VTS Costs		
2 Base terminals	$ 6,000	
Installation	2,000	
Integration	25,000	
Comms/console mods & add'l. radios	25,000	
Maintenance @ 1000		$10,000
TOTAL:	$58,000	$10,000
Vessel Costs		
2 terminals	$ 2,520	
Installation	250	
2 VHF radios	1,000	
Maintenance @ 250		$ 2,500
TOTAL:	$ 3,770	$ 2,500

4.0 MISCELLANEOUS SURVEILLANCE TECHNOLOGIES

4.1 VHF COMMUNICATIONS

VHF communications are employed in all VTS sub-zones. The major variations are the number of frequencies used and the radiated power output of the installation. Since the number of frequencies are determined by the existing regulations and the VTS design itself, it is not variable. Radiated power output however, is a significant choice for the VTS designer. Low power (1-10 watts) facilities are used within sub-zones when it is desirable the limit the coverage area and reduce interference in other sub-zones. High power (10 to 50 watts) is used when wider coverage is desired and the resultant interference can be tolerated. This leads to two VHF modules.

4.1.1 VHF MODULES

MODULE 10 - Low power VHF Transmitting/Receiving Facility

Output power -- 1-10 watts
Effective range -- up to 10 miles
Capable of operating on four frequencies simultaneously

MODULE 11 - High power VHF Transmitting/Receiving Facility

Output power -- 10-50 watts
Effective range -- as required up to LOS
Capable of operating on four frequencies simultaneously

4.1.2 VHF MODULE HARDWARE COSTS

MODULE 10

	Non-recurring	Recurring (10 yr.)
VTS Costs		
VHF Transceiver (4)	$ 8,000	
2 Guard Receivers	1,000	
Antenna/install	10,000	
Maintenance		$13,000
TOTAL:	$19,000	$13,000
Vessel Costs	N/A	N/A

MODULE 11

	Non-recurring	Recurring (10 yr.)
VTS Costs		
VHF Transceiver (4)	$32,000	
2 Guard Receivers	1,000	
Antenna/install	15,000	
Maintenance		$20,000
TOTAL:	$48,000	$20,000
Vessel Costs	N/A	N/A

4.2 METEOROLOGICAL SENSORS

Meteorological sensors in current VTS systems are capable of measuring air temperature, wind speed/direction, and visibility. The measurement of visibility is not always required at remote sensor sites and is employed only when fog presents a significant navigation problem. This leads naturally to two levels of meteorological sensor implementation. All meteorological sensors are assumed to be connected to a general purpose computer that can be interrogated over a telephone line.

4.2.1 METEOROLOGICAL MODULES

MODULE 12 - Air temperature, wind direction and speed

Performance:
Air temperature to ±1 degree F.
Wind direction to ±1 degree
Wind speed to ±1 kt.

MODULE 13 - Air temperature, wind direction and speed, visibility

Performance
Air temperature to ±1 degree F.
Wind direction to ±1 degree
Wind speed to ±1 kt.
Visibility to less than 1/4 nm

4.2.2 METEOROLOGICAL HARDWARE COSTS

MODULE 12

	Non-recurring	Recurring (10 yr.)
VTS Costs		
Inst/interface	$20,000	
Maintenance		$ 5,000
TOTAL:	$20,000	$ 5,000
Vessel Costs	N/A	N/A

MODULE 13

	Non-recurring	Recurring (10 yr.)
VTS Costs		
Inst/interface	$40,000	
Maintenance		$ 5,000
TOTAL:	$40,000	$ 5,000
Vessel Costs	N/A	N/A

4.3 HYDROLOGICAL SENSORS

The hydrological sensors employed in modern VTS systems measure one or more of the following: water temperature, current, and water depth. The major division in capabilities for a VTS designer is the choice between measuring either current or depth or both. This leads to a logical choice of two levels of performance. It is assumed that all sensors are interfaced to a general purpose computer that can be interrogated by telephone modem.

4.3.1 HYDROLOGICAL MODULES

MODULE 14 - Water Temperature and Depth

Performance:
Water temperature to ±1 degree F.
Water depth to ±0.5'

MODULE 15 - Water Temperature, Depth and Current

Performance:
Water temperature to ±1 degree F.
Water depth to ±0.5'
Current to ±0.2 kt.

4.3.2 HYDROLOGICAL MODULE HARDWARE COSTS

MODULE 14

	Non-recurring	Recurring (10 yr.)
VTS Costs		
Inst/interface	$10,000	
Maintenance		$ 2,500
TOTAL:	$10,000	$ 2,500
Vessel Costs	N/A	N/A

MODULE 15

	Non-recurring	Recurring (10 yr.)
VTS Costs		
Inst/interface	$50,000	
Maintenance		$ 5,000
TOTAL:	$50,000	$ 5,000
Vessel Costs	N/A	N/A

4.4 VHF/DF SENSORS

These radio direction finders are employed in many VTS systems. The major technical variable is the accuracy of the measured line of position in degrees. This accuracy varies according to on site conditions and the aperture of the antenna utilized. A VHF/DF site furnishes one LOP. If used in conjunction with a radar it can provide positive vessel identification. If used alone, two sites are required to locate a vessel. The technical variation is not great enough to justify more than one VHF/DF hardware level. This level assumes complete remote control capability, a wide aperture array of at least 16 dipoles, and a site accuracy of 2 degrees.

4.4.1 VHF/DF MODULES

MODULE 16

Performance:
Line of position measurement to 2 degree RMS

4.4.2 VHF/DF MODULE HARDWARE COSTS

MODULE 16

	Non-recurring	Recurring (10 yr.)
VTS Costs		
VHF/DF equipment	$90,000	
Maintenance		$ 5,000
TOTAL:	$90,000	$ 5,000
Vessel Costs	N/A	N/A

4.5 CLOSED CIRCUIT TELEVISION (CCTV) MODULES

Low light level closed circuit television is used in many VTS systems. These devices provide visual surveillance of small areas where specific problems exist that are not solved by other surveillance sensors. Some CCTV installations are also used to identify vessels. Current CCTV installations range from fixed focus, fixed azimuth cameras to cameras with complete remote control of pan, tilt and zoom functions. Video data can be sent to the VTC via telephone lines (delayed in time) or microwave links. Two levels of performance have been selected for CCTV implementation. Both levels are assumed to require a climate controlled, weatherproof housing with window wipers, washers and defoggers.

4.5.1 CCTV MODULES

MODULE 17 - Fixed Focus CCTV via Telephone Lines

This module consists of two fixed focus cameras. These are not remotely controllable except for camera selection. The data is compressed and transmitted over a 9600 baud modem.

Performance: (each camera)
Magnification -- 1 camera less than 50 mm.
1 camera greater than 50 mm.
Minimum scene illumination -- 0.01 lux
Image update rate @ 9600 baud -- 10-20 seconds

MODULE 18 - Remotely Controllable CCTV via Microwave

This module consists of two independently controllable cameras. Each camera is capable of remotely producing over 50 pre-set scenes under microprocessor control. The computerized control is also capable of producing any programmed sequence of pre-set scenes, each visible for a selectable time period. Video from these cameras are multiplexed and sent to the VTC over a microwave link.

Performance: (each camera)
Magnification -- 10 to 160 mm.
Zoom -- 10X
Minimum scene illumination -- 0.01 lux

4.5.2 CCTV MODULE HARDWARE COSTS

MODULE 17

	Non-recurring	Recurring (10 yr.)
VTS Costs		
Cameras (2 ea.)	$ 2,000	
Housing	600	
2-20" monitors	600	
Remote Camera switching	200	
Compression	10,000	
Maintenance		$10,000
TOTAL:	$13,400	$10,000
Vessel Costs	N/A	N/A

MODULE 18

	Non-recurring	Recurring (10 yr.)
VTS Costs		
Cameras (2 ea.)	$ 4,000	
Housing	600	
2-20" monitors	750	
Pan/tilt w. preset	1,500	
Microwave link	100,000	
up control/multiplex	10,000	
Maintenance		$50,000
TOTAL:	$116,850	$50,000
Vessel Costs	N/A	N/A

MODULE PERFORMANCE SUMMARY
TABLE A-1

Module #	Range	Resolution	Discrimination	Positive Vessel ID	Comments
RADAR 1	LOS	.7 DEG AZ 8 M RANGE	35M	NO	
RADAR 2	LOS	2 DEG AZ 8 M RANGE	35M	NO	
RADAR 3	LOS	.5 DEG AZ 8 M RANGE	35M	NO	
RADAR 4	LOS	1.4 DEG AZ 8 M RANGE	35M	NO	
RADAR 5	LOS	.5 DEG AZ 8 M RANGE	35M	NO	EXC. SIDE/BACK LOBE REJECTION
RADAR 6	LOS	1.4 DEG AZ 8 M RANGE	35M	NO	EXC. SIDE/BACK LOBE REJECTION
ADS 7	LOS	*	*	YES	* ACCURACY SAME AS RADAR USED
ADS 8	LOS	5 TO 10 M	SAME	YES	
ADS 9	LOS	.25NM (1)	SAME	YES	
VHF 10	5 NM	N/A	N/A	NO	
VHF 11	LOS	N/A	N/A	NO	
MET 12	N/A	N/A	N/A	NO	TEMP. WIND SPEED/DIR
MET 13	N/A	N/A	N/A	NO	TEMP. VIS, WIND SPEED & DIR
HYD 14	N/A	N/A	N/A	NO	WATER TEMP & DEPTH
HYD 15	N/A	N/A	N/A	NO	WATER TEMP, DEPTH & CURRENT
DF 16	LOS	2 DEG	SAME	YES (2)	
CCTV 17	LOS	N/A	N/A	YES **	** ID POSSIBLE, FIXED CAMERAS, TELEPHONE LINE
CCTV 18	LOS	N/A	N/A	YES **	** ID POSSIBLE, REMOTE PAN, TILT, ZOOM- MICROWAVE LINK

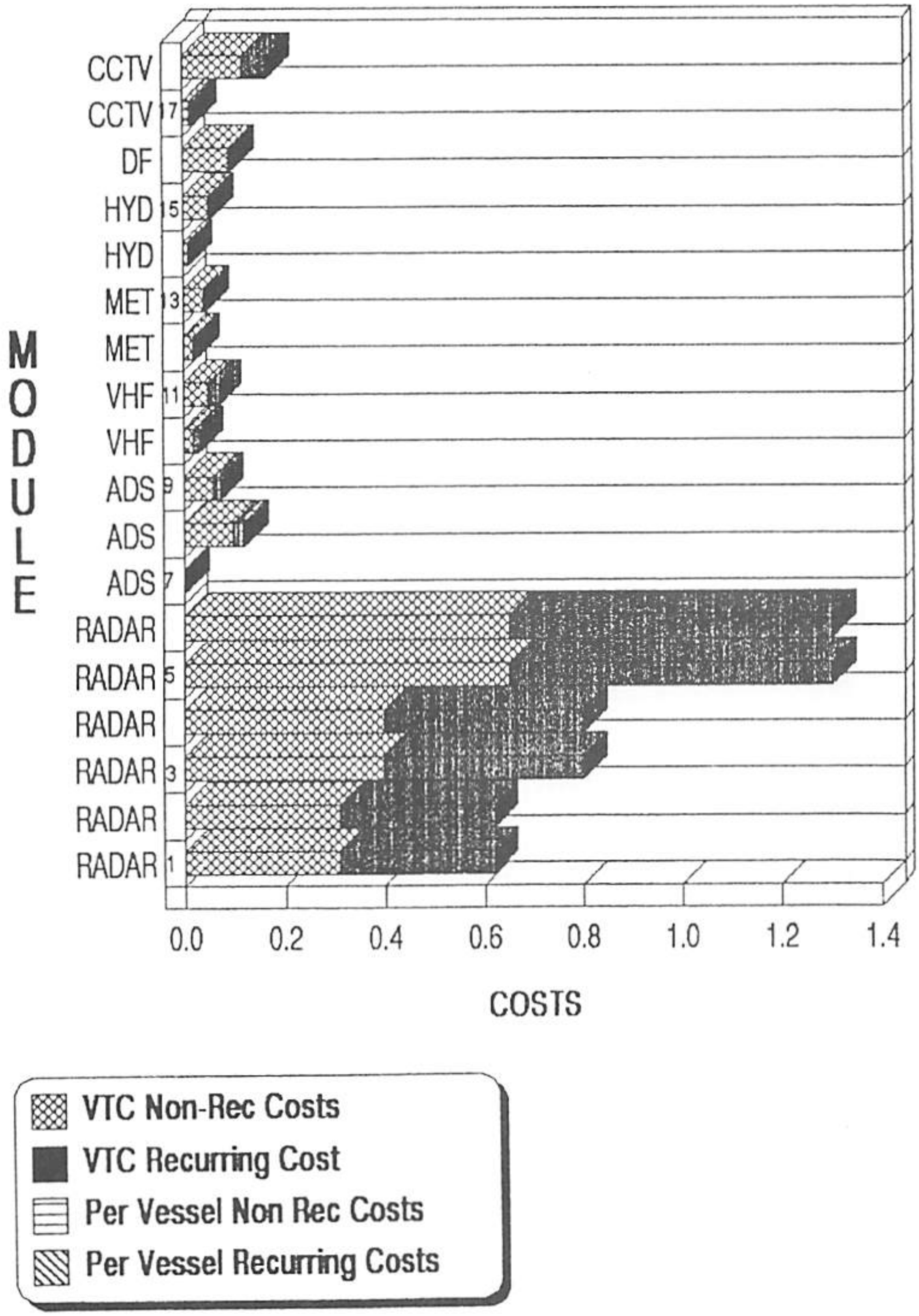
NOTES

(1) THIS ACCURACY CAN BE INCREASED TO APPROXIMATELY .03NM

(2) POSITIVE VESSEL ID POSSIBLE WHEN USED WITH A RADAR. IF NO RADAR THEN TWO MODULES ARE REQUIRED

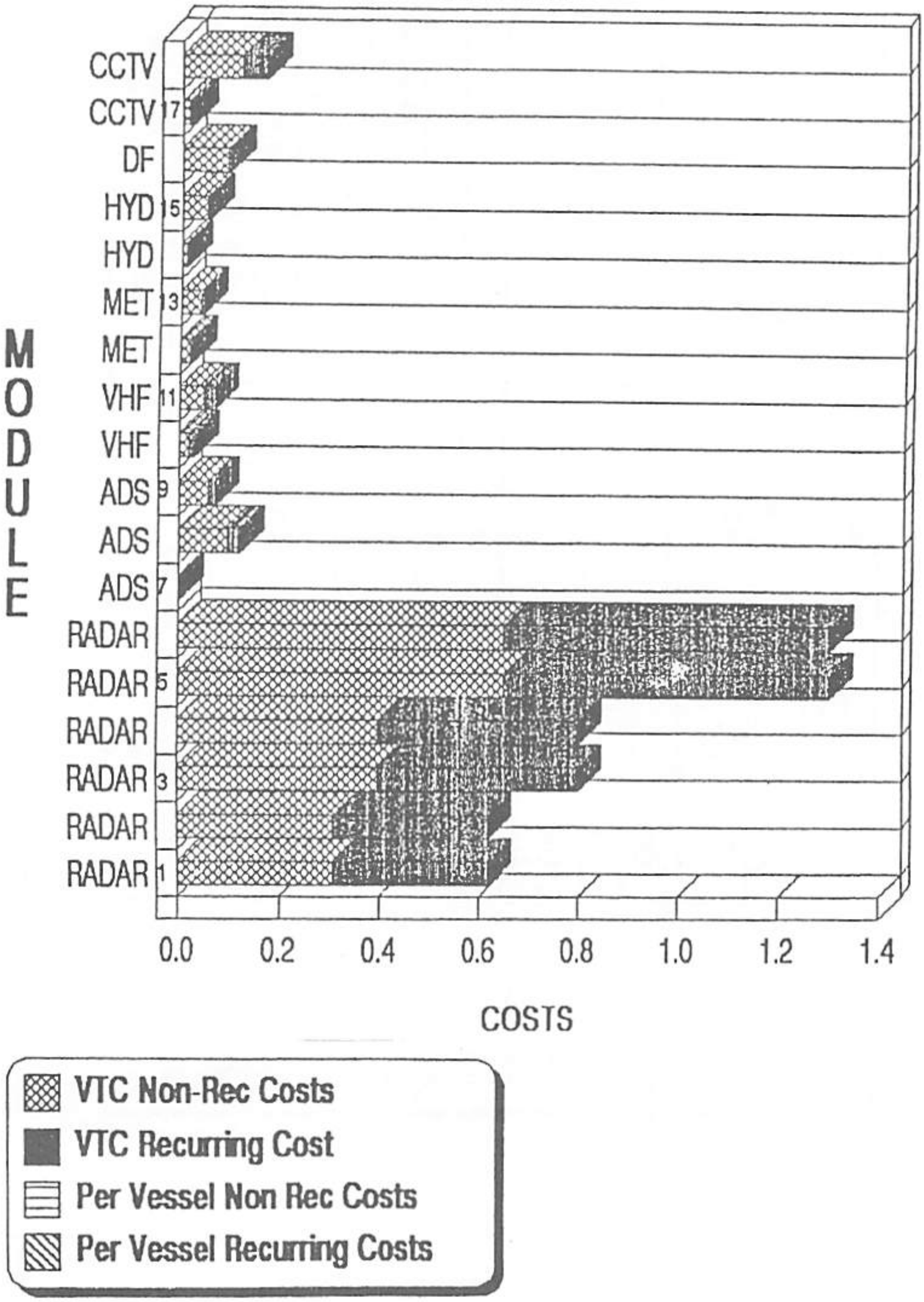
MODULE COSTS SUMMARY ($000)

TABLE A-2



MODULE COSTS SUMMARY ($000)

TABLE A-2



MODULE PERFORMANCE SUMMARY
TABLE A-1

Module #	Range	Resolution	Discrimination	Positive Vessel ID	Comments
RADAR 1	LOS	.7 DEG AZ 8 M RANGE	35M	NO	
RADAR 2	LOS	2 DEG AZ 8 M RANGE	35M	NO	
RADAR 3	LOS	.5 DEG AZ 8 M RANGE	35M	NO	
RADAR 4	LOS	1.4 DEG AZ 8 M RANGE	35M	NO	
RADAR 5	LOS	.5 DEG AZ 8 M RANGE	35M	NO	EXC. SIDE/BACK LOBE REJECTION
RADAR 6	LOS	1.4 DEG AZ 8 M RANGE	35M	NO	EXC. SIDE/BACK LOBE REJECTION
ADS 7	LOS	*	*	YES	* ACCURACY SAME AS RADAR USED
ADS 8	LOS	5 TO 10 M	SAME	YES	
ADS 9	LOS	.25NM (1)	SAME	YES	
VHF 10	5 NM	N/A	N/A	NO	
VHF 11	LOS	N/A	N/A	NO	
MET 12	N/A	N/A	N/A	NO	TEMP. WIND SPEED/DIR
MET 13	N/A	N/A	N/A	NO	TEMP. VIS, WIND SPEED & DIR
HYD 14	N/A	N/A	N/A	NO	WATER TEMP & DEPTH
HYD 15	N/A	N/A	N/A	NO	WATER TEMP, DEPTH & CURRENT
DF 16	LOS	2 DEG	SAME	YES (2)	
CCTV 17	LOS	N/A	N/A	YES **	** ID POSSIBLE, FIXED CAMERAS, TELEPHONE LINE
CCTV 18	LOS	N/A	N/A	YES **	** ID POSSIBLE, REMOTE PAN, TILT, ZOOM- MICROWAVE LINK

NOTES

(1) THIS ACCURACY CAN BE INCREASED TO APPROXIMATELY .03NM

(2) POSITIVE VESSEL ID POSSIBLE WHEN USED WITH A RADAR. IF NO RADAR THEN TWO MODULES ARE REQUIRED

SECTION 6.

UNIT COSTS OF VESSEL CASUALTY CONSEQUENCES

Prepared By:

Judith C. Schwenk, DTS-49
U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142
July 1991

6. UNIT COSTS OF VESSEL CASUALTY CONSEQUENCES

NOTE: This section documents Judith C. Schwenk's effort in support of Section 6 of the Port Needs Study (Volume I).

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF APPENDICES

6.1 INTRODUCTION

This technical supplement presents a detailed discussion of the analytical techniques and data sources employed in the development of the costs to society of the consequences of vessel casualties addressed by the Port Needs Study. The consequences listed below are discussed in Sections 6.3 through 6.14.

- Spill consequences
  - Loss of and injury to animal species
  - Decrease in tourism, recreational and commercial use and property value of shoreline and harbor
  - Cleanup activities
  - Losses to subsistence households
  - Damage assessment
- Vessel damage and loss
- Cargo damage and loss
- Injury to and loss of human life
- Emergency response
- Blocked channels and waterways
- Damage to bridges and navaids
- Damage from LNG and LPG explosions

The consequences listed below were not analyzed for various reasons: data were unavailable; they were outside the scope of the study; or they occurred infrequently in a very limited number of casualties.

- Legal fees for litigation over vessel casualties
- Damages to overhead power cables, pipelines, docks, piers and platforms
- Damages to facilities and water supplies
- Cumulative effects of consecutive spills of hazardous materials on natural resources

- Effects of chemical releases into the air
- Damages to vessels too small for participation in VTS

6.2 DEFINITIONS

6.2.1 Direct and indirect benefits of VTS

The direct benefits of VTS are the avoided vessel casualties and associated losses due to VTS effectiveness. The indirect benefits of VTS are diverse, including acquisition of information for better placement of navaids, improved quality of weather and traffic information available to non-VTS-participating vessels, and enhanced reputations of VTS harbors as desirable and safe locations for terminals and ports of entry.

6.2.2 Social costs[1]

The costs estimated in this section are all "social" costs of vessel casualties, defined to be the value of the reduced availability of goods and services desired by society due to consequences of vessel casualties. Social costs include both costs that are measured directly by market prices, costs that are borne by others not subject to market fluctuations, such as government agencies and volunteers, and damages that cannot be measured by market prices, such as loss of wildlife and natural resources.

The following examples illustrate social costs. The costs of government response to a vessel casualty are social costs, because the limited resources must be diverted from other important activities. The reduced enjoyment of persons visiting a beach soiled with oil spilled from a vessel is a net loss to society that cannot be replaced. Similarly, people who are totally prevented from visiting an oil-damaged beach experience reduced enjoyment of an alternative beach. The social costs due to vessel damage represent the value of the lost vessel resource to industries needing it to transport their goods.

---

[1]U.S. Department of Commerce, National Oceanic and Atmospheric Administration, "Assessing the Social Costs of Oil Spills: The AMOCO CADIZ Case Study", July, 1983.

6.2.3 Use value[2]

The value of a natural resource based on its use to society is its "use value". The possible uses of resources considered by CERCLA regulations include recreational, agricultural, commercial, aesthetic, and extractive (mining).

6.2.4 Willingness-to-pay

The dollar value of natural resources is measured by the "willingness-to-pay" methodology for the purposes of the Port Needs Study, since individuals are "willing to pay" to preserve, for instance, endangered species or pristine coastline, using resources that might otherwise be used to purchase goods or services in the marketplace.

---

[2] U.S. Department of the Interior, "Techniques to Measure Damages to Natural Resources," June 1987.

6.3 DAMAGE TO ANIMAL SPECIES AND ENVIRONMENT DUE TO A SPILL

6.3.1 Background

When a vessel casualty produces a spill of its cargo or fuel, environmental damages may occur if the spilled material is toxic to organisms living in waters exposed to the substance or if it destroys the aesthetic beauty of the water or shoreline. These damages directly affect not only people who rely on those resources for their livelihoods, but also people who use them for recreation and enjoyment. Further, the simple existence of natural resources in a pristine state is indirectly important to many people.

Placing a value on a natural resource that has been lost or damaged is a controversial and somewhat subjective process, and the value may vary widely according to the valuation method used and the valuator. The use or the importance of the natural resource has a great deal to do with its value. Valuation of a natural resource with a tangible use, such as a food source, is less controversial than valuation of one whose value lies merely in its existence. The use value as determined by the willingness-to-pay method, generally accepted in the literature as most appropriate for natural resources, is the value determined by this analysis.

6.3.2 Natural Resource Damage Assessment Model for Coastal and Marine Environments[3]

Numerous small scale spill damage assessment models have been developed for specific spills and specific ports, but only one model was identified for application throughout the United States, the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME). It was developed by the Department of the Interior (DOI) as part of CERCLA regulations for assessing damages due to Type A spills of hazardous materials. It estimates the lost use values of damaged natural resources, specifically, animal species. The value of damaged vegetation and habitat is reflected in the model as they affect the food chain of the animal species, causing decreased primary and secondary productivity up the food web.

NRDAM/CME underwent rigorous testing and was reviewed by the public before inclusion in the regulation. However, in two 1989 federal court rulings, the assessment procedures advocated by DOI and represented in NRDAM/CME were struck down as not in the "spirit of

[3]This section is based on information from "Measuring Damages to Coastal and Marine Natural Resources, Concepts and Data Relevant for CERCLA Type A Damage Assessments", Volume I, U.S. Department of the Interior, January, 1987.

CERCLA".[4] DOI regulations under CERCLA measured natural resource damages as the lesser of either the costs of replacing or restoring damaged resources, or the costs of the lost use value of the resources. The rulings stated the latter measure was to be used only when replacement costs were grossly disproportionate to the value of the resource. NRDAM/CME bases its assessment of natural resource value on the latter and less preferred resource damage measure. DOI was ordered to modify its assessment techniques, but has not yet complied. In the meantime, the Oil Pollution Act transferred responsibility for natural resource damage assessment to the National Oceanographic and Atmospheric Administration (NOAA), which has only just begun to develop new regulations and procedures.[5] Consequently, NRDAM/CME, in spite of its limitations, remains the only comprehensive model available, and the only practical option for the Port Needs Study.

Description of NRDAM/CME

The NRDAM/CME estimates the effects on marine animal life of 469 petroleum and chemical substances spilled into the sea in terms of both quantity and economic value of organisms killed. Originally applicable to marine and estuarine environments in ten U.S. "provinces" or regions, the model was modified to represent the species found in the 23 ports of the Port Needs Study.[6] Given the details of a spill, such as substance spilled, quantity, date, wind and current speeds and directions at time of spill, location of spill relative to land, and other information, the model demonstrates the dispersion of the substance in the water and air and its effects on marine organisms, and estimates the economic value of losses not only in the year of the spill, but also out to 20 years following the spill. NRDAM/CME has additional features of estimating the loss of recreational use of public beaches closed because of spills, and of estimating the lost commercial fishing catch if areas are closed because of spills. The model is written in three modules described below.

---

[4]Statement of Edmund Welch, chief counsel for the House Merchant Marine and Fisheries Committee, on the ruling of the federal court in "Ohio v. U.S. Department of the Interior" and "Colorado v. U.S. Department of the Interior".

[5]Golob, Richard, "Golob's Oil Pollution Bulletin," January 18, 1991, p.1, p.4.

[6]Applied Science Associates, Inc. of Narragansett, RI, the original developers of NRDAM/CME, performed the modifications to the computer model and species data bases for the Port Needs Study.

Physical fates submodel

This submodel estimates the distribution of the contaminant on the sea surface, in the water column, and in the sediments over time. It takes into account the sea state and weather conditions, the currents and tides, the climate and the physical properties of the substance spilled in determining the contaminant's fate.[7]

Biological effects submodel

This submodel estimates both immediate losses resulting from a spill in terms of biomass or numbers of organisms killed and biomass not produced in the future due to the initial kill and to loss of food resources. The initial or short-term kill occurs during the time when the spill first occurs until the contaminant is dispersed to where concentrations are below toxic levels.[8] The long-term loss is usually determined by the lost recruitment of larvae and juveniles killed at the time of the spill, lost future growth of adults killed at the time of the spill, changes in productivity of specific trophic levels, and chronic effects of sublethal concentrations of the contaminants in the tissues and organs of those species inhabiting the area affected by the spill. Due to the general nature of the current model, it is assumed that the food web structure is not changed, predator-prey relationships are not changed and reproductive potential is not changed. Therefore, the impacts estimated are direct effects on long-term productivity and yield.[9]

Individual animal species are grouped by their ecological role into fourteen categories, defined in Table 6-1 below. The individual species included in the model and the species categories to which they are assigned are listed in Appendix 6-A. A more detailed discussion of the biological effects submodel is presented in the documentation to the NRDAM/CME model and in the French & French paper cited above.

---

[7]"Measuring Damages to Coastal and Marine Natural Resources", Volume I, U.S. Department of the Interior, January, 1987, p. II-1.

[8]French, Deborah P. and Fred W. French III, "The Biological Effects Component of the Natural Resource Damage Assessment Model System", Oil & Chemical Pollution 5, (1989), pp. 125-163.

[9]Ibid.

TABLE 6-1. SPECIES CATEGORY DEFINITIONS[10]

	Category	Habitat	Examples
1.	Anadromous fish	upper water column	salmon, alewives, shad
2.	Planktivorous fish	upper water column	menhaden, herring, butterfish, mackerel
3.	Piscivorous fish	upper water column	bluefish, striped bass, angler fishes, weakfish
4.	Top carnivores	entire water column	tuna, bonito, sharks
5.	Demersal fish	lower water column	flat fishes
6.	Semi-demersal fish	entire water column	cod, hake, scup, sea bass, groupers, snappers
7.	Mollusks	sediments	clams, mussels, oysters
8.	Decapods	sediments	shrimp, lobsters, crabs
9.	Squid	entire water column	squid, cuttlefish
10.	Mammals	surface	fur seals, sea otters
11.	Waterfowl	surface near shore	ducks, geese, swans
12.	Shorebirds	intertidal	sandpiper, plovers, turnstones
13.	Seabirds	surface	cormorants, loons, pelicans, puffins, shearwaters
14.	Raptors*	surface, intertidal	hawks, eagles

* This category was added in a modification of NRDAM/CME for the Port Needs Study.

[10] "Measuring Damages to Coastal and Marine Natural Resources", Volume I, p. III-2.

Adult and juvenile losses are calculated for each species group, and in addition, for categories 1-9 (fish and invertebrates) larval losses are calculated separately. Plant and habitat losses are reflected in the model as they affect the food chain of the animal species, causing decreased primary and secondary productivity up the food web. The submodel tracks the effects of losses on species categories out to twenty years following the spill.[11]

Economic damages submodel

This submodel assigns an economic value to the losses calculated in the previous submodel. The dollar values of the losses are based on the lost in situ use value of the resources, as measured by the economic concept of willingness-to-pay. For commercially harvested species of fish and invertebrates, only the portion of the kill that would have been caught is valuated; similarly, for recreationally harvested species. For waterfowl and mammals that are hunted, the portion that would have been hunted is valued differently from the portion that would have been enjoyed in non-consumptive ways, such as viewing, photographing, or feeding. Other species categories are valued for their non-consumptive uses only.[12]

The price indexes in the NRDAM/CME data base were developed in 1982 dollars, and are listed in the appendix to the NRDAM/CME documentation. Rather than modifying the data base, the prices were adjusted to 1990 dollars during each program run by using a Consumer Price Index ratio of 1990 to 1982 dollars of 129.6. The value of raptors, a new species category, was taken to be $135 in 1990 dollars, based mainly on a case study of the effects of the T/V "Puerto Rican" oil spill on birds off the coast of San Francisco.[13]

Modification of model

To make it more representative of the study zones, data bases were developed to reflect the species occurring at each zone, instead of the provinces in the original model. A maximum of three databases was developed for each zone, reflecting the species found in tidal fresh, estuarine and marine

---

[11]Ibid., pp. III-1 and III-3.

[12]Ibid., pp. V-1 - V-4.

[13]U.S. Department of Commerce, National Oceanic and Atmospheric Administration, "Resource Damage Assessment of the T/V "Puerto Rican" Oil Spill Incident" prepared by James Dobbin Associates, Inc., 1986.

environments. Modifications were also made to allow batch processing of the model runs.

The 23 port-specific species data bases contain the species presence, density and seasonality for fish, fish larvae and birds. Volume II of the Port Needs Study contains the species data bases for individual ports. Density is in grams per square meter for fish, number per square meter for larvae, and number per square kilometer for birds. The data were obtained from an extensive review of published data and through personal communication with authorities at state and federal agencies, universities, and conservation groups. Specifically, literature reviews were conducted at:

- University of Rhode Island Graduate School of Oceanography Library

- University of Rhode Island Sea Grant Office

- Applied Science Associates, Inc. in-house library

In addition, the U.S. Fish and Wildlife Service, the NOAA Strategic Assessment Branch, several U.S. Environmental Protection Agency laboratories, and several state universities and departments of natural resources were contacted for current data on their work. The National Audubon Society also provided bird counts for some areas. For one port, Mobile, the provincial data base was used due to unavailability of more specific data. Occasionally, data were unavailable for the specific port under study, and data for nearby areas were used to represent the port. Marine fish and fish larvae numbers were often taken from large study areas and an average density reported. Estuarine numbers are often averages of similar habitats within the province when specific data were unavailable.

6.3.3 Development of spill scenarios

A hypothetical spill site was determined and scenarios were developed for each subzone based on a number of criteria. Maps showing the spill site locations in each port are found in Appendix 6-B.

- The site was placed in the navigation channel toward the center of the subzone.

- It was located near a known obstacle, such as a shoal or anchorage area, or a convergence point of traffic lanes.

- For subzones with wide-ranging environments and those covering a large area, multiple spill sites were chosen.

Scenarios were developed for spills of hazardous materials, reflecting typical conditions under which the spills might occur. Limiting assumptions were made to minimize the number of model runs required. Appendix 6-C shows the specific data used to define the scenarios for Boston, selected as an illustrative example of the 23 VTS study zones.

- Predominant weather conditions for the zone were used rather than worst case conditions.

- Only those hazardous commodities passing through each subzone in the greatest quantities based on annual Army Corps of Engineers data were assumed to have spilled.

- Four spill sizes were analyzed for each commodity and spill site. The categorization of spill sizes was based on categories defined by the Coast Guard in 40 CFR Part 300, as well as by environmental groups, and agencies that are involved with monitoring and classifying spill data. The categories are shown in Table 6-2. NRDAM was run only for small, medium and large spills. Since the damages resulting from a catastrophic spill would be more severe than those of a CERCLA Type A spill, it would not be appropriate to use the model to estimate them. Catastrophic spills would not only cause decreases in the size and productivity of the fisheries, but also might affect fish market prices, seafood processors and other supporting businesses. Shellfish beds and fishing areas would likely be closed for lengthy periods of time.

TABLE 6-2. SPILL SIZE CATEGORIES

SPILL SIZE	RANGE	SIZE USED AS POINT ESTIMATE
Small	0 - 10,000 gal.	8,000 gal.
Medium	10,000 gal.- 100,000 gal.	90,000 gal.
Large	100,000 gal.- 750,000 gal.	500,000 gal.
Catastrophic	750,000 gal.+	4,000,000 gal.

Catastrophic damages are estimated as a function of damages from a large spill. In most cases, the damages due to a large spill of 500,000 gallons was multiplied by a factor of 8 to obtain an estimate of damages due to a catastrophic spill of 4,000,000 gallons. Exceptions were made when the result approached or exceeded the overall value of the fishery for the zone according to National Marine Fisheries Service data on the value of the landed catch, and a lower factor was used.

- Uniform bottom characteristics and water depth were assumed throughout the subtidal areas within each subzone.
- The model was run for each season of the year.
- The effect of closing shellfish beds and fisheries was not estimated. The costs of closures, however, would be quite significant if they lasted for a long period of time or if alternate fishing grounds did not exist. They would inflict a loss not only on the fishing industry, but also to secondary industries relying on fish as their raw materials. Long-term loss of a fishery might also result in higher fish market prices.
- The movement of the spill was monitored by the NRDAM/CME model. It was assumed that when the spill came in contact with the shoreline, the substance remained on shore. The beach carrying capacity was not determined and the substance did not respill into the water. When the spill came ashore, the amount of the substance reaching the shore was noted and an intertidal run using that amount determined the environmental damage in the intertidal region.
- When the slick left the boundaries of the port (greater than 1,000 kilometers into the open ocean), no further runs were made. When a slick left the boundaries of a subzone and entered a subzone of a different marine environment, then another run was made for the portion of the original slick that migrated into the new environment. In certain weather and seasonal conditions, the slick sometimes moved back and forth over the subzone boundaries according to tidal currents. If the slick was in the original subzone the majority of the time, no further runs were made.

6.3.4 Results

Table 6-3 shows the dollar value of species losses by subzone, hazardous commodity spilled and spill size. The loss value reflects the total dollar loss of the fourteen species groups of Table 6-1, including future year effects of each spill measured in constant 1990 dollars. Detailed losses both in physical units and in dollars for each species category are illustrated for Boston in Appendix 6-D. Physical units for fish, shellfish and invertebrates are pounds and physical units for birds and mammals are individual organisms.

The severity of losses resulting from a given spill scenario depends on many variables, as indicated by the extent of spill information required by the model. The effects of the variables are interrelated, and thus difficult to identify individually. However, analysis of the results reveals some general trends and patterns.

- Holding other conditions constant, damages increase with the amount spilled.

- Among petroleum and petroleum products, the damages to fish and shellfish increase and the damages to birds and mammals decrease as the product becomes more refined. The toxicity of unrefined crude and of residual fuel oil to organisms living in the water, for example, is not as great as that of highly refined gasoline. Toxins in gasoline will affect organisms in two significant ways: 1) toxins will kill larvae in the water column affecting population numbers in years to come, and 2) toxins will sink to the sediments, where they will remain for years and cause long-term damage to bottom-feeding and bottom-dwelling species.

- Commodities such as residual fuel oil that tend to float on the water's surface or to foul the beaches, cause significant losses to birds and mammals which feed there, while commodities such as gasoline tend to evaporate from the water's surface before harming significant numbers of birds.

- When a hazardous commodity reaches an intertidal area such as a marsh, damages increase dramatically, because the intertidal ecosystem, where many deepwater organisms spawn, hosts larvae which are more vulnerable to these commodities than adult fish. Significant damages to larvae are manifested years after the spill in decreased productivity of the species.

According to Table 6-3, the greatest damages to natural resources occur in the ports on the Gulf of Mexico and in Chesapeake North/Baltimore, MD due to spills of gasoline and alcohol. Although spills of gasoline and alcohol appear to vanish because a significant portion evaporates quickly, their toxins remain in the environment indefinitely by sinking into the sediments, as explained above. These ports are characterized by extremely high concentrations of shellfish, oysters and rangia in the Gulf ports and mussels and oysters in Chesapeake North/Baltimore, MD, which are extremely susceptible to the effects of the toxins in the sediments. The toxins also cause harm in the water column to shrimp and blue crab larvae, found in high concentrations in the Gulf and the Chesapeake, respectively.

In contrast, Puget Sound, known for its productive fisheries, shows relatively low damages due to spills of hazardous commodities. Its deep waters cause the materials spilled to disperse more quickly to concentrations that are tolerable to adult fish; the depth also makes it less likely that toxins will settle in the sediments in high concentrations. Salmon spawning upriver are not exposed to pollutants from spills downriver in the Sound.

TABLE 6-3. NATURAL RESOURCE LOSSES DUE TO SPILLS OF HAZARDOUS COMMODITIES BY SPILL SIZE AND LOCATION
(Page 1 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE SMALL	MEDIUM	LARGE	CATASTROPHIC
01 - Boston				
0101				
2911 (gasoline)	8	110	621	4,968
2912, 2913 (kerosene)	1	15	122	976
2914 (#2 fuel oil)	7	122	518	4,144
2915 (#6 fuel oil)	2	23	126	1,008
0102				
2911 (gasoline)	11	135	760	6,080
2912, 2913 (kerosene)	1	20	142	1,136
2914 (#2 fuel oil)	7	130	548	4,384
2915 (#6 fuel oil)	2	23	124	992
0103				
2911 (gasoline)	25	371	2,316	18,526
2912, 2913	2	37	226	1,808
2914 (#2 fuel oil)	13	203	968	7,744
2915 (#6 fuel oil)	3	35	195	1,560
0104				
2911 (gasoline)	32	432	2,567	20,536
2912, 2913 (kerosene)	3	46	273	2,184
2914 (#2 fuel oil)	10	85	340	2,720
2915 (#6 fuel oil)	4	41	225	1,800
0105				
2911 (gasoline)	13	164	1,009	8,072
2912, 2913 (kerosene)	1	25	187	1,496
2914 (#2 fuel oil)	11	134	535	4,280
2915 (#6 fuel oil)	3	35	192	1,536
02 - Puget Sound				
0201				
1311 (crude)	71	445	2,018	16,144
2911 (gasoline)	3	30	185	1,480
2915 (#6 fuel oil)	53	468	2,451	19,608
0202				
1311 (crude)	56	339	923	7,384
2911 (gasoline)	13	146	680	5,440
2915 (#6 fuel oil)	33	227	882	7,056
0203				
1311 (crude)	15	155	897	7,176
2911 (gasoline)	20	407	3,245	25,960
2914 (#2 fuel oil)	22	432	2,799	22,392
2915 (#6 fuel oil)	17	184	1,014	8,112

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 2 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE: SMALL	MEDIUM	LARGE	CATASTROPHIC
02 - Puget Sound				
0204				
1311 (crude)	39	140	472	3,776
2911 (gasoline)	4	175	1,925	15,400
2914 (#2 fuel oil)	29	301	1,642	13,136
2915 (#6 fuel oil)	19	100	441	3,528
0205				
2810 (sodium hydroxide)	7	22	99	792
2911 (gasoline)	1	12	75	600
2914 (#2 fuel oil)	7	54	272	2,176
2915 (#6 fuel oil)	8	75	398	3,184
0206				
2810 (sodium hydroxide)	5	432	3,397	27,176
2911 (gasoline)	26	539	8,387	67,096
2915 (#6 fuel oil)	6	66	367	2,936
0207				
1311 (crude)	5	64	443	3,544
2911 (gasoline)	26	556	9,498	75,984
2914 (#2 fuel oil)	23	502	2,991	23,928
2915 (#6 fuel oil)	6	67	370	2,960
0209				
2915 (#6 fuel oil)	7	70	382	3,056
0210				
1311 (crude)	9	112	688	5,504
2915 (#6 fuel oil)	12	133	737	5,896
03 - Los Angeles, Long Beach				
0301				
1311 (crude)	20	91	438	3,504
2915 (#6 fuel oil)	53	203	590	4,720
0302				
1311 (crude)	21	99	477	3,816
2915 (#6 fuel oil)	53	204	596	4,768
0303				
1311 (crude)	21	101	478	3,824
2915 (#6 fuel oil)	54	207	606	4,848
0304				
1311 (crude)	49	608	3,698	29,584
2915 (#6 fuel oil)	65	736	4,100	32,800
04 - Santa Barbara				
0401				
1311 (crude)	42	450	2,667	21,336
2911 (gasoline)	5	262	2,882	23,056
2914 (#2 fuel oil)	42	508	2,920	23,360
2915 (#6 fuel oil)	61	672	3,725	29,800

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 3 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE SMALL	MEDIUM	LARGE	CATASTROPHIC
05 - Port Arthur				
0501				
1311 (crude)	42	381	1,806	14,448
2911 (gasoline)	341	2,984	14,172	113,376
2914 (#2 fuel oil)	416	3,362	16,084	128,672
2915 (#6 fuel oil)	59	255	1,346	10,768
0502				
1311 (crude)	16	343	1,787	14,296
2813 (alcohol)	3,500	31,618	142,418	569,672
2817 (benzene, toluene)	221	2,095	8,823	70,584
2911 (gasoline)	401	7,123	84,859	678,872
2914 (#2 fuel oil)	461	3,727	18,190	145,520
2915 (#6 fuel oil)	7	128	1,026	8,208
0503				
1311 (crude)	16	343	1,787	14,296
2911 (gasoline)	401	7,123	84,859	678,872
2914 (#2 fuel oil)	461	3,727	18,190	145,520
2915 (#6 fuel oil)	7	128	1,026	8,208
0504				
1311 (crude)	7	87	530	4,240
2813 (alcohol)	612	4,608	10,561	84,488
2817 (benzene, toluene)	19	174	577	4,616
2911 (gasoline)	41	2,857	16,161	129,288
2914 (#2 fuel oil)	10	99	566	4,528
2915 (#6 fuel oil)	7	89	535	4,280
06 - New Orleans				
0601				
1311 (crude)	51	189	539	4,312
2813 (alcohol)	324	2,583	10,479	83,832
2911 (gasoline)	32	322	1,678	13,424
2915 (#6 fuel oil)	164	677	1,867	14,936
0602				
1311 (crude)	31	263	1,296	10,368
2813 (alcohol)	374	18,120	86,521	692,168
2911 (gasoline)	185	3,658	67,025	536,200
2915 (#6 fuel oil)	13	129	933	7,464
0603, 0605, 0606				
1311 (crude)	12	136	739	5,912
2911 (gasoline)	38	315	1,335	10,680
2914 (#2 fuel oil)	112	579	1,705	13,640
2915 (#6 fuel oil)	9	100	587	4,696

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 4 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SMALL	MEDIUM	LARGE	CATASTROPHIC
06 - New Orleans				
0604				
1311 (crude)	16	395	2,761	22,088
2911 (gasoline)	3,171	59,855	334,962	2,679,696
2914 (#2 fuel oil)	808	6,450	18,321	146,568
2915 (#6 fuel oil)	8	105	791	6,328
07 - Houston, Galveston				
0701				
1311 (crude)	7	117	639	5,112
2813 (alcohol)	1,453	11,682	45,665	365,320
2817 (benzene, toluene)	67	648	2,711	21,688
2911 (gasoline)	131	1,346	6,740	53,920
2914 (#2 fuel oil)	173	1,438	7,362	58,896
2915 (#6 fuel oil)	2	20	286	2,288
0702				
1311 (crude)	19	371	1,784	14,272
2813 (alcohol)	10,339	76,458	263,926	1,055,704
2817 (benzene, toluene)	306	2,382	9,256	72,048
2911 (gasoline)	560	7,411	44,723	357,784
2914 (#2 fuel oil)	536	5,308	23,123	184,984
2915 (#6 fuel oil)	2	44	678	5,424
0703				
1311 (crude)	13	281	1,411	11,288
2813 (alcohol)	3,308	28,774	111,121	444,484
2817 (benzene, toluene)	209	1,826	7,888	63,104
2911 (gasoline)	348	4,387	27,780	222,280
2915 (#6 fuel oil)	7	116	745	5,960
08 - Chesapeake Bay				
0801				
2911 (gasoline)	7	105	608	4,864
2914 (#2 fuel oil)	10	117	710	5,680
2915 (#6 fuel oil)	7	40	176	1,408
0802				
2911 (gasoline)	7	101	655	5,240
2914 (#2 fuel oil)	7	120	729	5,832
2915 (#6 fuel oil)	5	34	159	1,272
0803				
2911 (gasoline)	4	55	350	2,800
2914 (#2 fuel oil)	3	57	346	2,768
2915 (#6 fuel oil)	2	26	146	1,168

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 5 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE: SMALL	MEDIUM	LARGE	CATASTROPHIC
08 - Chesapeake Bay				
0804				
1311 (crude)	3	22	117	936
2911 (gasoline)	5	70	472	3,776
2914 (#2 fuel oil)	6	79	422	3,376
2915 (#6 fuel oil)	3	28	151	1,208
0805				
2912 (jet fuel)	6	102	838	6,704
2915 (#6 fuel oil)	31	359	2,014	16,112
0806				
2911 (gasoline)	5	70	433	3,464
2912 (jet fuel)	0	8	71	568
2915 (#6 fuel oil)	30	340	1,909	15,272
09 - Baltimore				
0901				
2911 (gasoline)	8	145	2,700	21,600
2914 (#2 fuel oil)	19	262	2,198	17,584
2915 (#6 fuel oil)	30	338	1,896	15,168
0902				
2911 (gasoline)	10	339	20,970	167,760
2914 (#2 fuel oil)	23	346	7,217	57,736
2915 (#6 fuel oil)	29	324	1,816	14,528
0903				
2911 (gasoline)	16	11,093	191,159	1,529,272
2912 (jet fuel)	1	36	3,844	300,752
2914 (#2 fuel oil)	17	6,708	67,659	541,272
2915 (#6 fuel oil)	4	42	226	1,808
10 - Corpus Christi				
1001				
1311 (crude)	4	64	346	2,768
2911 (gasoline)	64	709	3,732	29,856
2914 (#2 fuel oil)	90	828	4,338	34,704
2915 (#6 fuel oil)	1	14	201	1,608
1002				
1311 (crude)	4	79	379	3,032
2911 (gasoline)	90	910	4,555	36,440
2914 (#2 fuel oil)	110	1,042	5,335	42,680
2915 (#6 fuel oil)	1	20	281	2,248
1003				
1311 (crude)	8	55	226	1,808
2911 (gasoline)	33	979	73,176	585,408
2914 (#2 fuel oil)	46	673	24,438	195,504
2915 (#6 fuel oil)	3	25	221	1,768

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 6 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE SMALL	MEDIUM	LARGE	CATASTROPHIC
10 - Corpus Christi				
1004				
1311 (crude)	8	55	226	1,808
2911 (gasoline)	33	979	73,176	585,408
2914 (#2 fuel oil)	46	673	24,438	195,504
2915 (#6 fuel oil)	3	25	221	1,768
11 - New York				
1101				
2911 (gasoline)	20	286	1,470	11,760
2914 (#2 fuel oil)	20	334	1,885	15,080
2915 (#6 fuel oil)	5	34	169	1,352
1102				
2911 (gasoline)	48	547	4,190	33,520
2914 (#2 fuel oil)	40	640	3,922	31,376
2915 (#6 fuel oil)	3	31	160	1,280
1103				
1311 (crude)	22	248	1,465	11,720
2911 (gasoline)	55	662	5,858	46,864
2914 (#2 fuel oil)	59	822	4,891	39,128
2915 (#6 fuel oil)	31	341	1,915	15,320
1104				
2911 (gasoline)	17	173	1,276	10,208
2914 (#2 fuel oil)	71	308	1,047	8,376
1105				
2911 (gasoline)	9	144	1,468	11,744
2914 (#2 fuel oil)	75	812	4,797	38,376
2915 (#6 fuel oil)	97	1,049	5,785	46,280
1106				
1311 (crude)	72	689	3,921	31,368
2911 (gasoline)	11	123	3,709	29,672
2914 (#2 fuel oil)	50	565	3,392	27,136
2915 (#6 fuel oil)	65	1,039	5,693	45,544
1107				
2911 (gasoline)	94	1,415	8,015	64,120
2914 (#2 fuel oil)	61	781	5,356	42,848
2915 (#6 fuel oil)	4	41	233	1,864
12 - Long Island Sound				
1201				
2911 (gasoline)	21	248	1,291	10,328
2914 (#2 fuel oil)	100	609	2,318	18,544
2915 (#6 fuel oil)	141	452	1,165	9,320

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 7 of 11)
($000)

ZONE SUBZONE COMMODITY	SPILL SIZE SMALL	 MEDIUM	 LARGE	 CATASTROPHIC
12 - Long Island Sound				
1202				
2911 (gasoline)	51	639	3,239	25,912
2914 (#2 fuel oil)	62	845	4,079	3,832
2915 (#6 fuel oil)	16	71	272	2,176
1203				
2911 (gasoline)	27	346	1,797	14,376
2914 (#2 fuel oil)	25	400	2,065	16,520
2915 (#6 fuel oil)	4	40	166	1,328
1204				
2914 (#2 fuel oil)	24	218	751	6,008
2915 (#6 fuel oil)	4	32	180	1,440
1205				
2911 (gasoline)	32	406	2,382	19,056
2914 (#2 fuel oil)	27	440	2,218	17,744
2915 (#6 fuel oil)	4	43	220	1,760
1206				
2914 (#2 fuel oil)	1	15	55	440
13 - Philadelphia				
1301				
1311 (crude)	49	180	637	5,096
2911 (gasoline)	59	634	4,945	39,560
2914 (#2 fuel oil)	52	1,010	5,565	44,520
2915 (#6 fuel oil)	47	264	1,117	8,936
1302				
1311 (crude)	16	78	382	3,056
2911 (gasoline)	35	508	3,572	28,5776
2914 (#2 fuel oil)	37	703	3,824	30,592
2915 (#6 fuel oil)	12	94	484	3,872
1303				
1311 (crude)	5	15	35	280
2911 (gasoline)	9	99	450	3,600
2914 (#2 fuel oil)	9	75	314	2,512
2915 (#6 fuel oil)	1	5	11	88
1304				
1311 (crude)	24	248	1,399	11,192
2911 (gasoline)	4	66	344	2,752
2914 (#2 fuel oil)	23	292	1,733	13,864
2915 (#6 fuel oil)	31	341	1,913	15,304
1305				
2911 (gasoline)	7	103	655	5,240
2914 (#2 fuel oil)	97	1,199	7,041	56,328
2915 (#6 fuel oil)	127	1,429	7,964	63,712

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 8 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE: SMALL	MEDIUM	LARGE	CATASTROPHIC
14 - San Francisco				
1401				
1311 (crude)	36	152	591	4,728
2914 (#2 fuel oil)	24	159	743	5,944
2915 (#6 fuel oil)	17	117	542	4,336
1402				
1311 (crude)	31	149	631	5,048
2911 (gasoline)	2	111	1,221	9,768
2914 (#2 fuel oil)	26	138	930	7,440
2915 (#6 fuel oil)	16	118	555	4,440
1403				
1311 (crude)	17	206	1,219	9,752
2914 (#2 fuel oil)	215	3,442	19,555	156,440
2915 (#6 fuel oil)	9	89	485	3,880
1404				
1311 (crude)	11	152	899	7,192
2915 (#6 fuel oil)	7	80	449	3,592
1405				
2911 (gasoline)	134	3,430	29,004	232,032
1311 (crude)	8	115	690	5,520
2915 (#6 fuel oil)	7	83	468	3,744
15 - Portland, OR				
1501				
1311 (crude)	105	362	949	7,592
2813 (alcohol)	54	481	1,972	15,776
2817 (benzene, toluene)	1	24	122	976
2911 (gasoline)	4	54	272	2,176
2914 (#2 fuel oil)	16	105	440	3,520
2915 (#6 fuel oil)	38	160	552	4,416
1502				
1311 (crude)	3	36	248	1,984
2911 (gasoline)	41	801	5,083	40,664
2914 (#2 fuel oil)	28	496	2,666	21,328
2915 (#6 fuel oil)	36	32	177	1,416
1503				
1311 (crude)	5	63	426	3,408
2911 (gasoline)	53	901	5,110	40,880
2914 (#2 fuel oil)	34	476	3,759	30,072
2915 (#6 fuel oil)	6	68	376	3,008
16 - Cook Inlet				
1601				
1311 (crude)	432	980	2,615	20,920
2912 (jet fuel)	12	67	258	2,064
2915 (#6 fuel oil)	185	462	1,253	10,024

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 9 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE SMALL	MEDIUM	LARGE	CATASTROPHIC
16 - Cook Inlet				
1602				
1311 (crude)	119	607	1,529	12,232
2911 (gasoline)	2	112	1,232	9,856
2912 (jet fuel)	21	108	401	3,208
2915 (#6 fuel oil)	58	339	1,293	10,344
1603				
1311 (crude)	9	27	53	424
2911 (gasoline)	10	80	468	3,744
2912 (jet fuel)	9	32	94	752
2915 (#6 fuel oil)	4	19	55	440
17 - Portland, ME				
1701				
1311 (crude)	12	41	143	1,144
2911 (gasoline)	6	80	462	3,696
2914 (#2 fuel oil)	11	95	416	3,328
1702				
1311 (crude)	21	137	640	5,120
2911 (gasoline)	9	121	741	5,928
2914 (#2 fuel oil)	20	199	977	7,816
1703				
1311 (crude)	10	108	652	5,216
2911 (gasoline)	10	218	1,987	15,896
2914 (#2 fuel oil)	16	177	919	7,352
1704				
1311 (crude)	15	112	563	4,504
2911 (gasoline)	14	214	1,107	8,856
2914 (#2 fuel oil)	20	280	1,415	11,320
18 - Portsmouth				
1801				
2913 (kerosene)	2	11	60	480
2914 (#2 fuel oil)	9	89	471	3,768
2915 (#6 fuel oil)	13	129	701	5,608
1802				
2913 (kerosene)	5	25	105	840
2914 (#2 fuel oil)	19	137	669	5,352
2915 (#6 fuel oil)	17	140	725	5,800
1803				
2913 (kerosene)	3	26	188	1,504
2914 (#2 fuel oil)	15	164	939	7,512
2915 (#6 fuel oil)	13	128	697	5,576

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 10 of 11)
($000)

ZONE SUBZONE COMMODITY	SPILL SIZE SMALL	MEDIUM	LARGE	CATASTROPHIC
18 - Portsmouth				
1804				
2913 (kerosene)	1	18	185	1,480
2914 (#2 fuel oil)	8	92	534	4,272
2915 (#6 fuel oil)	13	130	721	5,768
19 - Providence				
1901				
2911 (gasoline)	29	350	1,787	14,296
2914 (#2 fuel oil)	29	510	2,534	20,272
2915 (#6 fuel oil)	42	268	1,221	9,768
1902				
2911 (gasoline)	34	442	2,498	19,984
2914 (#2 fuel oil)	51	657	3,550	28,400
2915 (#6 fuel oil)	34	350	1,926	15,408
1903				
2911 (gasoline)	84	3,560	57,470	459,760
2914 (#2 fuel oil)	83	1,290	11,394	91,152
20 - Wilmington				
2001				
2813 (alcohol)	451	4,021	15,773	126,184
2911 (gasoline)	22	450	2,853	22,824
2914 (#2 fuel oil)	29	466	2,783	22,264
2915 (#6 fuel oil)	19	59	170	1,360
2002				
2813 (alcohol)	708	5,892	21,787	174,296
2911 (gasoline)	30	499	2,434	19,472
2914 (#2 fuel oil)	45	620	2,895	23,160
2915 (#6 fuel oil)	21	75	162	1,296
2003				
2813 (alcohol)	841	10,750	32,324	258,592
2911 (gasoline)	26	914	12,842	102,736
2914 (#2 fuel oil)	161	1,360	4,651	37,208
2915 (#6 fuel oil)	26	263	1,546	12,368
21 - Jacksonville				
2101				
2911 (gasoline)	22	466	2,923	23,384
2914 (#2 fuel oil)	26	488	2,847	22,776
2915 (#6 fuel oil)	20	230	1,355	10,840
2102				
2911 (gasoline)	75	1,047	7,652	61,216
2914 (#2 fuel oil)	38	336	1,657	13,256
2915 (#6 fuel oil)	23	263	1,530	12,240

TABLE 6-3. NATURAL RESOURCE LOSSES (Page 11 of 11)
($000)

ZONE / SUBZONE / COMMODITY	SPILL SIZE SMALL	MEDIUM	LARGE	CATASTROPHIC
22 - Tampa				
2201				
2911 (gasoline)	8	80	395	3,160
2914 (#2 fuel oil)	15	104	404	3,232
2915 (#6 fuel oil)	5	21	77	616
2202				
2912 (jet fuel)	26	250	1,125	9,000
2911 (gasoline)	98	666	2,570	20,560
2914 (#2 fuel oil)	153	1,148	5,935	47,480
2915 (#6 fuel oil)	24	243	1,500	12,000
2203				
2911 (gasoline)	13	149	751	6,008
2914 (#2 fuel oil)	21	238	1,263	10,104
23 - Mobile				
2301				
1311 (crude)	11	254	1,471	11,768
2911 (gasoline)	264	2,434	12,575	100,600
2914 (#2 fuel oil)	382	2,908	14,294	114,352
2915 (#6 fuel oil)	4	38	472	3,776
2302				
1311 (crude)	27	454	2,434	19,472
2911 (gasoline)	496	4,670	21,726	173,808
2914 (#2 fuel oil)	655	4,394	15,048	120,384
2915 (#6 fuel oil)	9	177	1,409	11,272
2303				
1311 (crude)	31	400	2,397	19,176
2911 (gasoline)	563	5,362	23,871	190,968
2914 (#2 fuel oil)	483	3,971	13,315	106,520
2915 (#6 fuel oil)	10	156	1,212	9,696
2304				
1311 (crude)	14	123	1,375	11,000
2911 (gasoline)	435	31,959	227,254	1,818,032
2914 (#2 fuel oil)	147	10,565	143,955	1,151,640
2915 (#6 fuel oil)	9	94	798	6,384
2305				
1311 (crude)	8	99	561	4,488
2911 (gasoline)	109	13,018	130,232	1,041,856
2915 (#6 fuel oil)	7	92	577	4,616

6.3.5 Bibliography

Adler, Jerry, 1989. Alaska after Exxon. Newsweek. September 18, 1989.

Environment Canada and BC Ministry of Environment, 1989. Nestucca Oil Spill: Impact Assessment on Avian Populations and Habitat. Technical Report Series No. 68. Canadian Wildlife Service, Pacific and Yukon Region, prepared by Michael S. Rodway, Moira J.F. Lemon, Jean-Pierre L. Savard, Richard McKelvey. Delta, BC.

Environment Canada and BC Ministry of Environment, 1989. The Nestucca Oil Spill: Preliminary Evaluation of Impacts on the West Coast of Vancouver Island. Prepared by ESL Environmental Sciences Limited. Vancouver, BC.

French, Deborah P. and Fred W. French, "The Biological Effects Component of the Natural Resource Damage Assessment Model System", Oil & Chemical Pollution 5. 1989.

Hodgson, Bryan, 1990. Alaska's Big Spill, Can the Wilderness Heal? National Geographic. January, 1990.

Minerals Management Service, 1984. Analysis of Oil Discharges from Proposed Tankering Operations in Eastern Gulf of Mexico. Prepared by National Oceanic and Atmospheric Administration, Strategic Assessment Branch. Metairie, LA.

National Oceanic and Atmospheric Administration, 1983. Assessing the Social Costs of Oil Spills: The Amoco Cadiz Case Study. Washington, DC.

National Oceanic and Atmospheric Administration, 1986. Assessment of Economic Damages to the Natural Resources of New Bedford Harbor: Damages to the Commercial Lobster Fishery. Prepared by Department of Agricultural and Resource Economics, University of Maryland and Industrial Economics, Inc. Rockville, MD.

National Oceanic and Atmospheric Administration, 1986. Resource Damage Assessment of the T/V Puerto Rican Oil Spill Incident. Prepared by James Dobbin Associates, Inc. under Contract Number 50-DGNC-6-00102. Washington, DC.

National Oceanic and Atmospheric Administration, 1984. The Use of Economic Analysis in Valuing Natural Resource Damages. Prepared by Environmental Law Institute. Washington, DC.

Pilson, Michael E.Q., 1990. Summary of Scientists' Response to the World Prodigy Oil Spill at Brenton Reef, Rhode Island, June 23, 1989. GSO Technical Report No. 90-1. University of Rhode Island, Narragansett, RI.

Stevens, Thomas, 1990. The Economic Value of Bald Eagles, Wild Turkeys, Atlantic Salmon, and Coyotes in New England. Resources and Environment: Management Choices, Cooperative Extension Service, University of Massachusetts. November, 1990.

Stevens, T. and T. Hager, 1989. Economic Value of Salmon Restoration in New England. Resources and Environment: Management Choices, Cooperative Extension Service, University of Massachusetts. May, 1989.

Storey, David A., 1987. The Difference between "Economic Impacts" and "Economic Benefits": A Sport Angler Example. Resources and Environment: Management Choices, Cooperative Extension Service, University of Massachusetts. September 1, 1987.

Storey, David A., 1984. New England's Commercial Ocean Fisheries. Resources and Environment: Management Choices, Cooperative Extension Service, University of Massachusetts. May 1, 1984.

Storey, David A., 1989. Oil Spills and Their Costs: Using Economic Analysis to Improve Policy. Resources and Environment: Management Choices, Cooperative Extension Service, University of Massachusetts. July, 1989.

Trudel, B.K., R.C. Belore, B.J. Jessiman and S.L. Ross, 1989. A Microcomputer-based Spill Impact Assessment System for Untreated and Chemically Dispersed Oil Spills in the U.S. Gulf of Mexico. Prepared for the American Petroleum Institute 1989 Oil Spill Conference. Ottawa.

U.S. Department of the Interior, 1987. Measuring Damages to Coastal and Marine Natural Resources: Concepts and Data Relevant for CERCLA Type A Damage Assessments. Volumes I and II. Prepared by Economic Analysis, Inc. and Applied Science Associates, Inc. Washington, DC.

U.S. Department of the Interior, 1987. Techniques to Measure Damages to Natural Resources. Prepared by Center for Economics Research. Washington, DC.

NOTE: The bibliography for the modifications to the species data base is included as Appendix 6-E.

6.4 DECREASE IN TOURISM AND RECREATIONAL USE AND IN PROPERTY VALUE OF SHORELINE AND HARBOR DUE TO SPILLS OF HAZARDOUS COMMODITIES

6.4.1 Background

This section addresses losses from spills of hazardous substances to tourism and recreational uses of coastal shoreline and waters and to values of shoreline properties. Marine-related recreational activities, such as beach use, swimming and surfing, water sports, boating, fishing, and wildlife observation, require clean water and unspoiled coastal areas, and are negatively affected when spills occur. Both local residents and visitors to the spill area are forced to participate in alternate activities or to forego their planned activities. In addition, spills cause a decrease in property values temporarily until the spill is cleaned up and the memory of the spill fades from the public memory.

This section estimates net costs to the U.S. as a whole, rather than individual localized costs. Losses to commercial entities in the vicinity of a closed beach, for example, may be gains to commerce in the vicinity of beaches experiencing increased usage by people displaced from the closed beach, yielding no net loss to society.

6.4.2 Methodology

Recreation and tourism losses

A model was developed to predict tourism and recreation losses due to spills of crude petroleum.[14] Some of the model's attributes are outlined below. A thorough discussion of the model can be found in the Kearney report.

- The model predicts losses in a region[15] as a function of the estimated number of recreational user-days impacted by a spill, the value of the types of recreation pursued in the region, and the length of shoreline affected by a spill in the region.

---

[14]The model is fully documented in Chapter 10.0, "Spill-related Recreation and Tourism Losses", of the preliminary draft report entitled "Methodology for Estimating the Environmental Costs of OCS Oil and Gas Exploration, Development, Production, and Transportation", written by A. T. Kearney, Inc., Kearney Centaur Division and published in November, 1990.

[15]The regions are Outer Continental Shelf (OCS) Planning Areas, defined in Appendix 6-F, taken from the Kearney preliminary draft report cited in the previous footnote.

- The willingness-to-pay method is used to determine the cost of a recreational user day for the U.S. as a whole. The costs are determined for two types of recreation: the first is shore-based recreation, such as beach activities and swimming; the second is at-sea recreation, such as waterskiing and sailing.

- The model separates user counts and values into two groups: residents and tourists. Tourists are further separated into U.S. and foreign.

- The duration of a spill's effects is assumed to be 35 days, based on an analysis of historical spills. Seasonality of usage is averaged.

- The model assumes that during the period of spill impact all recreational use of the affected area is either lost or shifted to substitute sites. Specifically, it assumes the user will substitute an alternate for the desired activity about 75% of the time, in which case half the value of the desired experience will be lost, and the user will not be able to find a substitute about 25% of the time, in which case the entire value of the experience will be lost.

- The model is driven by the amount of oil spilled which reaches shore and the length of coastline it soils. Based on a historical analysis of a sample of spills, the model assumes that each barrel of oil reaching shore contaminates 0.0036 miles of shoreline.

- There is some overlap between the values of recreational activities estimated in this model and the value of decreased recreational fishing estimated by the NRDAM/CME.

The Kearney model was developed only for spills of crude petroleum. Losses due to spills of petroleum products are taken to be 75 percent of the losses due to crude petroleum, since effects of more refined products, at least visibly, have a shorter duration. Effects of other chemicals were not estimated because it was not possible to identify any studies that quantified them.

The Kearney model produced estimates of recreation and tourism losses for spills in each OCS region. The estimate for losses in a particular VTS port was taken to be the same as that for the corresponding OCS planning area.

Property value losses

A second model was developed to predict property value losses due to spills of crude petroleum.[16] Some attributes of the model are outlined below.

- The model estimates property value losses for land held by individual property owners. Property losses occur whether or not the property changes hands; they are equivalent to the decrease in rent the owner would experience while the property was damaged or perceived to be at risk. Only the portion of coastal property in each zone which has a non-industrial use is included in the valuation.

- The model is port-specific in that property values are based on a survey of current waterfront property values in the 23 study zones of the Port Needs Study. The property values per front foot used in the model, as well as some of the intermediate steps in the derivation of the model results, are shown for the 23 study zones in Appendix 6-G.

- The model assumes that five percent of the total property value is lost initially after the spill, and that the property gradually returns to its full market value by the end of the year. On average, a 2.74 percent decrease is experienced for the year.

- Like the model for recreation losses, the property value model is driven by the amount of oil spilled which reaches shore and the length of coastline it soils. Based on a historical analysis of a sample of spills, the model assumes that each barrel of oil reaching shore contaminates 0.0036 miles, or 16 feet, of shoreline.

The property value model was developed only for spills of crude petroleum. Losses due to spills of petroleum products are taken to be 75 percent of the losses due to crude petroleum, since effects of more refined products, at least visibly, have a shorter duration. Effects of other chemicals were not estimated because it was not possible to identify any studies that quantified them.

---

[16]The model is based on 1) Chapter 8.0, "Property Losses" in a preliminary draft report written by A.T. Kearney, Inc. entitled "Methodology for Estimating the Environmental Costs of OCS Oil and Gas Exploration, Development, Production, and Transportation" and published in November, 1990; and 2) the results of a telephone survey of real estate appraisers conducted by VNTSC to obtain information on current property values in VTS study zones.

6.4.3 Results

Results of the recreation and tourism loss model are presented in Table 6-4 and results of the property value loss model are presented in Table 6-5. The two tables show dollar losses per barrel of spilled substance reaching shore. Total losses for a particular spill are obtained by multiplying the appropriate table entry by the number of barrels that reach the shore. That amount as a percent of the entire amount spilled varies according to a number of factors, especially wind direction and speed and location of spill. The percentages used to obtain the number of barrels reaching shore for a particular spill size and spill site are found in Table 6-6.

TABLE 6-4. LOSSES TO RECREATION AND TOURISM DUE TO RELEASES OF PETROLEUM AND PETROLEUM PRODUCTS ($1990 PER BARREL REACHING SHORE)

	PORT	COMMODITY SPILLED	
		PETROLEUM	PETROLEUM PRODUCT
1.	Boston	213	160
2.	Puget Sound	341	255
3.	Los Angeles	2,524	1,892
4.	Santa Barbara	2,788	2,091
5.	Port Arthur	678	509
6.	New Orleans	678	509
7.	Houston/Galveston	678	509
8.	Chesapeake Bay	1,008	755
9.	Baltimore	1,008	755
10.	Corpus Christi	678	509
11.	New York	213	160
12.	Long Island Sound	213	160
13.	Philadelphia	1,008	755
14.	San Francisco	461	346
15.	Portland, OR	341	255
16.	Cook Inlet	3	2
17.	Portland, ME	213	160
18.	Portsmouth	213	160
19.	Providence	213	160
20.	Wilmington	593	444
21.	Jacksonville	593	444
22.	Tampa	421	316
23.	Mobile	253	190

TABLE 6-5. LOST PROPERTY VALUE DUE TO RELEASES OF PETROLEUM AND PETROLEUM PRODUCTS
($1990 PER BARREL REACHING SHORE)

	PORT	COMMODITY SPILLED	
		PETROLEUM	PETROLEUM PRODUCT
1.	Boston	614	460
2.	Puget Sound	2,104	1,578
3.	Los Angeles	10,522	7,891
4.	Santa Barbara	10,522	7,891
5.	Port Arthur	140	105
6.	New Orleans	70	53
7.	Houston/Galveston	526	395
8.	Chesapeake Bay	701	526
9.	Baltimore	701	526
10.	Corpus Christi	701	526
11.	New York	614	460
12.	Long Island Sound	1,228	921
13.	Philadelphia	701	526
14.	San Francisco	1,403	1,052
15.	Portland, OR	2,104	1,578
16.	Cook Inlet	140	105
17.	Portland, ME	701	526
18.	Portsmouth	701	526
19.	Providence	1,228	921
20.	Wilmington	526	395
21.	Jacksonville	526	395
22.	Tampa	2,104	1,578
23.	Mobile	526	395

TABLE 6-6. PERCENT OF SPILLED OIL AND OIL PRODUCT REACHING SHORE[17]

Commodity Code	Commodity Name	Percent
1311	crude oil	60%
2811	petroleum products	15%
2817	benzene, toluene	10%
2911	gasoline	10%
2912, 2913	kerosene, jet fuel	35%
2914	distillate fuel oil	45%
2915	residual fuel oil	70%

---

[17] These percentages are based on the average portion of spilled commodity reaching shore in a series of NRDAM/CME runs. They reflect the fact that a large portion of certain commodities, such as gasoline, evaporate quickly or become dispersed in the water column before becoming a threat to shorelines, while others, such as crude oil, mix with water slowly, float on the surface if not cleaned up immediately, and cause extensive soiling of the shore.

6.4.4 References

A.T. Kearney, Inc., Preliminary Draft Report "Methodology for Estimating the Environmental Costs of OCS Oil and Gas Exploration, Development, Production, and Transportation". Written under contract to U.S. Department of the Interior - Minerals Management Service. November, 1990.

Appraisal Associates of Houston, Houston, TX. Telephone conversation with Phil Wiles on May 31, 1991.

Appraisal Group of the Northwest, Seattle, WA. Telephone conversation on May 31, 1991.

ERA, Rocky Point, NY. Telephone conversation with Linda Albo on May 31, 1991.

Golden State Appraisal Company, Los Angeles, CA. Telephone conversation on May 31, 1991.

Maine Land Appraisers, Portland, ME. Telephone conversation with Dave Harrington on May 31, 1991.

Massachusetts Conservation Commission. Telephone conversation on May 31, 1991.

Michael Epstein Real Estate Appraisers, Swampscott, MA. Telephone conversation on May 31, 1991.

New Orleans Real Estate Appraisal Company, New Orleans, LA. Telephone conversation with Jim Shelby on May 31, 1991.

Southeast Real Estate Appraisal Corporation, Tampa, FL. Telephone conversation on May 31, 1991.

Valuation Economics, Inc., Baltimore, MD. Telephone conversation on May 31, 1991.

Wilson, William. Telephone conversation with Baltimore, MD realtor on May 31, 1991.

6.5 CLEANUP COSTS FOR SPILLS OF PETROLEUM, PETROLEUM PRODUCTS AND HAZARDOUS SUBSTANCES[18]

6.5.1 Background

Spills of petroleum, petroleum products and hazardous substances require extensive cleanup efforts to minimize their effects on the environment. The general cleanup techniques for petroleum products and other chemicals that float on the water surface consist of the following:

- containing the substance at sea using containment or absorbent booms
- siphoning the substance from the water surface using skimmers onboard vessels
- controlled burning of the substance
- application of chemical or biological dispersant or neutralizers
- siphoning the substance near the shore from the water surface with vacuum trucks

Removing substances from rocky shorelines is more difficult, requiring:

- spraying water onto the covered rocks and the use of waterborne skimmers to scoop the resulting slick of removed substance from the surface as it reenters the water
- shovelling solidified substances into containers or depositing them into plastic garbage bags
- wiping off rocks with absorbent rags
- removing contaminated sand using bulldozers and other large equipment
- using chemical fertilizers to stimulate oil-eating bacteria in the sand to break down petroleum products into harmless substances

---

[18]This section is based on "Develop Estimates of Costs Associated with Oil and Hazardous Chemical Spills and Costs of Idle Resources During Vessel Repairs", Eastern Research Group, Inc., November, 1990. This report is included in its entirety as Section 7 of this technical supplement.

Spills that enter marsh and grassland areas are most difficult to clean up, because in many situations more harm is caused by the cleanup efforts than by the substance itself. Allowing these areas to cleanse themselves over time is often the method opted for.

This section covers the costs associated with cleaning up hazardous substances from the environment, and does not address other costs associated with spills, such as the cost of environmental damages and the costs of the Coast Guard and other agencies and groups involved in responding to the incident and monitoring the cleanup effort. Environmental damage and response costs are covered in Sections 6.3 and 6.11, respectively.

6.5.2 Spill cleanup data base

A data base of about 650 spill incidents occurring both in U.S. waters and worldwide was assembled. The following factors were obtained whenever possible for each incident in the data base. These factors were considered to have significant influence on the overall costs of a cleanup.

- Substance spilled
- Amount spilled
- Location of spill (in terms of country, distance from shore, depth of water, type of body of water)
- Date of spill
- Where spill migrated (did the spill hit the shoreline)
- Cleanup methods used
- Amount of spilled substance recovered during cleanup
- Length of cleanup effort
- Weather and sea state at time of spill
- Cost of cleanup effort, excluding government agency costs of emergency response and of monitoring the operations

These data were assembled from a variety of sources, both domestic and international, because a comprehensive source of these data does not exist. Data on spill circumstances and cleanup costs were located in the following sources:

- U.S. Coast Guard files on major spill events held at the Marine Environmental Response office (MER) in Washington, DC; files on federalized spills occurring in the First and Eighth Coast Guard Districts held at the Boston and

New Orleans MER offices; files on spill cleanup efforts from the Boston Marine Safety Office.

- Marine Pollution Incident Report system (MPIR), a computerized data base of three years of spill cleanups federalized[19] by the Coast Guard.

- Canadian Bureau of Management Consulting list of spills in Canadian waters between 1979 and 1987.

- Cases from two oil pollution compensation funds, the International Tanker Owners Pollution Federation Limited and the International Oil Pollution Compensation Fund.

- Golob's "Oil Pollution Bulletin", and miscellaneous sources.

- A draft report for the Minerals Management Service by Kearney/Centaur.

Although the MPIR provided the greatest number of incidents, 450, to the data base, it did not contain as much information on the factors surrounding the incidents as the other sources, which were often narrative in nature. Total cleanup costs as provided by MPIR were separated into Coast Guard expenses and cleanup contractor expenses to obtain data comparable to that from the other sources.

Since only five of the cases in the data base were positively identified as spills of hazardous chemicals other than oil or oil products, the analysis below does not cover spills of chemicals. By default, chemical spills are treated like oil product spills, unless the characteristics of the chemical render extensive cleanup efforts unnecessary in the event of a spill.

6.5.3 Methodology

Regression methods were applied to the data to develop a statistical relationship for the cost of spill cleanup efforts as a function of explanatory variables. The analysis revealed that spill size is the most significant factor, explaining over 75 percent of the cleanup cost. Various functional forms of independent and dependent variables were examined, as well as equations using different combinations of independent variables. The relationships explored in this analysis are summarized in Table 6-7 below. Section 7 of this technical supplement contains more detailed results.

---

[19] A spill cleanup is federalized for any one of three reasons:
1. The spiller cannot be identified.
2. The spiller is unable to assume responsibility for cleanup operations.
3. The Coast Guard finds the spiller's cleanup efforts unsatisfactory.

TABLE 6-7. SUMMARY OF REGRESSION RESULTS IN CLEANUP COST ANALYSIS

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	R-SQUARE	NUMBER OBSERV.
1. cleanup cost	spill size	0.0424	653
2. cleanup cost	spill size square of spill size	0.1125	653
3. cleanup cost	ln of spill size	0.0515	653
4. cleanup cost/gallon	spill size	0.0001	653
5. cleanup cost/gallon	spill size square of spill size	0.0002	653
6. cleanup cost/gallon	ln of spill size	0.0149	653
7. ln of cleanup cost	spill size	0.0400	653
8. ln of cleanup cost	spill size square of spill size	0.0909	653
9. ln of cleanup cost	ln of spill size	0.7536	653
10. ln of cleanup cost /gallon	spill size	0.0171	653
11. ln of cleanup cost /gallon	spill size square of spill size	0.0173	653
12. ln of cleanup cost /gallon	ln of spill size	0.2173	653
13. ln of cleanup cost	ln of spill size 1 if heavy oil; else 0 1 if chemical; else 0	0.7399	653
14. ln of cleanup cost	ln of spill size (chemical spills only)	0.1657	70
15. ln of cleanup cost	ln of spill size 1 if spill hit shore; else 0	0.7486	101
16. ln of cleanup cost	ln of spill size 1 if heavy oil; else 0 1 if spill hit shore; else 0	0.7605	101

TABLE 6-7. SUMMARY OF REGRESSION RESULTS IN CLEANUP COST ANALYSIS (Cont.)

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	R-SQUARE	NUMBER OBSERV.
17. ln of cleanup cost	ln of spill size (heavy oil only)	0.8095	371
18. ln of cleanup cost	ln of spill size (spills hitting shore only)	0.7467	92
19. ln of cleanup cost	ln of spill size (spills <= 1,000 gallons only)	0.2153	492
20. ln of cleanup cost	ln of spill size (spills > 1,000 gallons only)	0.5339	161
21. ln of cleanup cost	ln of spill size 1 if spill in U.S. waters; else 0	0.7414	653

The ninth relationship above between the natural logarithm of cleanup cost and the natural logarithm of spill size is both strong and statistically appropriate, with an R-squared of over 75 percent (the model accounts for over 75 percent of the variation in cleanup cost), and simple, requiring only one variable, spill size, as input for predicting cleanup cost. The addition of variables describing the type of material spilled, the spill's proximity to shore, and the country in which the spill took place did not add to the predictive power of the simpler model. Neither did the separate analysis of spills greater than and less than 1,000 gallons improve the results.

Model 9 was chosen for use in the Port Needs Study. The multiplicative model can be expressed as an additive model in natural logarithm form:

$$\text{Ln(cleanup cost)} = 4.7892 + (0.7232)\ \text{Ln(spill size)}$$

$$\text{Standard error [Ln(cleanup cost)]} = 1.3705$$

where Ln( ) is the natural logarithm of the quantity in parentheses

cleanup cost is the dollar amount spent in cleanup efforts in 1990 dollars

spill size is the amount of hazardous substance spilled in U.S. gallons

6.5.4 Results

Table 6-8 shows the results of applying the model to the same four spill categories used in Section 6.3 as well as 68 percent and 95 percent confidence intervals. The equation produces estimates that are somewhat low compared to costs of more recent spills in the U.S. One possible explanation is that the equation is based on data representing spills occurring during the ten-year period prior to 1990 and spills occurring not just in U.S. waters but worldwide. In recent years, the environmental focus of the U.S. public has forced spillers of hazardous materials to conduct more extensive cleanup efforts than they might have done in previous years. In addition, the cleanup goals do not require and resources available do not allow third world countries to achieve as thorough a cleanup as the U.S. To adjust for the possible tendency of the equation to underestimate cleanup costs in the current climate of environmental awareness in the U.S., the 97.5th percentile represented by the upper limit of the 95 percent confidence interval was chosen as the estimate of cleanup costs to be used in the cost/benefit analysis of the Port Needs Study.

TABLE 6-8. CLEANUP COSTS BY SPILL SIZE ($000)

Spill Size (gal.)	Cleanup Cost	68% Confidence Interval	95% Confidence Interval
8,000	80	(20; 315)	(5; 1,239)
90,000	460	(117; 1,811)	(30; 7,132)
500,000	1,590	(404; 6,261)	(103; 24,650)
4,000,000	7,154	(1,817; 28,167)	(461; 110,901)

6.6 LOSSES TO SUBSISTENCE HOUSEHOLDS[20]

6.6.1 Background

Native Americans in Alaska and the Pacific Northwest are the primary groups that participate in subsistence harvesting of foods. To Alaskan Native American communities, this activity is not only important economically, but also essential to their diet and culture. However, subsistence activities are not as extensive in the Pacific Northwest, nor are they as well documented. The special fishing rights of Native Americans in Puget Sound are generally used for commercial purposes rather than subsistence harvesting. Consequently, subsistence losses due to oil spills in the Pacific Northwest are not addressed in this section over and above commercial and recreational losses covered in previous sections of the supplement.

Wildlife has a subsistence value in addition to its value as a natural resource and as a commercial or recreational harvest, as covered in section 6.3. Subsistence losses are the costs of resources that cannot be harvested and the reduction in opportunities to participate in the harvesting experiences due to a spill of oil.

Valuation of subsistence losses has two components: the cost of the lost resources as represented by the alternate cost of substitute retail purchases of foodstuffs, and the cost of the experiential value lost in purchasing foodstuffs rather than hunting or fishing for them. No attempt was made to include cultural losses in this valuation.

This section assesses the effects of petroleum and petroleum products on subsistence harvesting. The effects of spills of chemicals are not specifically addressed, but are assumed to be similar to the effects of oil.

---

[20]This section is based on a chapter from a study by A.T. Kearney entitled "Methodology for Estimating the Environmental Costs of OCS Oil and Gas Exploration, Development, Production, and Transportation", Preliminary Draft Report. The report, dated November, 1990, describes a study performed under contract to the U.S. Department of the Interior - Minerals Management Service. The original sources of information in the discussion below can be found at the end of Chapter 13.0 "Spill and Non-spill Subsistence Losses" of the A.T. Kearney report.

6.6.2 Methodology

The model for subsistence losses due to an oil spill relies on the "alternative cost" method (Brown and Burch, 1989, as cited in the Kearney report). This method uses the cost of substitutes for resources destroyed by the spill as a proxy for the value of the lost resources themselves, but ignores both the value of the harvesting activity and the damage to cultural values. The subsistence model modifies the alternative cost to account for the experiential value, but takes no account of damages to cultural values.

First the annual per capita subsistence harvest levels by type of food harvested are developed for each of four Alaskan regions: the Arctic, Bering Sea, Kodiak/Shumagin and Gulf Coast. Next, using the alternative cost method, the annual values of subsistence harvest levels in each region are calculated.

Spill damages are then estimated in the following steps. The effects of oil spills on harvest activity and the time period it takes for the damaged resources to return to their pre-spill levels are analyzed for each region. The extent of the effects of varying spill sizes is estimated. Then the discounted present value of the future stream of economic damages to subsistence resource harvests is estimated. Finally the results are modified to reflect the lost experiential value of the harvest.

The model results for the Kodiak/Shumagin region are used to represent the expected subsistence losses for the VTS study zone of Cook Inlet, which lies in the geographic boundaries of that region.

A comprehensive description of the model, intermediate calculations, data sources and references can be found in the Kearney report.

6.6.3 Results

Table 6-9 shows the estimated subsistence losses by spill size. Subsistence losses, like other environmental losses in general, do not become significant until a large quantity of oil is spilled, and then rise at a faster rate than the increasing spill size.

TABLE 6-9. ALASKAN SUBSISTENCE LOSSES RESULTING FROM A SPILL OF PETROLEUM OR PETROLEUM PRODUCT ($000)

SPILL SIZE	LOSS
small	0.0
medium	5.1
large	12.3
catastrophic	6,109.2

6.7 DAMAGE ASSESSMENT

6.7.1 Background

When a spill occurs, the spiller must compensate the government and injured parties for damages to environmental resources, as well as pay for cleaning up the spill. The federal government (DOI or NOAA) and/or state environmental agencies usually assess the damages, and bill the responsible party for expenses. For small spills, the assessment may be a relatively simple process requiring some on-scene inspection and the use of NRDAM/CME to obtain an estimate of damages. Assessing damages from large spills may be quite complicated and costly, necessitating inspections, water and sediment testing, and special studies to determine both short- and long-term damages.

6.7.2 Results

Based on published references to damage assessment expenses for specific spills and conversations with NOAA representatives, the following costs of assessing damages resulting from spills of hazardous substances were estimated. The costs would be higher for persistent substances that remained in the environment for long periods of time.

TABLE 6-10. COSTS OF ENVIRONMENTAL DAMAGE ASSESSMENT FROM A SPILL OF PETROLEUM OR PETROLEUM PRODUCT ($000)

SPILL SIZE	COST
Small	no cost
Medium	$15.0
Large	$3,000.0
Catastrophic	$15,000.0

6.7.3 Bibliography

"Golob's Oil Pollution Bulletin". World Information Systems, Cambridge, MA. Issues referenced: 12/8/89, 1/5/90, 1/19/90, 4/13/90, and 6/22/90.

National Oceanographic and Atmospheric Administration, Office of Marine Assessment Division, Damage Assessment Branch. Telephone conversation with George Kinter on February 12, 1991.

6.8 VESSEL DAMAGE AND REPAIR COSTS[21]

A vessel casualty sets in motion a train of possible events depending on the precise nature and severity of the casualty and its location. The costs that result can vary widely. At one extreme, a vessel involved in a grounding may float free in a few hours when the tide rises and have only some scraped paint and minor damage above the waterline. At the other extreme, two vessels involved in a collision may suffer millions of dollars of damage apiece, block the waterway until they can be towed away, undergo repairs that take three months to complete, and cause a major release of a hazardous substance, triggering a cleanup response and causing severe environmental damage.

This section deals with costs of casualties stemming directly from damages to the VTS-addressable vessels involved. Costs covering the repair of the vessels and related charges are treated in detail here, while other social costs of idled vessels during their repair are only summarized, as the full discussion is found in Section 7 of this technical supplement. Costs are developed for individual vessels, rather than casualties. Consequently, the total cost of a collision between a passenger vessel and a barge-towboat combination would be the sum of the costs incurred by each of the three vessels involved in the casualty.

6.8.1 Background

Repair and Related Costs

Assessing the dollar value of "typical" damages is a complicated task. Because most vessels (except for barges) are unique, there are no "list prices" or standard manuals with which to estimate customary per-job repair charges. Some repair jobs can be performed on the spot, at a nearby dock, or at the nearest shipyard. Other repairs, on account of their complexity and/or the size of the vessel, can be undertaken only at a few special facilities. In addition, prices for repairs and vessels are highly negotiable for two reasons: the typical imbalance of supply and demand, and, where not restricted by government policy, a competitive international ship-building and repair market.

---

[21]This section is based on two studies conducted specifically for the Port Needs Study. The first, entitled "Vessel and Cargo Damage and Loss" and prepared in March, 1991 by Deanna Mirsky of EG&G/Dynatrend, Inc., provides the information on vessel repair and ancillary costs. The second, entitled "Develop Estimates of Costs Associated with Oil and Hazardous Chemical Spills and Costs of Idle Resources during Vessel Repairs" and prepared in November, 1990, by Jeff Cantin and John Eyraud of Eastern Research Group, Inc., provides information on other social costs attributed to damaged vessels in a casualty. The latter is included in its entirety as Section 7 of this technical supplement.

In addition to the repairs themselves, vessel casualties often necessitate the purchase of any or all of an assortment of extra services. It may, for example, be necessary to refloat a vessel and tow it to a scrapyard; tow or guide it to a dock or shipyard for repair; drydock it for below-the-waterline work; or clean its fuel or product tanks to free them of dangerous gases. Towing may be to a point a few hundred yards away, or, as with the Exxon Valdez, to a shipyard thousands of miles distant at the end of a multi-million-dollar odyssey. Leaking bunker fuel or hazardous products will affect the delicacy, and therefore the cost, of any of these operations. Lengthy and elaborate salvage procedures may cause prolonged channel closings and delay many vessels, especially when they occur in narrow, busy locations such as the Kill van Kull or the Houston Ship Channel.

Crew costs and lost revenue are treated under other social costs of vessel casualties in this section, and the impacts of bridge closings and channel blockage and federal response costs are treated in other sections.

Other social costs

During times of full utilization of the world vessel fleet, a vessel's unavailability while being repaired as a result of a casualty represents an idled resource that imposes a cost on society. The various costs that accrue to the shipowner over and above the repair costs and lost profit during the idle time are assumed to represent the lost worth of that vessel for the period, and are used as a proxy for the cost to society.

Typically, these costs are attributable to crew dismissal, vessel operation, capital charges, and exceptional port services. Operating costs include crew salaries, stores, supplies, maintenance, management and insurance.

6.8.2 Definitions

Vessel damage

Vessel damage may include both direct repair costs and ancillary costs. Direct cost is the cost of repairing damage to the vessel, whether in a shipyard, dockside, or at the site where the casualty occurred. The term ancillary cost comprises any or all of several additional costs that are auxiliary to the repair of damaged vessels or the removal of wrecked ones. Ancillary costs include:

- towing or refloating vessels, freeing them from bottoms, banks and reefs, and salvage work

- drydocking charges

- cleaning and gas freeing of fuel and/or product tanks[22]

Direct repair costs for vessel damage may or may not (in the case of the larger vessels) be for work done in US yards. All direct costs have been inflated to July 1990 prices based on the US Department of Labor's Producer Price Index (PPI).

Vessel replacement

Vessel replacement is assumed to involve the purchase of five-year-old vessels at 1990 market prices. Averaging of and/or selection among available prices was done in some cases. Many of the prices for tanker and bulk carriers were calculated from prices per deadweight ton for the vessel type in question, where no available sales records were found that represented the sizes and types under consideration.

Prices

All prices are stated in broad national terms, i.e., they are not port-specific. Price differences for commodities, vessel repairs and ancillary services at different ports were considered not substantial enough to justify preparation of separate prices. (In the case of vessel damage amounts, such a strategy would have reduced sample sizes so much as to obviate the validity of historically derived statistics.) A conservative approach to price assignment has generally been employed, and conservative choices have consistently been made where alternative prices existed. By specifying the probabilities of casualties to vessel type and size, severity and type of casualty, and the nature of affected cargoes, the VTS integrated model effectively shapes the generalized and representative price information into a port-specific picture of avoided costs.

Casualty

A casualty for the purpose of this subtask is any collision or grounding that is either potentially VTS-addressable, or similar to a VTS-addressable casualty, and that causes quantifiable damages to a vessel of a type and size under consideration.

Vessel types

The vessel types considered here are:

- tankers

[22]Tank cleaning and gas freeing are necessary and customary precautions against explosions and fires, which might otherwise be set off by the use of welding equipment during a repair job.

- dry freight vessels (including bulk carriers, container ships, breakbulk vessels, and any other conventional-hulled freight vessels that are not tankers)

- passenger vessels and ferry boats

- fishing boats

- tug and tow boats

- dry bulk (freight) barges

- tank barges

- other vessels (work boats, industrial-use vessels, research vessels, dredges, offshore supply vessels, conventional-hulled drilling vessels, and other, unclassified vessels)

These vessel type classifications are adapted from the categories used by the U.S. Army Corps of Engineers (USACOE) in recording vessel transits through port zones.

Vessel size

The operating draft of a vessel varies with its load, the season, the salinity of the water, and whether it is stationary or moving. The USACOE separates out vessel transits by operating draft at time of recordation for each class of vessels, summarizing all transits through an area of a given type that are under a given draft. (The Corps, obviously, has responsibilities for channel maintenance, so the operating draft of vessels is of particular interest to them.) On the other hand, since draft is not a fixed quantity, the Coast Guard records vessel size in CASMAIN in terms of gross tons and length. The tanker and freighter trades classify ship sizes and prices in deadweight ton quantities, which relate to cargo capacity. Barges, fishing, and pleasure boats are typically classed by their length. Tug and tow boats are most often classified by horsepower.

Translation of most vessel sizes from length to draft terms was performed on the basis of an analysis of gross-ton-to-draft relationships in Lloyd's Register of Ships. Passenger/ferry classification was based on similar analysis by Eastern Research Group.[23]

Barges were classified by means of estimating relationships of molded draft to gross tonnage (both quantities as listed in the Coast Guard's Merchant Vessels of the United States, 1988),

[23]See Section 7 of this technical supplement.

combined with consideration of barge sizes as described in several other written and oral sources. Since a fully loaded barge is essentially submerged up to the bottom of the deck, and barges are simple structures without propellers, etc., we assumed that in their molded depth would approximate the fully loaded draft.

Dry freight vessels and tankers were classed as small, medium and large, according to the equivalency of their gross tonnage to drafts less than nineteen feet, between nineteen and thirty feet, and over thirty feet. Passenger vessels and ferries were divided into small (under nineteen feet) and large (over eighteen feet) only. Both dry freight and tank barges were similarly classed as small and large. Towboats and tugboats, fishing boats, and other vessels are not classed by size.

It should be noted that these draft/tonnage conversions yield average relationships only. The different characteristics of vessels within categories affect the design draft of vessels. Container ships, for instance, are being designed with deeper drafts as the trend towards feeder barging to a few major ports continues. Conversely, as passenger ships have abandoned the Transatlantic for the Caribbean trade, many are being designed with relatively shallow drafts for a given tonnage, to enable them to dock easily in as many ports as possible.

Deadweight tonnage/gross tonnage equivalencies developed by Eastern Research Group (ERG) were used in the calculation of market prices of tankers and freighters. In the case of tankers, the ERG materials were supplemented by information from a chart of tanker sizes found in William V. Packard's Sea-Trading: Vol. 1, The Ships, p. 90. Again, these relationships are approximate and vary by type and individual design of ship.

The draft-based size categories used here are, in some cases, anomalous in terms of common practice. Tanker categories are an example of this. William V. Packard (Ibid, pp. 89-90 and Figure 13.2) describes and charts the commonly used tanker categories, in ascending order of size: Handy-size, MRX, Medium-Size Crude Carrier, VLCC, and smaller and larger ULCC. Packard also supplies the AFRA (Average Freight Rate Assessment Scale) categories, ranging from General Purpose up to ULCC. According to his data, even the medium-range cross-purpose (MRX) tanker of approximately 33,000 dwt (summer), which is smaller than what is categorized as a "medium size crude carrier" typically draws 35 feet. These tankers, however, which are classed on the small end of medium in the tanker universe, fall into our "large" tanker category. Even the small "handy-size" tankers, which are typically used for transport of chemicals, characteristically draw over 26 feet, making them comfortably "medium" by our schema. VLCCs typically draw over 60 feet (the Exxon Valdez falls into the 60 foot draft range), and ULCCs even more. By 1984, according to a sample of Lloyd's Register, 57% of tankers in the world fleet drew over 30 feet; this sample included vessels with gross tonnage ranging from

11,643 to 194,489. The very largest tankers do not enter all U.S. ports, or the inner harbors of many U.S. ports, but offshore loading facilities for supertankers, such as the Louisiana Offshore Oil Port (LOOP) do exist within port areas.

6.8.3 Data sources

Vessel damages

An initial search of listings of available vessel casualty data bases suggested that either of two, the Lloyd's Maritime Information Service Casualty Data Base, or the American Bureau of Shipping's (ABS) casualty records, might prove to be a useful basis for analysis of vessel damage costs. The Lloyd's data base seemed the most promising, because it is a comprehensive worldwide data base of casualties, not limited to Lloyd's-insured or -registered vessels; however, it does not contain any cost information. The ABS does not offer information on the costs of casualties either, nor is their data base current. We were not able to locate any other privately-compiled comprehensive information source on vessel casualties. Some information from litigated cases is available in legal data bases. It is not, however, in tabular form, and a time-consuming case-by-case review would be needed to extract any sizeable quantity of this information; nor do guidelines exist to our knowledge for evaluation of litigated versus non-litigated settlements.

The Coast Guard's CASMAIN data base was examined as a source of direct vessel damages. Although it was found to be the most comprehensive available historical source that attaches dollar figures to vessel casualties, it has some drawbacks. It includes U.S. casualties only, including a great number of inland casualties. Its cost data is likely to be estimated, because of time limits for shipowners to file a Report of Marine Casualty. CASMAIN also exhibits some inconsistencies and data entry errors. Nonetheless, it offers the best, largest and most complete available source of data on vessel damage costs.

A comparison of cost data in CASMAIN against costs cited in about 40 NTSB cases was made (costs in NTSB cases are often acquired later and based on actual expenditures); but, while cost figures did not always match, the comparison did not show any clear trends as to the amounts and direction of the discrepancies.

Direct vessel damages are derived statistically from the CASMAIN data base. The subset of CASMAIN used for this analysis was selected according to the criteria below, which were not necessarily the same criteria used to establish the subset of VTS-addressable casualties used in other tasks of the Port Needs Study.

- Geographic

  The Great Lakes area, the Mississippi River system above Baton Rouge, and the Columbia and Willamette Rivers above Portland were excluded from this analysis in order to obtain a "coastal" data base, in which vessel and casualty types approximated those found in the ports. Otherwise, no effort was made to limit the scope specifically to the port zones. To obtain as large a sample as possible of casualties to analyze, we addressed damages similar to those produced in VTS-addressable accidents, whether or not by its location and/or specific circumstance a particular casualty was in fact VTS-addressable.

- Casualty types

  The collision data used here include all types of collisions, allisions, and rammings. Damages resulting from casualties between moving vessels appear to be greater than those resulting from casualties in which a vessel hits a stationary object. Groundings include all casualties in which some type of grounding, accidental or intentional, is coded in CASMAIN as the primary or secondary nature of the casualty. In practice, almost all of these are listed primarily as groundings; and virtually all are unintentional groundings.

- Vessel damage categories

  CASMAIN records in which vessel damage is recorded as "0" or "BLANK" were excluded from consideration. Given the Coast Guard criteria for casualty reporting, a surprisingly great number of CASMAIN records contain no indication of vessel damage costs. CASMAIN records do not permit discrimination between genuine no-damage cases and those in which damage figures were unavailable or not entered. (Shipowners are required to report casualties to the USCG on Form 2692, "Report of Marine Casualties," when damages equal at least $25,000, any time death or injury is involved, or when an accidental grounding occurs.) Inquiries to the Coast Guard indicated that, since dollar damages to vessels are not a central concern of the USCG, the original entries to the data base are not necessarily updated if damage information was omitted from the original report.

- ABC coding

  The CASMAIN codes damaged vessels as A - total loss; B - unseaworthy; and C - seaworthiness not affected. In practice the distinction between cases coded "B" and "C" is not consistent, so this analysis did not rely on that distinction. We did rely on the distinction between "A" and the other two codes, and excluded total losses from all tables analyzed to establish severity ranges and typical casualty figures. We considered total losses separately, and based replacement costs for vessels of each size and type on market prices rather than historical records.

- Time period

  The Coast Guard supplied the VTS project with tapes of CASMAIN information containing records on casualties from 1980 through 1990. The set of 1990 records was clearly incomplete and excluded major casualties. The best-known severe 1989 casualties were also not included in the data base. We therefore concluded that 1989 was incomplete as well, and "capped" the data set that we used to analyze the cost of casualties as of December 31, 1988.

Vessel replacement prices

The area of replacement costs for vessels was simpler. Lloyd's Shipping Economist publishes monthly data on sales prices for new and used vessels, especially in the area of tankers, bulkers, and container ships. The Journal of Commerce also reports on new and used ship sales. Maritime Reporter and Engineering News publishes tables on new buildings in a number of areas including passenger and ferryboats, tug and towboats, work boats, and other vessels, and sometimes barges. It also reports on some second-hand sales, and its advertising columns feature offerings of barges, tugs, tows, etc. The Waterways Journal also prints some price information on barges and related vessels.

Services ancillary to vessel repairs

Prices for ancillary services were acquired from The Port of Boston Handbook:1990-1992 and through telephone interviews with officials of Boston Fuel Transportation, Boston; General Ship Corporation, Boston; and Moran Towing, New York. Regular perusal of reports of casualties and their aftermath in the Journal of Commerce, Golub's Oil Pollution Bulletin, the New York Times, National Transportation Safety Board marine casualty reports, and other sources provided background for assignment of occurrences of ancillary services. For gas freeing and tank cleaning, various diagrams and charts in Packard's Sea Trading: Volume 1: The Ships supported estimation of the number of tanks to be cleaned for each size and type of vessel.

6.8.4 Methodology

General requirements

Quantifying potential benefits of VTS in the areas of prevented vessel damages and losses demanded the collection, assimilation and analysis of a great deal of price information from various sources. Both statistical and empirical techniques of analysis were employed. The objective was to arrive at "typical" historically based dollar figures for damage or loss to be applied to a variety of scenarios. A set of plausible, representative costs, in 1990 dollars, was required for the following items:

- The repair of damages to vessels of different types and sizes, following collisions and groundings of three levels of severity: low, moderate and severe. Fifteen representative categories of vessels were constructed. Damages to each vessel category were estimated for low value, moderate, and severe instances of collisions and groundings respectively. In all, ninety representative casualty cases were thus constructed.

- Replacement values for representative vessels of each type and size (fifteen in all).

  The first cost above includes allowances for ancillary expenses where applicable. The second cost includes a rather modest allowance for towing and/or salvage charges.

Direct repair costs

- Constructing the casualty data bases

  Once CASMAIN was chosen as the data source for direct repair cost analysis, it was necessary to limit the data to relevant records, update the dollar values, and divide the data first into smaller tables of records pertaining to particular sizes and types of vessels, and then further still, into collisions and groundings for each type and size.

  The original table was an extract of some 50,000 casualty (collision, grounding, allision, ramming) records from CASMAIN. The first step was to exclude all records with 0s or blanks in all the dollar fields. (The Coast Guard advised that no conclusions should be drawn about or based upon 0 or blank values.) Records falling outside coastal and port areas were then removed. The major exclusions were the Mississippi river system above Baton Rouge and the entire Great Lakes region. Values for vessel damage were updated to 1990 values using the

Producer Price Index. 1989 and 1990 were excluded completely, as few of the high-value and high-visibility casualties on our list had yet been entered into the data base. Finally, thirty-two smaller tables, defined by size expressed in gross tons, vessel type, and casualty type were created. Minor editing was done in the process, for example, to correct obvious decimal point errors or to fill in average gross tonnage figures where this entry was omitted for barges of standard sizes. The small tables excluded total losses and records with 0s or blanks in the vessel damage (VDAM) field.

- The statistical approach

  Frequency tabulations and graphs of the frequency distributions were prepared from all the small tables that resulted from the extraction described above. Some examples of the tabulations and graphs are shown in Appendix 6-H. Each graph typically exhibits a high peak in the low-damage range, and a long tail in the high-damage range. Inspection of the frequency tabulations and graphs allowed separation of each group into a low, moderate and severe range, shown in Appendix 6-I, "Range of Vessel Damages in 1000s". Within these ranges, percentile distributions were used as a guide to selecting direct damage values for Table 6-11, "Benefits of VTS - Avoided Vessel Damage and Ancillary Costs". A reasonably high point was chosen from the low-damage casualties to avoid the very bottom cluster of figures, many of which appear to contain errors. A representative figure, somewhere around the median of its range, was chosen for the moderate-damage casualty. For severe casualties, we chose a very high percentile - often the 98th or 99th percentile unless there was a sizeable collection of very expensive casualties.

- Ancillary costs

  The ancillary costs include towing and/or salvage, drydocking, and tank cleaning and gas freeing charges.

  For towing, it is assumed that the vessel is towed or piloted to the nearest suitable yard. The nearest suitable yard for very large vessels is very frequently in another port. Preparation for towing, especially if there is a pollution threat or bad weather, may easily take as long as the tow itself.

  The number of tugs assigned to various casualties is a function of vessel size, severity, and casualty type. Services are quantified in varying numbers of "towdays", a towday being the cost of one tug for one day. Low-value collisions are assumed to involve above-the-waterline damage and no towdays. Low-value groundings requiring repairs, however, are assumed to require some assistance. For simplicity, miscellaneous salvage and refloating services are also quantified as towdays, although this procedure doubtless understates salvage costs greatly. We assume that every vessel lost in a port area would be the subject of some type of salvage activity.

Drydocking costs are based on figures provided by General Ship Corporation of Boston. Drydocking prices have two components. "Haul days" are charged when the blocking is assembled or disassembled, and/or the vessel moved into drydock or out of it. It is standard to charge half a haul day at each end of a job, in addition to blocking time. The remaining days spent in drydock are charged at a lower rate as "lay days," with weekends generally excluded from the computation. Drydocking charges are based on the weight of the vessel. Typical repair times for jobs of a given dollar value and vessel type, computed by Eastern Research Group in its report (Section 7 of this technical supplement), formed the basis for calculating numbers of haul and lay days for each category of vessel and casualty. Drydocking charges have been applied only in cases of severe collisions and moderate and severe groundings.

Tank cleaning and gas freeing charges have been applied on the basis of information supplied by General Ship Corporation, Boston, MA. Most or all fuel and/or product tanks on a vessel are customarily cleaned and freed of gas before any welding is done, unless damage is slight and far away from any potential source of explosion. Charges vary with the size, number and condition of the tanks, the available facilities, and the nature and amount of product in the tanks. Heavier oils require the use and rental of a steam boiler and its operator. An additional charge is made for an engineer's certification that a tank is free of gasses. We estimated the number and size of tanks (and the likelihood that a steam boiler would be needed). Tank cleaning/gas freeing charges have not been applied to low-severity casualties or to dry barges.

Replacement costs for vessels

Replacement costs for vessels in each category are market or market-based prices for five-year-old vessels. These values are shown in Table 6-11, "Benefits of VTS: Avoided Vessel Damage and Ancillary Costs." They appear for each type and size of vessel opposite the indication T (Total Loss) in the column headed SEVERITY.

Within each size and/or type of vessel category, a representative - rather than statistically average - member of the class was generally chosen. Since tanker sizes as defined by the 10/20/30-foot draft categories were on the whole smaller than tankers offered in the market, the Lloyd's Shipping Economist per deadweight ton prices for five-year-old hulls are used rather than sample sales.

The "dry bulk" category includes freighters, bulkers, container ships, breakbulk, ore carriers, ro-ro's, refrigerated vessels, etc. Prices per gross ton are not necessarily comparable among these vessels. In view of generally recognized trends away from bulk transportation toward containerization, the decision was made to construct a hypothetical compound dry vessel consisting of two parts bulker and one part containership, excluding the more specialized vessels from the computation. For each size category, a weighted average was thus constructed using Lloyd's per-deadweight-ton prices.

The large size passenger/ferry ship was presumed to be a rather large passenger vessel. The new building price for such ships averages about $120 million, with prices often closer to $200 million. Used passenger ships are heavily discounted, because major remodeling is a frequent occurrence in the cruise ship market, so a figure of $60 million was used. (This represents acquisition cost only; remodeling could double the price.)

The shallower-draft vessels in this category include ferries, surface-effect ships, and short-cruise vessels. The new building prices of such vessels vary enormously, from a few million dollars to over $100 million. Many of these vessels, especially ferries, could not be replaced by anything but new tonnage because of various special requirements.

The "Other" category covers a range from large yachts to oceanographic research vessels and includes dredges; offshore supply vessels and crewboats; fish factory vessels; drilling units mounted on conventional hulls; industrial vessels; workboats (but most of these are excluded from consideration on the basis of size); and other unclassified vessels. The most frequently encountered member of the class, and therefore the one priced here, is the dredge. It is not a cheap dredge, but then many other members of this class can be very expensive indeed. (The price was derived from a newbuilding price published in Maritime Reporter and Engineering News, November, 1989.)

The sizes of tug and towboats and fishing vessels priced here are based on the mean size of the vessels in each category that are listed in CASMAIN.

6.8.5 Results

Table 6-11 shows the total damages for each vessel type and damage severity category, including total loss of the vessel. The total column represents the sum of direct vessel damage repair and the appropriate ancillary costs. The ancillary costs applicable to each case are further broken down in Appendix 6-J into the categories discussed above.

The ranges by which severity of casualties were determined are found in Appendix 6-I.

Table 6-12 shows other social costs of idled vessels. Further results obtained through personal interviews with industry experts, shipyard operators, ship's agents, and consultants, and through published information on specific cases, anecdotes and examples, as well as supporting data for the estimates, and the construction and underlying assumptions for the social cost estimates for each vessel type and damage severity can be found in the ERG report which is included in its entirety as Section 7 of this technical supplement.

6.8.6 Bibliography

American Waterways Operators. Big Load Afloat. Washington, DC, 1973.

Eastern Research Group,Inc. Final Report: Develop Estimates of Costs Associated with Oil and Hazardous Chemical Spills and Costs of Idle Resources During Vessel Repairs. Arlington, MA, 1990.

Journal of Commerce. New York, New York, 6/90 ff. Weekly.

News reports on vessel casualties and shipping trade, ship sale reports, and listings of petroleum product and chemical prices.

Special insert, "Containerization and Intermodalism," 6/27/90.

Lloyd's Maritime Directory 1990. Lloyd's of London Press, Colchester, Essex, U.K., 1990.

Lloyd's Shipping Economist. Lloyd's of London Press. London, U.K. 5/90-12/90. Monthly.

Market reports on sales of large merchant vessels, new and used, including per deadweight ton prices for used tonnage.

TABLE 6-11. VESSEL DAMAGE AND ANCILLARY COSTS
(Page 1 of 3)

Vessel Type	Size	Casualty Type	Severity	Damage ($000)	Ancillary Costs ($000)	Total ($000)
Passenger	S	C	L	16.0	0.0	16.0
			M	99.2	25.7	124.9
			S	625.0	45.0	670.0
		G	L	11.2	7.0	18.2
			M	261.6	31.2	292.8
			S	1,870.0	41.1	1,911.1
		T	T	10,000.0	10.5	10,010.5
	L	C	L	62.5	0.0	62.5
			M	187.5	30.0	217.5
			S	1,240.0	80.0	1,320.0
		G	L	67.3	7.0	74.3
			M	140.9	43.0	183.9
			S	1,250.0	87.0	1,337.0
		T	T	60,000.0	21.0	60,021.0
Dry Cargo	S	C	L	18.1	0.0	18.1
			M	58.9	25.7	84.6
			S	600.0	42.1	642.1
		G	L	12.3	7.0	19.3
			M	125.0	37.1	162.1
			S	1,000.0	45.1	1,045.1
		T	T	3,200.0	14.0	3,214.0
	M	C	L	48.1	0.0	48.1
			M	231.4	30.0	261.4
			S	6,250.0	191.8	6,441.8
		G	L	25.4	7.0	32.4
			M	231.4	64.8	296.2
			S	1,300.0	85.8	1,385.8
		T	T	8,548.3	21.0	8,569.3
	L	C	L	62.5	0.0	62.5
			M	248.2	39.5	287.7
			S	6,000.0	582.5	6,582.5
		G	L	23.1	7.0	30.1
			M	344.7	132.5	477.2
			S	1,800.0	279.5	2,079.5
		T	T	18,000.0	21.0	18,021.0

TABLE 6-11. VESSEL DAMAGE AND ANCILLARY COSTS
(Page 2 of 3)

Vessel Type	Size	Casualty Type	Severity	Damage ($000)	Ancillary Costs ($000)	Total ($000)
Tanker	S	C	L	25.0	0.0	25.0
			M	112.7	29.0	141.7
			S	220.7	38.9	259.6
		G	L	55.2	7.0	62.2
			M	169.1	37.9	207.0
			S	441.2	42.9	484.1
		T	T	5,000.0	10.5	5,010.5
	M	C	L	78.7	0.0	78.7
			M	330.9	40.0	370.9
			S	1,360.0	237.0	1,597.0
		G	L	40.5	7.0	47.5
			M	163.4	94.5	257.9
			S	1,051.0	184.0	1,235.0
		T	T	15,000.0	28.0	15,028.0
	L	C	L	58.9	0.0	58.9
			M	136.0	58.0	194.0
			S	1,870.0	397.0	2,267.0
		G	L	63.6	14.0	77.6
			M	462.8	170.0	632.8
			S	12,500.0	767.0	13,267.0
		T	T	20,000.0	42.0	20,042.0
Dry Barge	S	C	L	17.7	0.0	17.7
			M	99.8	2.0	101.8
			S	270.5	7.2	277.6
		G	L	7.3	2.0	9.3
			M	42.0	6.2	48.2
			S	281.8	7.2	288.9
		T	T	300.0	3.5	303.5
	L	C	L	52.9	0.0	52.9
			M	120.0	3.5	123.5
			S	405.0	13.8	418.7
		G	L	26.3	3.5	29.8
			M	120.0	11.1	131.1
			S	318.1	13.8	331.8
		T	T	650.0	7.0	657.0
Tank Barge	S	C	L	30.0	0.0	30.0
			M	112.7	22.5	135.2
			S	294.5	33.0	327.5
		G	L	13.6	7.0	20.6
			M	108.9	28.2	137.1
			S	1,051.0	43.0	1,094.0
		T	T	1,300.0	10.5	1,310.5

TABLE 6-11. VESSEL DAMAGE AND ANCILLARY COSTS
(Page 3 of 3)

Vessel Type	Size	Casualty Type	Severity	Damage ($000)	Ancillary Costs ($000)	Total ($000)
Tank Barge	L	C	L	52.5	3.5	56.0
			M	240.0	40.0	280.0
			S	563.5	52.9	616.4
		G	L	33.1	7.0	40.1
			M	259.0	43.5	302.5
			S	1,200.0	65.5	1,265.5
		T	T	3,000.0	21.0	3,021.0
Tow, Tug		C	L	25.2	0.0	25.2
			M	87.5	6.0	93.5
			S	516.7	14.8	531.5
		G	L	28.2	3.5	31.7
			M	98.0	8.5	106.5
			S	625.0	14.8	639.8
		T	T	800.0	7.0	807.0
Fishing		C	L	19.3	0.0	19.3
			M	78.9	6.2	85.1
			S	176.7	29.1	204.8
		G	L	18.8	3.5	22.3
			M	180.0	24.6	204.6
			S	408.0	45.7	453.7
		T	T	450.0	7.0	457.0
Other		C	L	26.3	0.0	26.3
			M	87.5	8.5	96.0
			S	506.7	25.3	532.0
		G	L	30.5	3.5	34.0
			M	110.3	13.2	123.5
			S	901.6	29.6	931.2
		T	T	6,000.0	7.0	6,007.0

Size: S = small; M = medium; L = large
Casualty type: C = collision or ramming; G = grounding; T = total loss
Severity: L = low; M = moderate; S = severe; T = total loss

TABLE 6-12. SOCIAL COSTS OF IDLED VESSELS PER VESSEL CASUALTY[24] ($000)

Vessel Type	Size	Vessel Damage Severity: Low	Moderate	Severe
Passenger/ferry				
	small	151	751	1,051
	medium	306	1,506	2,106
	large	508	2,508	3,508
Dry cargo vessel				
	small	94	242	692
	medium	125	321	921
	large	167	426	1,226
Tanker				
	small	164	417	1,217
	medium	205	521	1,521
	large	247	626	1,826
Barges - dry and tanker (including tow boat)				
	small	9	38	83
	large	13	60	135
Fishing vessels				
	small	151	201	376
	large	361	481	901

[24]This table is based on information found in "Develop Estimates of Costs Associated with Oil and Hazardous Chemical Spills and Costs of Idle Resources during Vessel Repairs", Eastern Research Group, Inc., November, 1990.

Maritime Reporter & Engineering News. New York, NY, 11/89 ff. Monthly.

Information on orders and sales for all types of vessels, but especially good on all segments of the passenger/ferry trade and tugs and towboats.

Packard, William V. Sea-Trading. Fairplay Publications Ltd. London, U.K., 1985. 2 volumes.

Razdan, Lana S., ed., Boston Shipping Association Inc. 1990-1992 Port of Boston. Boston, MA. 1990.

Information on Boston ocean trade and prices of port services.

Stopford, Martin. Maritime Economics. Unwin Hyman. London, U.K., 1988.

United States Government

Bureau of Labor Statistics. Consumer Price Index, July, 1990.

-------------------------. Producer Price Index, July, 1990.

Council of Economic Advisors. Economic Indicators. July 1990, "Changes in Producer Prices for Finished Goods: Capital Equipment, 1980-June 1990." Source: Bureau of Labor Statistics.

Department of the Army, Corps of Engineers, Water Resources Support Center, Waterborne Commerce of the United States, Calendar Year 1987. 4 Volumes.

---------------------, Report series: Portland, Oregon.

Department of Commerce, Bureau of the Census. Statistical Abstract of the United States 1990. January, 1990, pp. 467, 476-479, (Tables 769-773).

National Transportation Safety Board, Marine Accident Report series. Washington, DC, 1986ff.

United States Coast Guard, Merchant Vessels of the United States. 1988, Vol. I.

The Wall Street Journal. New York, July 1-10, 1990.

The Waterways Journal. St. Louis, MO, 01/90 ff.

Personal Contacts

Fred Miller, Carol Brown. American Bureau of Shipping, Paramus, NJ. July 12, 1990. Characteristics and cost of ABS casualty data.

Mary Jane Dengil. Lloyd's Maritime Information Services, Stamford, CT. July 12, 1990. Discussion of information in casualty data base and retrieval costs.

M. Larson. Moran Towing, New York. 8/15/90. Cost of towing and related services.

Arthur McKenzie. Tanker Advisory Center, New York. 8/90. Invaluable background information on the structure of repair costs, how they are estimated, how valid the estimates are, etc.

Thomas Pettin. Marine Investigation Division. U.S.Coast Guard, Washington, D.C. Questions on CASMAIN data and casualty reporting criteria.

Michael Riley, Russell Morrison. General Ship Corp. Boston, MA. Description and usual costs of drydocking and tank cleaning and gas freeing.

Donald Tyrell. Marine Investigation Division. National Transportation Safety Board, Washington, D.C. 8/9/90. Questions on damage cost reporting in NTSB Marine Accident Reports.

Jonathan Wales, Boston Fuel Transportation, Boston, MA. 8/13/90. Cost of towing, etc.

6.9 CARGO LOSS[25]

6.9.1 Scope and Background

This section is limited primarily to cargo that is lost overboard in a vessel casualty by falling from the deck or leaking into the water from a penetrated cargo tank. This cargo is generally not retrievable, and is considered totally lost for the purposes of the Port Needs Study. Allowances have not been made for the small proportion of oil and petroleum products that may be recovered from the surface of the water. Packing and protective coverings generally prevent damage to most non-bulk cargo, barring the vessel's sinking. Such cargo is often lightered from the damaged vessel for delivery to port, and damages are not an issue.

Most scheduled liner trade is now containerized, and the trend towards containerization of additional categories of cargo continues. One possible consequence of a casualty is loss of, or damage to, some or all of the containers carried.

A given container may carry almost any product, or nearly any combination of goods. Originally, containerization was largely limited to the carriage of high-value manufactured goods, but more and more often commodities formerly shipped in bulk, coffee and bananas to name just two, are apt to be stowed in containers prior to loading aboard ship.

The list of commodities for which values were derived consists of the individual hazardous substances customarily carried in bulk form and used in the environmental damages model described in Section 6.3, and commodity groups at the two-digit USACOE code level for the remaining non-toxic substances. In addition to specific commodities, the value of a typical import and the value of a typical export container were calculated for container vessel casualties, which often result in one or more containers falling overboard. The values of both the commodity groups and the containers were difficult to establish, because they consist of unknown proportions of many individual commodities and containerized loads, respectively.

6.9.2 Data sources

Commodity prices

Commodity prices are derived from several sources. The Maritime Administration's <u>United States Oceanborne Foreign Trade Routes 1986/87</u> collects Department of Commerce aggregate information on major waterborne export and import groups, their tonnage and dollar

---

[25]This section is based on a report prepared by Deanna Mirsky of EG&G/Dynatrend, Inc. entitled "Vessel and Cargo Damage and Loss" and dated March, 1991.

values, both nationally and by separate trade route areas. Adjustments to reflect differences in grouping practice between DOC and the USACOE were made.

Prices for petroleum products are taken from The Wall Street Journal and The Journal of Commerce. The Journal of Commerce also serves as the source for most of the chemicals and chemical products. American Metals Market is the price source for many scrap metals and for uranium (the major component of radioactive materials). The price for liquefied gas comes from the Energy Information Administration.

It was not possible to obtain some textile and other scrap prices directly from large scrap dealers. They were universally unwilling to divulge the prices they sell for. In the end, these prices were obtained via manipulation of United States Oceanborne Foreign Trade Routes data on the aggregate values and quantities of leading imports and exports.

Containers and containerized cargo

Container prices are obtained from the Journal of Commerce and Maritime Reporter and Engineering News. Prices for the value of containerized cargo are derived from Table No. 4A, "Liner Service Exports, Top 20 Commodity Groups in Descending Tonnage Order, Calendar Year 1987;" and Table No. 5A, "Liner Service Imports, Top 20 Commodity Groups in Descending Tonnage Order, Calendar Year 1987", in United States Oceanborne Foreign Trade Routes, September, 1989.

6.9.3 Methodology

The objective in pricing the commodity list was to obtain a plausible set of prices for estimating the value of damaged or lost cargoes, rather than to conduct exhaustive trade studies to price each substance and/or class definitively. Most of the commodities priced in Table 6-13 in subsection 6.9.4 are in fact not single substances but groups of products. The term "crude oil", for example, describes a "basket" of oils, each with different properties and a slightly different price; and even the spot price of a single type of crude on a given day may represent a number of deals at different prices. A category like "farm products" or "processed food and other manufactures" is in practical terms almost infinitely complex. There are many grades and types of "greases and lubricating oils", and to construct a strictly "correct" single price for these would require effort clearly disproportionate to the desired result. The search was limited to readily available materials to produce results that are reasonable.

Commodity groupings

The commodities listed are grouped according to the USACOE classification system, which is used to record transits of goods through the port zones. These groupings were disaggregated in many cases, to find prices for single commodities or smaller groupings; these in turn were reaggregated to construct a price. A computerized index maintained at VNTSC cross-references COE and Customs codes and descriptions and was invaluable in this process.

In many cases, judgments were made as to the relative importance of components of a class, and as to which of the commodities most frequently move through the study ports in maritime commerce. The treatment of radioactive substances, discussed below illustrates this.

In some instances, the individual hazardous substances are also components of the larger classes. For instance, "Crude Oil", "Salt" and "Sulphur" are listed as members of the class "Mining Products", but they have been excluded from the pricing of that group. Similar treatment has been applied to other commodity groups containing substances listed individually. Since the VTS model breaks out cargoes of these substances separately, a cargo of, say, mining products can be presumed <u>not</u> to consist of crude, salt or sulphur.

Conversion of quantities to short tons

All prices in Table 6-13 are for short ton quantities. In the case of liquids priced in the sources by gallons or barrels, the price/quantity conversion required determination of the specific gravity of the substance in order to determine the weight of the original quantity. William V. Packard's <u>Sea-Trading: Cargoes</u> was a most helpful resource in this endeavor. The LNG conversion was done with the aid of a table from the Office of Technology Assessment's <u>Transportation of LNG</u> (September, 1977). The weight per gallon of lubricating oils/greases was taken from the Federal Aviation Administration's <u>Pilot's Weight and Balance Handbook</u>.

What the prices represent

We tried to obtain prices for the largest available quantities of a commodity. In the case of many chemical products, prices were quoted for small units without amplification concerning the quantities traded. Since our attempts to clarify this point were unsuccessful, we have assumed that these represent large-scale trades, and that in most cases pounds and gallon prices could be simply multiplied into ton prices.

Prices are U.S. prices except for crude oil, which is customarily given as of the port of loading. Most of the petroleum prices are New York prices. (Kerosene and naphtha, however, are based on Venezuelan prices, which have been adjusted to reflect the price differential on similar products for delivery in New York.) Commodity prices are given in mid-1990 dollars.

The U.S. Government producer price indices for the appropriate classifications were used to inflate commodity group prices where these were derived from prior-year (1987) trade figures.

Use of trade route data

Data from MARAD's Oceanborne Trade Routes 1986-1987 were used in estimating prices for farm products, mining products, processed food and other manufactures, timber and timber products, natural fertilizer material, basic chemicals and chemical products, and miscellaneous chemical products. The statistics published by MARAD give both price and volume information for each item, and separate export from import statistics. Separate statistics are provided for leading products in the liner, bulk and tanker trades nationally and for the leading commodities traded on each major international route. One difficulty had to be surmounted in order to employ these data in the VTS context. Where the Corps categories aggregate a variety of disparate commodity types by stage of processing (e.g., "Processed Food and Other Manufactured Goods"), the MARAD listings combine different processing stages of the same or closely related commodities (e.g., "Tobacco and "Tobacco Products"). The challenge was to look through the MARAD reports for statistics from which the stage of processing could reasonably be inferred. For example, bulk (non-liner) shipments of grains and oilseeds exported from Gulf ports can be reasonably presumed to be largely unprocessed (especially if the per-ton price is close to an average of common grain prices).

Notes on particular commodities and prices

"Farm Products" (COE 01) is a composite price derived from the US Oceanborne Foreign Trade Routes Liner, Tanker, and Non-liner statistics for 1987. The categories Fruits and Vegetables, Oilseeds, Oilnuts and Kernels, Coffee, Cocoa, Tea, and Spices and (non-liner exports only) of Cereal and Cereal Preparations were used. Despite the word "Products" in the title of this category, it includes only non-processed items. Butchered meat (as opposed to livestock on the hoof), for example, is excluded from "Farm Products" because it is considered a processed item.

The price for "Fresh Fish" (COE 09) was estimated by constructing a weighted average of boatload prices for a variety of species published in the Boston Globe. This price includes only finfish, and is therefore rather low. The relevant COE category is for fresh and frozen (but not processed or canned) fish and seafood. The trade route data does not separate fresh and processed fish. We looked at West Coast trade route data for fish and seafood (exports, because imports would include fish meal), and obtained a much higher value than our Boston price, amounting to some four dollars a pound, or $8,000 per ton. Since it was not apparent, however, how much of the greater value to attribute to the inclusion of shellfish and expensive finfishes, and how much to processing and canning, we opted to use the modest Boston figure.

The "Processed Foods and Manufactures" (COE 2011-3911) price is the mean per-ton value of the aggregate of all relevant categories of leading imports and exports in bulk, liner and tanker services for 1987.

"Timber, Timber Products" (COE 24) includes logs, lumber, and paper, but not furniture. Furniture is included under "Processed Foods and Manufactures."

"Manufactured Waste" (COE 4011-4112) includes scrap metals, paper, and textile waste. Components of this price were taken from a variety of sources. Scrap metal and paper prices were acquired from market sources. Textile scrap values were acquired by matching locations where the COE records indicated waste exports and MARAD listed textile waste and scrap exports. Extremely high-value metals were excluded on the assumption they would be transported by air.

The price for "Crude Petroleum" (COE 1311) is the mean of spot prices published in the Wall Street Journal, July 2, 1990. Most other petroleum product categories are also spot prices, and simple averages for grades of "Fuel Oils" (2914, 2915), "Gasoline" (2911), and "Jet Fuel" (2912) were used. These averages were not weighted, because the differences between grades of product were not considered significant enough to have much impact on our generalized results.

"Lubricating Oils and Greases" (COE 2916) was deemed to consist of two parts oils to one part grease, on the ground that lubricating oils, although applied in smaller quantities than greases, are used in engines where they need frequent replacement. Prices were supplied by the Mobil Oil Company.

"Natural Fertilizer Material" (COE 1479) is a single product, crude potassium nitrate. The price for "Alcohols" (COE 2813) is an average of butyl, ethyl, and isopropyl alcohols. "Basic Chemicals and Products" (COE 2819) combines the 1987 price and quantity statistics for Customs categories "Organic Chemicals" and "Inorganic Chemicals" as reported in the MARAD listings.

"Molten Sulfur" (COE 1493) is an average of Houston and Los Angeles prices. This was an isolated instance of a substantial price difference between ports.

"Radioactive Material" (COE 2816) was assumed to be uranium (URUO8), the largest-volume component of COE Code 2816. The category includes a variety of radioactive isotopes which are used in minute quantities, but which we excluded on the assumption that they travel by air.

The price given for COE 2921, "LPG-LNG-Liquefied Coal Gas" is the price for LNG. No convenient weighting factors for waterborne commerce in these liquefied gasses were found. William V. Packard suggests that the major seaborne trade in liquefied petroleum gas takes place outside the U.S., and we assumed further that most liquefied coal gas is not transported by ship (Sea-Trading: Vol. II, Cargoes, Chapter 19). LNG is shipped as a liquid but sold as a gas, and so a volumetric conversion table specifically designed for LNG conversions was used.

Prices for "Timber and Timber Products" (COE 24) are for products less than fully manufactured, i.e., logs, lumber, and paper.

Containerized cargo

An analysis of the value of containers and their contents was conducted. Since a significant difference in value was found between containerized imports and exports, two hypothetical containers were constructed. This reflects the reality that even in the higher-value liner trade the U.S. currently imports high-value manufactured goods, and exports lower-value products.

A price of $3,000 was set on the container in each case, regardless of container size. (There are two sizes - twenty foot equivalents and forty foot equivalents.) This represents a discount on the typical value for a new regular container of about $4,000. We did not attempt to average in the many types of special-purpose containers available, which may range up to forty or fifty thousand dollars for the most sophisticated refrigerated containers equipped with computerized temperature and humidity sensors. Substitutions may be made by subtracting $3,000 from the value of either container and adding in a higher value. Similarly, a forty-foot equivalent container may be constructed by subtracting out the container value, doubling the remaining value, and adding back the container value.

We used trade statistics for the liner trade to arrive at two hypothetical representative loaded twenty-foot equivalent containers. The contents of each container were assumed to weigh ten long tons (22,000 pounds). The value of the loaded import container was set at $46,450. The export container and its contents were valued at $18,930.

The prices for loaded containers, based on 1987 prices, were not inflated. In recent years, more and more lower value goods, which formerly travelled as bulk commodities, have been containerized to cut handling costs and time. The result is - and this is borne out by the liner trade statistics for 1986 and 1987 - that the value per ton of containerized exports and imports alike has not risen over time.

6.9.4 Results

Table 6-13 shows the unit prices of commodity groups per short ton in 1990 dollars. Container prices are given in the previous section.

TABLE 6-13. UNIT COST OF DAMAGED COMMODITIES

COMMODITY CODE	COMMODITY GROUP	COST PER SHORT TON*
1	Farm products	213
2	Timber, timber products	158
3	Fresh fish	2,300
4	Mining products	113
5	Processed foods, other manufactured goods	1,742
6	Manufactured waste	200
1311	Crude petroleum	92
1492	Sulfur, dry	140
1493	Sulfur, molten	84
2810	Sodium hydroxide	342
2811	Products from coal tar & crude petroleum	890
2813	Alcohols	418
2817	Benzene, toluene	375
2818	Sulfuric acid	76
2871	Nitrogenous fertilizers	231
2872	Potassic fertilizers	74
2873	Phosphatic fertilizers	144
2911	Gasoline	203
2912	Jet fuel	183
2913	Kerosene	189
2914	Distillate fuel oil	147
2915	Residual fuel oil	113
2916	Lubricating oils, greases	883
2917	Naphtha, petroleum solvents	188
2921	LPG, LNG, liquid coal gas	2,780**

* Short ton = 2000 pounds
** Cost per million cubic feet

6.9.5 Bibliography

American Metal Market. Fairchild Publications. New York, NY. 11/21/90. Daily.

Encyclopedia Americana, International Edition. New York, NY, 1976. "Disinfectants, Vol. 9, p. 178;" "Fertilizers, Vol. 11, pp. 132-135; "Insecticides," Vol. 15, p. 2009; and "Paints," Vol. 21, pp. 107-109.

Information on the nature and composition of these substance classes.

Journal of Commerce. New York, New York, 6/90 ff. Weekly.

News reports on vessel casualties and shipping trade, ship sale reports, and listings of petroleum product and chemical prices.

Special insert, "Containerization and Intermodalism," 6/27/90.

United States Government

Bureau of Labor Statistics. Consumer Price Index, July, 1990.

--------------------------. Producer Price Index, July, 1990.

Council of Economic Advisors. Economic Indicators. July 1990, "Changes in Producer Prices for Finished Goods: Capital Equipment, 1980-June 1990." Source: Bureau of Labor Statistics.

Department of the Army, Corps of Engineers, Water Resources Support Center, Waterborne Commerce of the United States, Calendar Year 1987. 4 Volumes.

----------------------, Port Report series: Portland, Oregon.

Department of Commerce, Bureau of the Census. Statistical Abstract of the United States 1990. January, 1990, pp. 467, 476-479, (Tables 769-773).

Department of Energy, Energy Information Administration, Petroleum Supply Annual 1988, Vol. 1. pp. 141-148, "Definitions of Petroleum Products and Other Terms".

Excellent brief technical dictionary of many processes and products.

----------------------------------, Energy Facts, 1988.

Information on nuclear fuel.

--------------------------------, Annual Outlook for Oil and Gas, 1990.

--------------------------------, Natural Gas Annual 1989.

Includes LNG price information.

Federal Aviation Administration, Pilot's Weight & Balance Handbook.

The Wall Street Journal. New York, July 1-10, 1990.

Personal Contacts

Thomas Baldwin, Division Manager, Cargoes, Port of New York. Wm. H. McGee & Co., Marine Underwriters, New York. 7/24/90. Conversation about sources and methods for pricing "market basket" container loads.

Chuck Gross. Eastern Region Sales, Mobil Oil. Conversation about average large scale wholesale prices for lubricating oils and greases.

Marsha Olinto. Lykes Steamship Co. Quincy, MA. 7/25/90. Information on contents of containers.

Rosalie Spiller. Journal of Commerce Chemical Pricing Information Service, Phillipsburg, NJ. 11/20/90. Questions on chemical quantities.

6.10 INJURY TO AND LOSS OF HUMAN LIFE[26]

6.10.1 Background

When a crew member or a passenger is injured in a vessel casualty, costs are incurred by the individual injured and by society in general in a number of areas. Some of them are:

- Hospital care, medical treatment, and rehabilitation training
- Legal fees
- Insurance payments
- Pain and suffering compensation
- Lost productivity and wages

For the VTS cost/benefit analysis, a measure incorporating all the social costs of an injury is appropriate.

When a human fatality results from a vessel casualty, the same types of costs as for an injury are incurred except for the medical costs, assuming the fatality occurs during the casualty. However, the pain and suffering compensation to bereaved relatives and the lost productivity and wages may be much greater. Many studies, too numerous to list here, have attempted to place a value on human life with as many different estimates of value resulting. Even within the U.S. Department of Transportation (USDOT) values for human life used in cost/benefit analyses have ranged from one to one and a half million dollars. A recent study performed at VNTSC for the Office of the Secretary of Transportation recommends that USDOT use a value of one and one half million dollars in its studies. The VTS study will comply with this recommendation.

6.10.2 Methodology

A literature review revealed only one source of injury costs by body region that incorporates the full social costs of injuries: a study developed by Ted Miller of the Urban Institute in Washington, DC, but not yet published, that contains estimates of the costs of nonfatal highway accident injuries. These estimates were developed for the Federal Highway Administration using data from the National Accident Sampling System, the National Council of Compensation Insurers, and several other sources. The estimates are presented by body region and Minimum Abbreviated Injury System (MAIS) code. MAIS codes take on values of one to five to reflect the threat to

---

[26]This section is based on a memo written by Herb Weinblatt of Jack Faucett Associates in December, 1990, entitled "Costs of Human Injury".

life posed by the maximum injury sustained. A MAIS of 5 is used to represent critical injuries. The injury costs by MAIS code from the unpublished Miller study are shown in Appendix 6-K.

For use in the VTS study, Miller's estimates were adjusted to 1990 dollars from the original 1988 dollars by multiplying all costs by 1.10, the change in the consumer price index for all urban consumers between July 1988 and July 1990. The results, shown in the section below, break out "Pain and Suffering" cost component from "All Other" costs to emphasize the magnitude of this component - 50 to 85 percent of total costs for all injury categories. "All Other" costs include costs for hospitalization, medical prescriptions, attendant and nursing home services; vocational rehabilitation, lost wages and household production; employment transport, fire and police services, and travel delay. The largest category of these other costs is that of lost wages and household production.

The cost for the VTS injury category of "Multiple Injuries" is double the weighted average of the costs of all MAIS 2 through 5 injuries, assuming typically that "multiple" implies "two" injuries. Minor injuries and spinal cord injuries, which are unlikely in VTS-addressable vessel casualties, do not contribute to this figure.

Injuries suffered in automobile accidents are likely to be quantitatively similar to those suffered in maritime accidents, though there could be some significant differences in some of the individual cost components (e.g., insurance and legal costs). However, adjustment for these cost differences is impractical within the scope of the present effort.

The costs in the Miller study incorporate a four percent discount rate applied to all costs not incurred in the year of the accident. Somewhat lower cost estimates would result if a slightly higher discount rate had been used. However, adjustment to represent a different discount rate is not practical within the scope of the present effort.

The injury classification used in Miller's work does not distinguish burns as a separate class. A separate estimate of the costs for burns would be most desirable for analyzing the cost of fires resulting from casualties involving LNG and LPG tankers. For the body regions that are most likely to be affected by burns (upper and lower extremities, trunk and abdomen, and face, head and neck), Miller's estimates of costs for MAIS class 3 injuries range from $310,000 to $472,000 and for classes 4 and 5 they range up to $1.36 million (for injuries to the face, head and neck). These figures suggest that $500,000 would probably be an appropriate cost to use for all nonfatal burns resulting LNG and LPG tanker casualties. Since nearly all fatal burns resulting from such casualties are likely to prove fatal before the injured persons are reached by would-be rescuers, it is suggested that the analyses not incorporate any additional cost estimates for the treatment of persons that are fatally burned as the result of such casualties.

Data on actual injuries and fatalities occurring as a result of vessel casualties is found in the Coast Guard's PCAS data base. Appendix 6-L shows the mapping of the PCAS codes into the VTS injury categories, so that the integrated model may calculate the probabilities of various injuries occurring in terms of the same categories as the cost factors.

6.10.3 Results

Table 6-14 shows the cost factors for human injuries and human fatalities by body region. Pain and suffering costs are separated from all other costs to illustrate their magnitude.

TABLE 6-14. COSTS OF HUMAN INJURIES AND FATALITIES ($000)

BODY REGION	PAIN & SUFFERING	ALL OTHER*	TOTAL
Spinal Cord	813	713	1,526
Brain	76	17	93
Lower Extremity	118	39	57
Upper Extremity	40	21	61
Trunk & Abdomen	37	10	47
Face, Other Head, Neck	11	7	18
Minor External	2.3	2	4
Multiple Injuries	220	60	280
Death			1,500

* ALL OTHER includes medical care, hospitalization, vocational rehabilitation, lost productivity, lost wages, insurance administration, employer costs, emergency services, court costs, and legal expenses.

6.11 EMERGENCY RESPONSE

6.11.1 Background

Range of response activities

The Coast Guard responds to every casualty that is reported. At minimum, a Coast Guard cutter or other vessel is sent to the scene for casualties occurring near the shore, or an overflight is conducted by a helicopter or search plane for casualties occurring offshore. For severe casualties, the Coast Guard may respond by sending numerous vessels and personnel to the scene, monitoring the situation until the vessel is moved or the spill is cleaned up, conducting search and rescue missions, federalizing the spill cleanup, and more.

Every marine casualty is treated as potentially life threatening, and the first Coast Guard vessel on the scene is equipped for rescue if needed. That first vessel determines whether further resources are needed.

Search and rescue situations often bring local agencies into action. Harbor patrols, harbor police, Coast Guard Auxiliary, the harbor master, and volunteers may all contribute to the effort.

Spills of hazardous substances bring other federal and state and local agencies into action, as well as many volunteers. For example, the federal Departments of the Interior, Commerce, Agriculture, Defense, Health and Human Services, Justice, Labor, and Transportation, and the Environmental Protection Agency were all involved in responding to the Exxon Valdez spill. In addition, many agencies from the State of Alaska were heavily involved.

Finally, casualties involving passenger vessels often require the shipowner to provide a vessel onto which the passengers are evacuated and transported to the nearest port, accommodations and transportation home.

Cost of response activities

The costs of response activities range widely depending on the degree of the response to an incident. They may include salaries of personnel involved in the response, equipment and vessel usage charges, and costs of supplies.

Scope of section

In this section the costs of response to vessel casualties by the Coast Guard, other government agencies, and shipowners are analyzed and estimated. The product of this analysis is a table of estimated costs, a matrix that substitutes conservative judgments and probabilities for the heavily branched decision tree that would most fully describe these costs. The table can be applied to all types of vessel casualties from the simplest groundings to complicated casualties involving pollution or the threat of pollution by petroleum products and other hazardous substances.

The cost of physically cleaning up spills is treated in Section 6.5. This section treats only non-cleanup activities associated with a pollution incident -- the monitoring of cleanup efforts (and their supervision when a spill is federalized), investigation, interface with shipowners, salvage firms, and mobile ship repair units to prevent or limit pollution, close monitoring of lightering and salvage efforts, the creation of safety zones and sometimes the closing of waterways, enforcement actions, coordination with state and local resources, approval of plans, standby duty, extensive report writing. Some of these apply only in cases involving pollution or threatened pollution and some apply universally. It should be remembered that virtually every casualty involving at least one self-propelled vessel threatens pollution until proved otherwise.

6.11.2 Methodology

The first step in attempting to price responses to casualties was participating in a round-table discussion held with Lt. Cmdr. Richard Wells, Asst. Chief of Inspections & Investigations, Robert Corbin, Boston MSO, and Ken Achey, Chief Warrant Officer of Group Operations, at the Boston Marine Safety Office. The discussion centered around a series of casualty scenarios, loosely based on press reports of incidents that had recently occurred in the area. Each scenario, as well as variations, was analyzed for the type and quantity of effort that it would require from each division of the local operation. General Coast Guard response practices were discussed, starting with the most basic and universal response and branching upwards and outwards, and involvement practices of other federal agencies and state and local entities in various situations were analyzed. Thus information was obtained on the quantity (in personnel, vessel and aircraft hours), of response that would be elicited in different scenarios, from minimum to maximum, while varying many factors. VNTSC then applied these responses to typical casualties and translated the responses into dollars on the basis of other reports and accounts from a variety of sources.

This most fruitful discussion prepared the way for translating the responses into dollars using COMINDST 7310.1D: Standard Rates, and a variety of other sources, including the USCG report on the World Prodigy grounding (supplemented by a University of Rhode Island study of scientific response to the spill), a GAO report on Exxon Valdez costs, cost summary reports from the First Coast Guard District, and many general and specialized press accounts of casualties and their aftermath.

Certain costs were not treated here either because of their seeming rarity in VTS-addressable casualties, their relative insignificance, difficulty of generalizing about them, or all of the above. The matrix does not, for instance, include costs of fires or of search and rescue efforts for persons overboard. (SAR is, however, built into the heavy and catastrophic pollution instances.)

The same figures were used for pollution response to a given range of spill sizes for dry cargo vessels as for tankers and tank barges (except for the catastrophic range, where the upper limits of spill amount for tank barges are clearly much smaller than for tankers). On the one hand, spills of bunker fuel in a port area are apt to cause severe consequences; on the other hand, larger spills within the broad size ranges are more apt to be caused by tankers: so we assumed, for simplicity's sake, equality of costs.

Most of the entries in the matrix were built from the bottom up, i.e., by considering the ingredients of response in a particular instance and the probabilities of variations to it based on critical reading of news accounts of VTS-addressable casualties, restating the particulars in terms of vessels and personnel, and estimating their cost using the figures in COMINDST 7310.1D. When a choice was available, the least expensive response vessel or aircraft was chosen. The entries for heavy and catastrophic pollution, however, were created by disaggregating, adjusting and reassembling the documented costs of two actual casualties, the World Prodigy and Exxon Valdez, respectively.

6.11.3 Results

Table 6-15 shows the results of the analysis of response costs.

TABLE 6-15. RESPONSE COST FACTORS BY SOURCE ($000)

VESSEL TYPE	BASIC RESP	POLL THRT	LITE POLL	MED. POLL	HVY. POLL	CATA. POLL	SIMP. EVAC	DIFF. EVAC	BRDG. RAM
Tanker	1.4	4.5	11.7	28.0	701.6	29,500.0	0.0	0.0	20.7
Dry Cargo	1.4	4.5	11.7	28.0	701.6	0.0	0.0	0.0	20.7
Tank Barge	1.4	4.5	11.7	28.0	701.6	19,667.0	0.0	0.0	20.7
Dry Barge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.7
Small Pass	3.3	3.4	10.6	20.6	0.0	0.0	58.0	116.0	20.7
Barge Pass	4.5	4.5	11.7	28.0	701.6	0.0	220.0	440.0	20.7
Tow	1.4	2.2	5.8	22.2	0.0	0.0	0.0	0.0	0.0

Response costs include personnel and vessel costs for Coast Guard, other federal agency, and/or state and local response. Private sector response costs are included only in the case of evacuation of passengers.

The estimates of response costs for various situations are divided into four categories, separated by double lines. The categories are Basic Response, Pollution, Evacuation, and Bridge Ramming.

The Basic Response estimate for the type of vessel should be added to the appropriate selections, if any, from the other three categories to arrive at a total. Choose only <u>one</u> figure for each category. Take the example of a casualty to a large passenger ship, involving light pollution and an evacuation that is relatively uncomplicated, arranged and supervised by the company, but monitored by the USCG. Locate the row labelled Pass/Ferry LG and move horizontally. Add up the figures for Basic Response, Light Pollution, and Simple Evacuation.

PASS/FERRY LG $4500 + $11,682 + $220,000 = $236,182

For multi-vessel casualties we estimate that some cost aspects of response to two-vessel casualties - safety zone creation, navaid checks, etc. - would be less than twice as expensive as for single-vessel casualties. However, others, like investigation costs, would surely exceed the sum of such costs for single-vessel accidents.

In the absence of good data and/or highly detailed analysis on this point, therefore, adding the estimated per vessel costs appears reasonable.

Basic Response includes routine SAR response, navaid checking and report writing. Specifically, it assumes that a single 41-foot utility boat visits from a nearby location and, after ascertaining that there is no immediate danger, requests a brief navaid check, and remains on scene to assure that no complications develop before the vessel involved in the casualty gets underway.

Basic Response, in tug/tow/barge cases, is attributed to the tug or towboat. Pollution responses are treated for tank barges only. Dry barges will normally incur separate response costs only in severe collisions (especially with bridges) that cause increased investigation and/or safety zone creation, and/or when a channel is blocked. We have isolated these costs only in the case of bridge rammings, but the estimate for pollution threat for other vessels could be used in such cases.

Actions taken under **Pollution Threat** have been considered in the figures for the states of pollution that follow. The assumption was made in calculating pollution costs, that cleanup of heavy spills would be federalized 60% of the time. Less than heavy spills were assumed not to be federalized. In a federalized spill, the Coast Guard hires and supervises contractors, but confines itself to monitoring when the shipowner takes responsibility along the way. (In some cases, like the Shinoussa/Apex barge casualty in Galveston TX on July 28, 1990, the owner initially takes responsibility but the Coast Guard takes over when insurance funds are exhausted.)

Costs for monitoring (but not performing) cleanup by other federal, state and local agencies, and costs for field work by various agencies (but not formal damage assessment) are included in our estimates.

Pollution Threat describes USCG response to the pollution potential of a given casualty, including precautionary actions. Given the simplified categories here, pollution threat costs for large vessels, especially large tankers, are understated. Pollution threat costs have been added into the subsequent pollution categories. Choose this category only if no pollution actually ensued.

Pollution Threat is assumed to be present for all self-propelled vessels and for dry barges; the threat will be less for smaller vessels and/or those that use diesel rather than bunker fuel. We assumed there is some threat to navigation as well, and that a safety zone is created until such time as the salvage master has determined there is no danger.

Light Pollution refers to a spill size up to 10,000 gallons. These cases are assumed to need no cleanup monitoring and to remain unfederalized. We assumed that the vessel could be patched, requiring the longer maintenance of a safety zone, consultations with the salvage master, inspection of the patching, and additional investigation and report writing.

Medium Pollution denotes a spill size from 10,000 to 100,000 gallons. These cases were assumed to be federalized (thus at least doubling the cost) 30% of the time. An aircraft was assumed to be used 20% of the time, with an equal probability of helicopter or fixed-wing aircraft, depending on both the location of the spill and the availability of aircraft. A three-person strike team was assumed to be called in for 3 days 30% of the time.

Heavy Pollution denotes a spill size from 100,000 to 750,000 gallons. These entries are based on the costs in the World Prodigy grounding. This is a relatively modest example, as fairly light product was involved and it came ashore in relatively small amounts. Given the location of the casualty, there was not significant interference with other shipping. We have added a probability of 50% that a significant waterway or channel would be closed for three days and valued it at $20,000.

Catastrophic Pollution refers to spills in the Exxon Valdez range, 750,000 gallons and up. The catastrophic instance was based on federal agency costs reported by the General Accounting Office in connection with the Valdez. The report covers costs through November 1989, and separates cleanup monitoring and other response costs from damage assessment costs for the Coast Guard and other agencies. After analysis of the reported costs, we determined that the amount meeting our criteria, including USCG, DOI, DOC, DOA, EPA, and HHS expenditures for monitoring and real-time (usually field) damage assessment, was $44.3 million. (We did not include DOD costs - reported at 62.8 million - as we could not assess their nature.) We estimated that the bulk of response expenses were incurred in the first season, and added on another $14.7 million as an estimate of second season monitoring and response expenses. In view of special characteristics of this casualty - lack of preparedness and location - the total was then halved to arrive at our estimated figure for the matrix of $29,500,000.

A Simple Evacuation is one where the shipowner takes responsibility and no complicating factors apply. The complicating factors that would make for a **Difficult Evacuation** include: 1) a total loss or severe damage (or moderately severe damage and the casualty occurred far offshore); 2) imminent danger to passengers; 3) severe weather; or, 4) the inability of the owners to take responsibility. Any of these would cause the Coast Guard or another government entity to move to more active involvement.

For the purposes of this cost category, a large passenger vessel is assumed to be a cruise ship with about 500 passengers. The smaller vessel is assumed to be carrying about half as many passengers and to be on a ferry run or day trip. We assumed that the cruise ship passengers would be transported to the nearest sizeable city, housed overnight and fed before being provided with air transportation home. For the small vessel, transportation was assumed to be provided only to the boat's point of origin. We did not calculate evacuation costs for cargo vessels because our Coast Guard contacts assured us that in most cases they would be able to evacuate crew from casualties within port areas using the capacity of USCG vessels that would be responding in any case.

Bridge Ramming costs include estimates for waterway closing/control, investigation, and preliminary inspections of the bridge and evaluation of the damage to it. These figures assume two days of channel closing, enforced by two boats; 80 hours of work by Coast Guard and other bridge (engineering) personnel; a navaid check; and 40 hours of investigative time. For OTHER vessels we charged 60% of this figure, on the assumption that perhaps 40% of vessels in the OTHER category would not be likely to cause bridge damage.

6.11.4 Bibliography

United States Coast Guard publications and reports

Commandant Instruction 7310.1D, 3/21/90. Commandant (G-CAC) Washington, D.C. Subject Standard Rates. This instruction establishes standard rates to be used in computing reimbursable charges, for personnel, cutters, aircraft, and small boats.

Commandant Publication P16114.1, 29 APR 1988, Subj: Boats of the United States Coast Guard: a catalog of boats currently used in the Coast Guard.

Cost Summary Reports for costs reimbursable to the Pollution Fund, First Coast Guard District.

First Endorsement of I.O. Report 16732/0422 BOS 82-MC84 00468, 16 June 1986. Report on ramming of Chelsea Street Bridge,Chelsea, MA by Tanker Scraptrade, 11/10/82. Includes information on CG and City of Boston response.

Marine Safety Office Providence. Expense Report for Pollution Response Activity Following the Oil Spill Involving the World Prodigy... . January 3, 1990. Includes letter to Commander William Thomas from D James Jacobsen, Department of Justice dated 11/5/90 and subsequent emendations.

Other materials

Arnold, David. "Oil spill barely averted in harbor crash, says Coast Guard." Boston Globe, 1/18/90.

"Barge Strikes Another in Arthur Kill." New York, Journal of Commerce, 7/19/90.

Belkin, Lisa. "Whereabouts of 500,000 Gallons of Oil is Baffling in Texas Spill." New York Times, August 2, 1990.

"Chelsea River closed to ships." Boston Globe, 1/24/90.

Coughlin, William P., "Tanker accident another close call in wave of Boston Harbor mishaps." Boston Sunday Globe, 1/28/90. Summary of potentials of six light casualties and near misses, based on interviews with Lt. Cmdr. George Matthews.

......................"New mishaps keep tanker routes closed," Boston Globe, c. 1/27/90.

......................"Tanker grounds at Chelsea; no spill, but much confusion." Boston Globe, 1/3/90. Gebze grounding.

......................"Patching work nearly completed on cruise ship's torn underside." Boston Globe, 1/17/90. Bermuda Star.

Dumanoski, Diane. "Oil spill threatens Cape's wildlife." Boston Globe, Tuesday, June 12, 1990. Bermuda Star.

"GIWW Traffic Restored After Grounding, Spill." Waterways Journal, 11/12/90. 2000 bbl spill (grounding at bend) caused 5 day closing, followed by one way restrictions. Descriptions of CG and other govt. role.

"A Massachusetts Valdez?" Boston Globe, 5/2/89.

Meyers, Jack. "Tanker collision probed." Boston Herald, Thursday, 1/18/90. USS Aylwin/Pluto collision. Light spill, catastrophic potential. Inside harbor.

Murphy, Sean P. and Coughlin, William P. "A shaky sealing limits flow into Buzzards Bay." Boston Globe, 1/12/90. Bermuda Star.

Pilson, Michael E.Q. Summary of the Scientists' Response to the World Prodigy Oil Spill at Brenton Reef, Rhode Island, June 23, 1989. Narragansett, R.I., University of Rhode Island Graduate School of Oceanography, GSO Technical Report No. 90-1, March 1990. Information on the spill and the field response of many groups.

Richard, Ray. "Tanker leaks oil into Hub Harbor." Boston Globe, c. 1/12/90 Elizabeth S.K.

"Ship Pilot Can't Explain Chesapeake Bay Crash: July 1 Accident Caused Oil Spill," Journal of Commerce, 7/9/90, reprint from Newport News Daily Press.

Shipyard Weekly. Washington, DC, Shipbuilders Council of America. 2/15/90; 6/14/90. Lists of spills with causes and spill amounts.

Smith, Heidi. "Monitoring System to Aid Navigation in Tampa Bay Area." New York, Journal of Commerce, 7/5/90.

Taylor, Gary. Series of seven articles on Shinoussa-Apex Barges collision, New York, Journal of Commerce, c. 8/1/90ff.

"Texas Bay Oil Spill Threatens Wildlife; Limited Shipping Begins After Blockage." Wall Street Journal, Wednesday, August 1, 1990. p. A3. Early Report on Shinoussa- Apex barges collision.

United States General Accounting Office: GAO Fact Sheet for Congressional Requesters, COAST GUARD: Federal Costs Resulting From the Exxon Valdez Oil Spill, January 1990, GAO/RCED-90-91FS.

Wastler, Allen R. "Ship-Collision Oil Spill Curbs Va. Operations," 7/3/90; "Columbus Ship Back in Service;" 7/19/90. New York, Journal of Commerce. Columbus America/Neptune Jade.

White, David F. "Spill Cleanup May Continue Into Next Week in NY. "New York, Journal of Commerce, 7/20/90. Barge collision in Arthur Kill.

6.12 BLOCKED CHANNELS AND WATERWAYS

6.12.1 Background

Vessel casualties occurring in or near channels and waterways can delay other vessels attempting to proceed through the area in a number of ways. Vessels involved in casualties may become stuck or lose power or steering ability, physically blocking a narrow channel, so that there is not enough room for another vessel to pass by. Narrow channels, such as those found in the Gulf ports of Houston and Corpus Christi and in the river ports of New Orleans and Portland, OR are especially vulnerable to blockage. A casualty might compel the Coast Guard to establish a safety zone around the vessel(s) involved in the casualty, through which other vessels must obtain permission to pass at a slow speed or in which one way traffic would be enforced. A safety zone would prevent passing vessels from exacerbating damages with their wakes, spreading spilled hazardous substances further, endangering persons overboard, and risking damage to themselves from fires. In extreme cases, a vessel casualty might necessitate the closing of the port, preventing other vessels from moving into, out of or within the port. Port closure would occur when a casualty produced catastrophic spills of hazardous materials, intense fires and explosions, or the potential for such.

Short-term delays are not usually a problem for most vessels. A certain amount of delay is built into the schedule of every vessel, for marine transportation is by nature not as predictable as other modes. Most companies moving cargo by sea can accommodate delays of several days before scheduling becomes problematic. Cargos with sensitive delivery schedules are more likely to be sent by air, if possible. Vessel owners build some leeway into their shipping rates to cover increases in operating costs due to short delays.

Long delays can be a problem. The recent July 28, 1990 collision between a tanker and a tug and three barges that left the Houston ship channel closed or restricted for almost two weeks, for example, proved quite costly. Shipowners and operators lost an estimated $20,000,000 when up to 60 ships were idled during the week-long closure. And the Port of Houston suffered losses in dockage fees when at least eleven vessels canceled scheduled arrivals, diverting to nearby ports.[27]

---

[27] Journal of Commerce, August 8 and 13, 1990. Quote of Ted Thorjussen of West Gulf Maritime Association.

6.12.2 Results

The loss factors developed for the costs of channel blockage are based on anecdotal information obtained from conversations with knowledgeable persons, and from articles in publications. It is assumed that delays to vessels of two days or less would not add significantly to the operating costs of the vessels, and would not divert the vessels to another port. It is also assumed that a safety zone in which passage of vessels was restricted, but not prohibited, would not cause a significant increase in operating costs. Table 6-16 shows the costs that would be incurred by vessel owners and operators for each day over two days a port is closed. No attempt is made to estimate the number of vessels that might divert to another port or the lost dockage fees to the port where the casualty occurred.

TABLE 6-16. DAILY COSTS OF CHANNEL BLOCKAGE BY TYPE OF VESSEL[28]

Vessel Type	Cost per Day ($000)
Passenger	
small	75
medium	150
large	250
Dry Cargo	
small	9
medium	12
large	16
Tanker	
small	16
medium	20
large	24
Barges, including Tow or Tug	
small	3
large	5
Fishing vessel	9
Other	4

[28] Costs include operating and capital costs as derived in the report "Develop Estimates of Costs Associated with Oil and Hazardous Chemical Spills and Costs of Idle Resources during Vessel Repairs", by Eastern Research Group, Inc., November, 1990, Section Five.

6.13 DAMAGE TO NAVAIDS AND BRIDGES

6.13.1 Background

In a ramming a vessel impacts a stationary object, such as a navigational buoy, drilling platform, pier or bridge, causing damage not only to the vessel but also to the object. This section addresses the costs of damages to navigational aids and bridges, the most likely to be damaged in a VTS-addressable casualty.

When a vessel hits a navaid, the navaid may simply be pulled off position, or it may be damaged or totally destroyed. Equipment and labor charges are incurred. In a vessel collision with a bridge, bridge damages may range from light to severe. Most critical bridge supports are equipped with cushioned fenders to minimize damage to the supports, to vessels, and to the fenders themselves. However, occasionally, a vessel strikes a bridge support with enough force to cause not only major damage to the vessel, but also major damage to the bridge, possibly even the collapse of a bridge span. When this happens, vehicles on the bridge may fall into the water below, and traffic must be rerouted until the bridge is repaired. Traffic congestion may ensue, wasting automobile fuel and causing driver aggravation and delays. Resulting costs can be quite severe.

6.13.2 Results

The cost of replacing a typical navaid is $20,400. This value is based on Coast Guard Standard rates (as established in Commandant Instruction 7310.1D on Standard Rates dated March 21, 1990) and the distribution of navaid types in a sample of study zones. It includes the cost of the replacement buoy, vessel and personnel charges, and the cost of a temporary buoy for two months. Fixed navaids (daymarkers and lights) were not included in the analysis, because they generally are located in water too shallow or on the obstacle they are marking, and thus out of range of most of the vessels that would be participating in VTS.

Table 6-16 shows the typical bridge damage resulting from varying severities of vessel rammings with bridges. The values are based on an analysis of historical CASMAIN data, described in Appendix 6-M. No attempt has been made to estimate the costs of bridge closure to users for two reasons. First, the probability of a bridge sustaining enough damage to rupture its span or to close it for a lengthy period of time is extremely small. In practice, the fendering systems and the slow speeds at which vessels approach bridges keep bridge damage from rammings at a minimum. Although a bridge closing would be quite costly (it was estimated that a ramming of the Tobin Bridge in Boston that closed it for 180 days would cost over $85 in deaths and injuries, loss of automobiles, travel delays and wasted gasoline), its low probability of occurrence would minimize its effect on the outcome of the cost-benefit analysis. Second, costs of bridge closure would vary according to a large number of variables, including among others the type of bridge (rail or auto), level of bridge traffic, availability of alternate routes, congestion of alternate routes, and gasoline prices. Impact studies for the closure of the approximately 170 bridges (listed in Appendix 6-N) over navigable waters of the 23 study zones is beyond the scope of the VTS Port Needs Study.

TABLE 6-17. COST OF BRIDGE DAMAGE BY SEVERITY OF CASUALTY

Severity of Casualty	Cost of Bridge Damage
Low	$35,196
Moderate	$254,741
Severe	$10,784,868

6.14 LNG AND LPG EXPLOSIONS[29]

6.14.1 Background

The transport by sea of liquified natural gas (LNG) and liquified petroleum gas (LPG) in tankers and in tank barges (LPG only) makes it possible, however unlikely, for a vessel casualty to cause a release of one of these fuels and a subsequent fire. The potential for catastrophic damage to both the vessels and nearby populations and structures requires the study to address the consequences of such an occurrence.

Characteristics of Tankers

LNG tankers typically have either a 125,000 cubic meter or a 75,000 cubic meter capacity. For entry into U.S. waters, they must be double-hulled. The largest LNG tankers contain five 25,000 cubic meter capacity refrigerated tanks, which maintain a temperature of minus 162 degrees Centigrade to keep LNG in a liquified state. Approximately 30 crew members are required to operate the vessels.

LPG tankers are also double-hulled and typically smaller, carrying between 24,000 and 75,000 cubic meters of the gas. The largest LPG tankers contain four 18,750 cubic meter capacity tanks, which maintain a temperature of minus 42 degrees Centigrade. There are approximately 25 crew members on an LPG tanker.

Release Scenarios

One of two scenarios would likely occur if an LNG or LPG tank were ruptured in a high energy casualty. The basic scenarios would be the same for the two liquid gases, but the severity of damages would differ according to their physical characteristics of the gasses. These differences are addressed in the development of damage models.

The first, the pool fire scenario, would occur in a collision or ramming in which a tank was ruptured above the water line of the vessel and its contents spilled onto the water. The liquid gas would spread to a maximum pool size, and evaporate as it spread. If it were ignited by a nearby spark, which has a probability of about ninety percent because of the proximity of vessel engines and

---

[29]The information in this section was taken for the most part from the following study:

"The Consequences of Casualties Affecting LNG and LPG Tankers", Herb Weinblatt of Jack Faucett Associates, prepared for the U.S. Department of Transportation, Volpe National Transportation Systems Center, December, 1990.

The study is included in its entirety as Section 8 of this technical supplement.

metal friction, there would be no way to extinguish it before it burned itself out, and it would cause significant damage to the vessel and total loss of the crew. If the fire occurred near land or other vessels, thermal radiation would cause significant damage to vessels and structures and death or injury to people in a wide radius.

The second scenario, the vapor cloud, would occur if the initial release due to a collision or ramming were not ignited at the release site or if a release resulted from a grounding. A vapor cloud would roll along the water surface pushed by the wind, eventually expanding and rising into a plume. The gas would become flammable when the gas-air mixture contained 5 to 15 percent gas. If it were ignited, it would cause damage both to the source of ignition, and to the source of the vapor cloud itself, but not as much damage as a pool fire. The probability of ignition would depend on the proximity of the casualty to land and whether the wind took the vapor cloud toward an ignition source such as a nearby vessel, land-based engine or other spark generator.

These scenarios for releases of LNG and LPG were used as the basis for estimating the dollar value of damages resulting from LNG and LPG tanker casualties.

6.14.2 Data Sources

Consequences of releases of LNG and LPG due to vessel casualties are speculative because they are based on models of what would be expected to happen rather than actual cases, since no tanker releases have occurred to date. Two studies have provided information on the consequences: a risk analysis of LNG pool fires by the Federal Power Commission, and a thermal radiation model for LNG fires developed for the Gas Research Institute by Risk and Industrial Safety Consultants, Inc. In addition, several releases of LNG and LPG which occurred on land provided information on the effects of fires and explosions on nearby buildings and people.

6.14.3 Methodology

Models were developed to predict the type and amount of damage resulting from a release of LNG or LPG, given the type of casualty, the location of the casualty, and the substance spilled. For LNG, a model was developed for each of eleven subzones through which LNG moves or is expected to in the future. Two study zones, Boston and Port Arthur, with active LNG terminal facilities, account for seven of the subzones. A third LNG terminal will become operational in 1992 at Cove Point, MD, requiring LNG tankers to pass through three subzones in the Hampton Roads zone and one in the Baltimore zone.

For LPG, a model was developed by subzone type, instead of specific subzone, because of the large number of subzones through which LPG passes. The models predict the damages to the LNG and LPG vessels and their crew, other vessels and crew, people and structures on shore, and nearby bridges.

All the models assume that one tank is ruptured in the casualty, and that consequent fires and explosions do not cause any further LNG or LPG tank ruptures. The models also assume that 1,340 crew and passengers are aboard large passenger vessels involved in LNG and LPG tanker casualties, and 59 crew passengers are aboard small passenger vessels. Intermediate results are shown in the spreadsheets in Appendix 6-O. Final results are shown in the sections below.

6.14.4 Results

Losses due to LNG tanker collisions and rammings

Losses to an LNG tanker and to nearby property and populations due to a collision or ramming resulting in a release of LNG are shown below in Table 6-18 by subzone. Damages to a second vessel involved in a collision are treated separately in Table 6-19, and are not included in Table 6-18. The area around the Chesapeake Bay Bridge-Tunnel is treated as a separate subzone because of the unique consequences that might occur in that area.

Table 6-18 demonstrates that the potential for injuries and deaths far outweighs the potential property damage in the Boston inner harbor and the Mystic River because of the high concentration of residents and workforce in the area during the daytime hours when LNG transits occur. Further, property damages are expected to be greater here than in other subzones, because the narrow waterways would cause an LNG casualty to occur near the downtown business district and densely built areas. In other subzones, LNG casualties would occur further from shore, and dollar losses from vessel damages would be greater than those from human injury and death.

TABLE 6-18. PROPERTY AND HUMAN LOSSES DUE TO AN LNG TANKER COLLISION OR RAMMING

SUBZONE	PROPERTY DAMAGE ($000)	COST OF FATALITIES ($000)	COST OF BURNS ($000)	COST OF INJURIES ($000)	EXPECTED LOSSES ($000)
0101	100,000.0	40,500.0	0.0	825.8	141,325.8
0102	100,000.0	40,500.0	0.0	825.8	141,325.8
0103	106,000.0	114,000.0	3,000.0	770.7	223,770.7
0104	260,000.0	5,550,000.0	215,000.0	385.4	6,025,385.4
0105	230,000.0	5,250,000.0	210,000.0	330.3	5,690,330.3
0501	100,000.0	40,500.0	0.0	825.8	141,325.8
0503	100,000.0	48,000.0	500.0	770.7	149,270.7
0801	100,000.0	40,500.0	0.0	825.8	141,325.8
0802	100,000.0	75,000.0	0.0	825.8	175,825.8
CHES BAY BRDG-TUNNEL	105,000.0	40,500.0	11,500.0	798.2	157,798.2
0803	100,000.0	40,500.0	0.0	825.8	141,325.8
0901	100,000.0	40,500.0	0.0	825.8	141,325.8

Table 6-19 demonstrates that the losses occurring to a second vessel involved in a collision vary by the type of vessel and are quite significant. The total damage to the second vessel is composed of the damage that would occur in an ordinary collision ("Collision Damage") and the damage due to one of the two LNG fire scenarios (a portion of "Vessel Value"). A collision of an LNG tanker with a large passenger vessel has the potential to cause the greatest number of fatalities.

TABLE 6-19. LOSSES TO SECOND VESSEL INVOLVED IN AN LNG TANKER COLLISION

VESSEL TYPE	FIRE DAMAGE ($000)	COLLISION DAMAGE ($000)	CREW LOSSES ($000)	POOL FIRE PROBABILITY	VAPOR CLOUD PROBABILITY	EXPECTED LOSSES ($000)	VESSEL VALUE ($000)	COLLISION DAMAGE ($000)	CREW SIZE
LARGE TANKER	4,500.0	2,267.0	21,047.0	0.90	0.10	27,813.96	20,000.0	2,267.0	24.0
MEDIUM TANKER	3,375.0	1,597.0	17,539.1	0.90	0.10	22,511.13	15,000.0	1,597.0	20.0
SMALL TANKER	1,125.0	259.6	14,908.3	0.90	0.10	16,292.86	5,000.0	259.6	17.0
LARGE BULK CARRIER	4,050.0	6,302.5	21,047.0	0.90	0.10	31,399.46	18,000.0	6,302.5	24.0
MEDIUM BULK CARRIER	1,923.4	6,441.8	17,539.1	0.90	0.10	25,904.30	8,548.3	6,441.8	20.0
SMALL BULK CARRIER	720.0	642.1	14,908.3	0.90	0.10	16,270.36	3,200.0	642.1	17.0
LARGE TANK BARGE	675.0	616.4	0.0	0.90	0.10	1,291.40	3,000.0	616.4	0.0
SMALL TANK BARGE	292.5	327.5	0.0	0.90	0.10	620.00	1,300.0	327.5	0.0
LARGE DRY BARGE	146.3	418.7	0.0	0.90	0.10	564.95	650.0	418.7	0.0
SMALL DRY BARGE	67.5	277.6	0.0	0.90	0.10	345.10	300.0	277.6	0.0
LARGE PASSENGER	13,500.0	1,320.0	1,147,459.1	0.90	0.10	1,162,279.09	60,000.0	1,320.0	1,340.0
SMALL PASSENGER	2,250.0	670.0	50,522.5	0.90	0.10	53,442.45	10,000.0	670.0	59.0
FISHING VESSEL	101.3	204.8	17,539.1	0.90	0.10	17,845.18	450.0	204.8	20.0
TOW BOATS	180.0	531.5	4,384.8	0.90	0.10	5,096.28	800.0	531.5	5.0
OTHER VESSEL	1,350.0	532.0	8,769.6	0.90	0.10	10,651.57	6,000.0	532.0	10.0

Losses due to LNG tanker groundings

Losses to an LNG tanker involved in a grounding that produces a release of LNG are shown in Table 6-20. Again, the losses in the Boston inner harbor and Mystic River are greater than for other subzones. Table 6-21 shows the losses that would occur to a second vessel if it were the source of ignition for the vapor cloud resulting from the tanker grounding. Losses to a second vessel are not included in Table 6-20. It can be seen from the first table that, like collisions, groundings of an LNG tanker would cause significantly greater damages to both humans and property in subzones that are near population centers or that consist of narrow waterways. Damages due to groundings, however, are less than those from collisions and rammings because groundings are more likely to produce vapor clouds which do not burn with the intensity of the pool fires that are more likely to be produced by collisions.

TABLE 6-20. PROPERTY AND HUMAN LOSSES DUE TO AN LNG TANKER GROUNDING

SUBZONE	PROPERTY DAMAGE ($000)	COST OF FATALITIES ($000)	COST OF BURNS ($000)	COST OF INJURIES ($000)	EXPECTED LOSSES ($000)
0101	2,500.0	90.0	60.0	8,213.5	10,863.5
0102	2,700.0	180.0	120.0	8,147.4	11,147.4
0103	4,400.0	1,800.0	900.0	7,762.1	14,862.1
0104	32,000.0	412,500.0	140,000.0	3,853.5	588,353.5
0105	32,500.0	480,000.0	160,000.0	3,303.0	675,803.0
0501	2,500.0	90.0	60.0	8,202.5	10,852.5
0503	2,500.0	105.0	65.0	8,202.5	10,872.5
0801	2,500.0	90.0	60.0	8,202.5	10,852.5
0802	2,500.0	90.0	60.0	8,202.5	10,852.5
CHES BAY BRDG-TUNNEL	4,300.0	2,400.0	1,100.0	7,762.1	15,562.1
0803	2,900.0	300.0	200.0	8,119.9	11,519.9
0901	2,700.0	180.0	120.0	8,158.4	11,158.4

Table 6-21 shows the losses to a second vessel if it were the source of ignition for the vapor cloud produced by an LNG tanker grounding. The probability of a vessel being the ignition source is greater than zero in subzones further from other sources of ignition, such as automobile engines on shore. In Type A subzones (Approach) the probability of another ship in the vicinity igniting the vapor is half that in Type B and C subzones (Convergence and Open Harbors).

TABLE 6-21. LOSSES TO SECOND VESSEL IGNITION SOURCE IN AN LNG TANKER GROUNDING

VESSEL TYPE	FIRE DAMAGE ($000)	COLLISION DAMAGE ($000)	HUMAN LOSSES ($000)	EXPECTED LOSSES ($000)
SUB-ZONES 0101, 0501, 0801 (P=.01)				
LARGE TANKER	20.0	22.7	146.4	189.09
MEDIUM TANKER	15.0	16.0	122.0	152.99
SMALL TANKER	5.0	2.6	103.7	111.31
LARGE BULK CARRIER	18.0	63.0	146.4	227.45
MEDIUM BULK CARRIER	8.5	64.4	122.1	194.99
SMALL BULK CARRIER	3.2	6.4	103.7	113.34
LARGE TANK BARGE	3.0	6.2	0.0	9.16
SMALL TANK BARGE	1.3	3.3	0.0	4.58
LARGE DRY BARGE	0.7	4.2	0.0	4.84
SMALL DRY BARGE	0.3	2.8	0.0	3.08
LARGE PASSENGER	60.0	13.2	8,175.3	8,248.50
SMALL PASSENGER	10.0	6.7	359.9	376.60
FISHING VESSEL	0.5	2.0	122.0	124.52
TOW BOATS	0.8	5.3	30.5	36.62
OTHER VESSEL	6.0	5.3	61.0	72.33
SUB-ZONES 0102, 0103, 0803, 0901 (P=.02)				
LARGE TANKER	40.0	45.4	292.8	378.19
MEDIUM TANKER	30.0	32.0	244.0	305.98
SMALL TANKER	10.0	5.2	207.4	222.63
LARGE BULK CARRIER	36.0	126.0	292.9	454.90
MEDIUM BULK CARRIER	17.0	128.8	244.2	389.97
SMALL BULK CARRIER	6.4	12.8	207.5	226.68
LARGE TANK BARGE	6.0	12.4	0.0	18.33
SMALL TANK BARGE	2.6	6.6	0.0	9.15
LARGE DRY BARGE	1.4	8.4	0.0	9.67
SMALL DRY BARGE	0.6	5.6	0.0	6.15
LARGE PASSENGER	120.0	26.4	16,350.6	16,497.00
SMALL PASSENGER	20.0	13.4	719.8	753.20
FISHING VESSEL	1.0	4.0	244.0	249.04
TOW BOATS	1.6	10.6	61.0	73.24
OTHER VESSEL	12.0	10.6	122.1	144.66

Losses due to LPG tanker collisions and rammings

Losses to an LPG tanker and to nearby property and populations due to a collision or ramming causing a release of LPG are shown in Table 6-22 by subzone type. Table 6-23 shows losses to the second vessel involved in a collision with an LPG tanker. Second vessel losses are not included in Table 6-22.

As with LNG, damages to property and humans due to a release of LPG increase as the waterway narrows and approaches population concentrations. The consequences to the crew of a large passenger ship colliding with an LPG tanker would be catastrophic in terms of human loss.

TABLE 6-22. PROPERTY AND HUMAN LOSSES DUE TO AN LPG TANKER COLLISION OR RAMMING

SUBZONE	PROPERTY DAMAGE ($000)	COST OF FATALITIES ($000)	COST OF BURNS ($000)	COST OF INJURIES ($000)	EXPECTED LOSSES ($000)
A. OPEN APPROACH	41,000.0	33,750.0	0.0	688.1	75,438.1
B. CONVERGENCE	41,000.0	33,750.0	0.0	688.1	75,438.1
C. OPEN HARBOR OR BAY	42,000.0	37,500.0	500.0	688.1	80,688.1
D. ENCLOSED HARBOR	58,000.0	585,000.0	21,000.0	495.5	664,495.5
E. CONSTRICTED WATERWAY	50,000.0	300,000.0	10,500.0	578.0	361,078.0
F. RIVER	50,000.0	300,000.0	10,500.0	578.0	361,078.0

TABLE 6-23. LOSSES TO SECOND VESSEL INVOLVED IN AN LPG TANKER COLLISION

VESSEL TYPE	VESSEL VALUE ($000)	COLLISION DAMAGE ($000)	HUMAN LOSSES ($000)	POOL FIRE PROBABILITY	VAPOR CLOUD PROBABILITY	EXPECTED LOSSES ($000)
LARGE TANKER	5,400.0	2,267.0	17,673.3	0.90	0.10	25,340.31
MEDIUM TANKER	4,050.0	1,597.0	14,727.8	0.90	0.10	20,374.76
SMALL TANKER	1,350.0	259.6	12,518.6	0.90	0.10	14,128.20
	0.0					
LARGE BULK CARRIER	4,860.0	6,302.5	17,673.3	0.90	0.10	28,835.81
MEDIUM BULK CARRIER	2,308.0	6,441.8	14,727.8	0.90	0.10	23,477.60
SMALL BULK CARRIER	864.0	642.1	12,518.6	0.90	0.10	14,024.70
LARGE TANK BARGE	810.0	616.4	0.0	0.90	0.10	1,426.40
SMALL TANK BARGE	351.0	327.5	0.0	0.90	0.10	678.50
LARGE DRY BARGE	175.5	418.7	0.0	0.90	0.10	594.20
SMALL DRY BARGE	81.0	277.6	0.0	0.90	0.10	358.60
LARGE PASSENGER	16,200.0	1,320.0	986,760.0	0.90	0.10	1,004,280.00
SMALL PASSENGER	2,700.0	670.0	43,445.7	0.90	0.10	46,815.70
FISHING VESSEL	121.5	204.8	14,727.8	0.90	0.10	15,054.06
TOW BOATS	216.0	531.5	3,681.9	0.90	0.10	4,429.44
OTHER VESSEL	1,620.0	532.0	7,363.9	0.90	0.10	9,515.88

Losses due to LPG tanker groundings

Losses to an LPG tanker and to nearby property and populations due to a grounding causing a release of LPG are shown in Table 6-24. Table 6-25 shows the losses that would occur to a second vessel if it were the source of ignition for the resulting vapor cloud. The latter losses are not included in Table 6-24. Again, the damages to nearby property and populations increase as the waterways narrow and approach population concentrations. As with LNG, the likelihood of a second vessel igniting the vapor cloud is greater in open subzone types than in constricted subzones where a land-based ignition source would exist.

TABLE 6-24. PROPERTY AND HUMAN LOSSES DUE TO AN LPG TANKER GROUNDING

SUBZONE	PROPERTY DAMAGE ($000)	COST OF FATALITIES ($000)	COST OF BURNS ($000)	COST OF INJURIES ($000)	EXPECTED LOSSES ($000)
A. OPEN APPROACH	1,000.0	180.0	15.0	6,303.2	7,498.2
B. CONVERGENCE	1,100.0	360.0	30.0	6,248.2	7,738.2
C. OPEN HARBOR OR BAY	1,200.0	750.0	50.0	6,220.7	8,220.7
D. ENCLOSED HARBOR	16,000.0	31,500.0	8,500.0	4,816.9	60,816.9
E. CONSTRICTED WATERWAY	8,000.0	15,000.0	4,000.0	5,505.0	32,505.0
F. RIVER	8,000.0	15,000.0	4,000.0	5,505.0	32,505.0

TABLE 6-25. LOSSES TO SECOND VESSEL IGNITION SOURCE IN LPG TANKER GROUNDING

VESSEL TYPE	VESSEL VALUE (A SUBZONES) ($000)	COLLISION DAMAGE (A SUBZONES) ($000)	HUMAN LOSSES (A SUBZONES) ($000)	EXPECTED LOSSES (A SUBZONES) ($000)	EXPECTED LOSSES (B,C SUBZONES) ($000)
LARGE TANKER	70.0	22.7	218.4	311.09	622.19
MEDIUM TANKER	52.5	16.0	182.0	250.49	500.98
SMALL TANKER	17.5	26.0	131.3	174.81	349.63
LARGE BULK CARRIER	63.0	63.0	218.4	344.45	688.90
MEDIUM BULK CARRIER	29.9	64.4	182.0	276.36	552.71
SMALL BULK CARRIER	11.2	6.4	154.7	172.34	344.68
LARGE TANK BARGE	10.5	6.2	0.0	16.66	33.33
SMALL TANK BARGE	4.6	3.3	0.0	7.83	15.65
LARGE DRY BARGE	2.3	4.2	0.0	6.46	12.92
SMALL DRY BARGE	1.1	2.8	0.0	3.83	7.65
LARGE PASSENGER	210.0	13.2	12,195.3	12,418.50	24,837.00
SMALL PASSENGER	35.0	6.7	536.9	578.64	1,157.28
FISHING VESSEL	1.6	2.0	182.1	185.64	371.29
TOW BOATS	2.8	5.3	45.5	53.62	107.24
OTHER VESSEL	21.0	5.3	91.0	117.33	234.66

APPENDIX 6-A
NRDAM/CME SPECIES NAMES AND CATEGORIES

Species Number	Category	Common Name	Scientific Name
	FISH		
1	1	American Shad	*Alosa sapidissima*
2	1	Alewife (and Blueback Herring)	*Alosa pseudoharengus, A. aestivalis*
3	2	Menhaden, Atlantic and Gulf	*Brevoortia tyrannis, B. patronus*
4	2	Atlantic Herring	*Clupea harengus harengus*
5	2	Butterfish	*Peprilus triacanthus*
6	2	Pollock	*Pollachius virens*
7	2	Atlantic Mackerel	*Scomber scombrus*
8	3	Bluefish	*Pomatomus saltatrix*
9	3	Striped Bass	*Morone saxatilis*
10	3	Monkfish (Goosefish)	*Lophius americanus*
11	3	Weakfish (Grey Sea Trout)	*Cynoscion regalis*
12	4	Tuna	*Thunnus* spp.
13	4	Swordfish	*Xiphias gladius*
14	4	Sharks	Odontaspididae, Carcharhinidae, etc.
15	4	Dogfish	*Squalus acanthias*
16	5	Yellowtail Flounder	*Limanda ferruginea*
17	5	Summer Flounder (Fluke)	*Paralichtys dentatus*
18	5	American Plaice	*Hippoglossoides platessoides*
19	5	Witch Flounder	*Glyptocephalus cynoglossus*
20	5	Winter Flounder (Blackback)	*Pseudopleuronectes americanus*
21	6	Atlantic Cod	*Gadus morhus*
22	6	Haddock	*Melanogrammus aeglefinus*
23	6	Redfish (Ocean Perch)	*Sebastes fasciatus*
24	6	Silver Hake (Whiting)	*Merluccius bilinearis*
25	6	Red Hake	*Urophycis chuss*
26	6	White Hake	*Urophycis tenuis*
27	6	Scup	*Stenotomus chrysops*
28	6	Tilefish	*Lopholatilus chamaeleonticeps, Caulolatilus microps*
29	6	Black Sea Bass	*Centropristis striata*
30	6	Atlantic Wolffish	*Anarchichas lupus*
31	1	Hickory Shad	*Alosa mediocris*
32	2	King Mackerel	*Scomberomorus cavalla*
33	2	Spanish Mackerel	*Scomberomorus maculatus*

Species Number	Category	Common Name	Scientific Name
34	6	Harvestfish	*Peprilus alepidotus*
35	6	Atlantic Croaker	*Micropogonias undulatus*
36	6	Drums	Sciaenidae
37	6	Spot	*Leiostomus xanthurus*
38	6	Yellow Perch	*Perca flavescens*
39	6	Carp	*Cyprinus carpio*
40	6	Eels	Anguilliformes
42	2	Atlantic Thread Herring	*Opisthonema oglinum*
43	2	Anchovy, Atlantic	*Anchoa* spp.
44	2	Striped Mullet, White Mullet, Silver Mullet	*Mugil cephalus, mugil curena*
45	6	Sheepshead	*Archosargus probatocephalus*
46	6	Spotted Sea Trout	*Cynoscion nebulosus*
47	6	Sand Sea Trout (White Sea Trout)	*Cynoscion arenarius*
48	6	Sea Catfish and others	*Arius felis*
49	3	Atlantic Halibut	*Hippoglossus hippoglossus*
50	3	Bonito (Tunny)	*Euthynnus alletteratus*
51	3	Crevalle Jack	*Caranx hippos*
52	3	Greater Amberjack	*Seriola dumerili*
53	3	Jacks, Other	Carangidae
54	3	Blue Runner	*Caranx crysos*
55	3	Dolphins	Coryphaenidae
56	5	Flounder, Southern	*Paralichthys lethostigma*
57	5	Flounder, Gulf	*Paralichthys albiqutta*
58	6	Drum, Red	*Sciaenops ocellatus*
59	6	Drum, Black	*Pogonias cromis*
60	6	Porgies	Sparidae
61	6	Florida Pompano	*Trachinotus carolinus*
62	6	Grunts	Haemulidae
63	6	Pinfish	*Lagodon rhomboides*
64	6	Kingfish	*Menticirrhus spp.*
65		duplicate of Sheepshead	
66	6	Cusk	*Brosme brosme*
67	6	Tautog	*Tautoga onitis*
68	6	Groupers	*Epinephelus spp., Mycteroperca spp.*
69	6	Snapper, Red	*Lutjanus campechanuc*

Species Number	Category	Common Name	Scientific Name
70	6	Snapper, Other	Lutjanidae
71	6	Whiting (Southern Hakes)	*Urophycis floridanus*
72	2	Spanish Sardine, Sardines	*Sardinella aurita*
73	6	Silver Jenny, Mojarras	*Eucinostomus gula* , Gerridae
74	6	Bonefish	*Albula vulpes*
75	3	Barracuda	Sphyraenidae
76	6	Sea Bass	Serranidae
77	6	Triggerfish	Balistidae
78	1	Salmon, Sockeye (= Red)	*Oncorhynchus nerka*
79	1	Salmon, Chum (= Keta)	*Oncorhynchus keta*
80	1	Salmon, Pink	*Oncorhynchus gorbuscha*
81	1	Salmon, Chinook (= King)	*Oncorhynchus tshawytscha*
82	1	Salmon, Coho (= Silver)	*Oncorhynchus kisutch*
83	2	Mackerel, Pacific	*Scomber japonicus*
84	2	Mackerel, Jack	*Trachurus symmetricus*
85	2	Anchovy, Pacific	*Engraulis mordax*
86	2	Herring, Sea (Pacific)	*Clupea harengus pallasi*
87	5	Flounder, Pacific	Pleuronectidae
88	5	Halibut, Pacific	*Hippoglossus stenolepis*
89	6	Perch, Pacific Ocean	*Sebastes alutus*
90	6	Rockfish, Other	*Sebastes* spp.
91	6	Perch, Other	*Embiotoca* spp., *Amphistichus* spp., *Hyperprosopon* spp.
92	6	Sablefish (Black Cod)	*Anoplopoma fimbria*
93	6	Cod, True (Pacific)	*Gaus macrocephalus*
94	6	Lingcod	*Ophiodon elongatus*
95	6	Hake, Pacific (Whiting)	*Merluccius productus*
96		duplicate of Sea Bass	
97	2	Pollock, Walleye	*Theragra chalcogramma*
98	2	Mackerel, Atka	*Pleurogrammus monopterygius*
99	5	Sole, Yellowfin	*Limanda aspera*
100	5	Flounder, Arrowtooth	*Atheresthes stomias*
101	5	Turbot, Greenland	*Reinhardtius hippoglossoides*
102	5	Plaice, Alaska	*Pleuronectes quadrituberculatus*
103	6	Smelt, Capelin	Osmeridae

Species Number	Category	Common Name	Scientific Name
104	5	Flounder, Starry	*Platichthys stellatus*
105	5	Sole, Butter	*Isopsetta isolepis*
106	5	Sole, Dover	*Microstomus pacificus*
107	5	Sole, English	*Parophyrys vetulus*
108	5	Sole, Rock	*Lepidopsetta bilineata*
109	6	Sculpins	Cottidae
110	2	Sand Lance	*Ammodytes* spp.
111	6	Poachers	Agonidae
112	6	Lumpfish, snailfish	Cyclopteridae
113	5	Sanddabs	Bothidae
114	6	Gunnels	Pholidae
115	6	Pacific tomcod	*Microgadus proximus*
116	6	Skates	Rajidae
117	6	Ratfish	Chimaeridae
118	6	Greeling	Hexagrammidae
119	2	Sardine	*Sardinops sagax*
120	6	Gobies	Gobiidae
121	2	Blenny	Blenniidae
122		duplicate of hickory shad	
123	6	White perch	*Monrone americana*
124	6	Spot	*Leiostomus xanthurus*
125	1	Gizzard shad	*Clupea naus*
126	2	Sunfish	*Centrar chinae*
127	2	Silversides, darters	Atherinidae, *Menidia mendia*
128	2	Searobins	Triglidae
129	2	Tonguefish	Cyncalossidae
130	2	Filefish	Balistidae
131	6	Rough Scad	*Trachurus lathami*
132	6	Frogfish	Antenariidae
133	6	Batfish	Ogcocephalidae
134	6	Lizardfish	Synodontidae
135	6	Toadfishes, Atlantic Midshipman	Batrachoididae
136	4	Tuna	Scombridae
137	5	Sand Sole	*Psettichthys melanostictus*
138	5	C-O Sole	*Pleuronichthys coenosus*
139	5	Speckled sand dab (duplicate)	
140	5	Slender Sole	*Lyopsetta exilis*
141	5	Flathead sole	*Hippoglossides elassoson*
142	6	Killyfish, mummichog	*Cypinodontidae, fundulus heteroclitus*

Species Number	Category	Common Name	Scientific Name
143	6	Surfperch	*Embiotocidae*
237	5	Rays	*Hypotremata*
238	2	Scaled Sardine	*Harengula jaguana*
239	6	Atlantic Bumper	*Chloroscombus chrysurus*
240	6	Atlantic Moonfish	*Selene setapinnis*
241	6	Pigfish	*Orthopristis chysoptera*
242	5	Sole	*Pleuronectiformes*
243	6	Hogchoker	*Trinescetes maculatus*
244	6	Pipefish	Syngnathidae
245	6	Skilletfish	*Gobiesox strumosus*
246	6	Lanternfish	Myctophidae
247	6	Ronquil	*Ronguilus jordani*
248	2	Pricklebacks	Stichaeidae
249	2	Quillfish	Ptilichthyidae
250	5	Rex Sole	*Glyptocephalus zachirus*
251	5	other flounder	*Heterosomata*
252	6	other Hake, Rocklings	Gabidae
253	6	White Croaker	*Genyonemus lineatus*
254	6	Ocean Pout	*Macrozoarces americanus*
255	6	Cunner	*Tautogolabrus adspersus*
256	2	Sticklebacks	*Gasterosteidae*
257	6	Puffers	*Tetraodontidae*
258	3	Atlantic bonito	*Sarda sarda*
259	6	Atlantic Tomcod	*Microgadus tomcod*
260	2	Shinners, Minnows	*Cyprinidae*
261		Lamprey	*Petromyzon marinus*
262	1	other Shad	*Dorosomatidae*
263	2	Nothern Anchovy	*Anchoa*
264	3	Trout	*Salmo sp*
265	6	Needlefish	*Scomberesox saurus*
266	6	Grunt	*Haemulidae*
267	6	Goatfishes	Mullidae
199	6	Other Fish	(generic)
	INVERTEBRATES		
201	7	Surf Clam	*Spisula solidissima*
202	7	Ocean Quahog	*Arctica islandica*
203	7	Atlantic Sea Scallop	*Placopecten magellanicus*
204	8	American Lobster	*Homarus americanus*

Species Number	Category	Common Name	Scientific Name
205	8	Northern Shrimp	*Pandalus borealis*
206	8	Red Crab	*Geryon quinquedens*
207	9	Squid, Atlantic	*Loligo pealei, Illex illecebrosus*
208	7	Blue Mussel	*Mytilus edulis*
209	8	Blue Crab (Hard Shell)	*Callinectes sapidus*
210	8	Blue Crab (Soft Shell)	*Callinectes sapidus*
211	7	Soft Clam	*Mya arenaria*
212	7	Oyster, Atlantic	*Crassostrea virginica*
213	7	Hard Clam (Quahog)	*Mercenaria mercenaria*
214	7	Conch	*Strombus* spp.
215	8	Shrimp (Brown, Pink, White)	*Penaeus* spp.
216	7	Calico Scallop	*Argopecten gibbus*
217	8	Crabs (General)	(generic)
218	8	Stone Crab	*Menippe mercenaria*
219	8	Lobster, Spiny	*Panuliris spp.*
220	7	Abalone	*Haliotis spp.*
221	8	Crab, Dungeness	*Cancer magister*
222	8	Shrimp, Pacific	*Pandalus borealis*
223	9	Squid, Pacific	*Loligo opalescens, Berryteuthis magister, Onychoteuthis boreali japonicus*
224	8	Crab, Snow (Tanner)	*Chionoecetes*
225	8	Crab, King	*Paralithodes camtschatica, P. platypus*
226	7	Clam, Butter	*Saxidomus nuttalli*
227	7	Clam, Horse	*Tresus capax*
228	7	Clam, Geoduc	*Panopea generosa*
229	7	Clam, Manila	*Tapes phillippinarum*
230	7	Oyster, Pacific	*Crassostrea gigas*
231	7	Oyster, Olympic	*Ostrea lurida*
232	7	Atlantic Bay Scallop	*Argopecten irradians*
233	7	Pacific Sea Scallop	*Pecten caurinus*
234	8	Rock Shrimp	*Sicyonia brevirostris*
235	8	Rangia Clam	*Rangia cuneata*
236	8	Seabob Shrimp	*Xiphopeneus kroyeri*
289	8	other Shrimp	(generic)
299	7	Other Invertebrates	(generic)

Species Number	Category	Common Name	Scientific Name
	BIRDS		
Waterfowl			
511	11	Dabbling Ducks	Anatinae, Oxyurinae
515	11	Diving Ducks	Aythyinae, Merginae
512	11	Coots, gallinules	Rallidae
513	11	Geese	Anserinae
514	11	Swans	Cygninae
516	11	Loons	Gaviidae
517	11	Grebes	Podicipedidae
Wading birds			
561	12	Herons, egrets, bitterns	Ardeidae
562	12	Rails	Rallidae
563	12	Cranes, storks	Gruidae, Ciconiidae
564	12	Flamingos, ibises, spoonbills	Phoenicopteridae, Threskiornithidae
Shore birds			
571	12	Sandpipers, plovers, turnstones	Scolopacidae, Charadriidae
572	12	Oystercatchers, avocets, stilts	Haematopodidae, Recurvirostridae
Seabirds			
531	13	Gulls	*Larus* spp.
533	13	Terns	Sterninae
530	13	Cormorants	Phalacrocoracidae
532	13	Kittiwakes	*Rissa* spp.
534	13	Shearwaters	*Puffinus* spp.
535	13	Jaegers	Stercorariidae
536	13	Fulmars	*Fulmarus* spp.
537	13	Storm Petrels	Hydrobatidae
538	13	Murres	*Uria* spp.
539	13	Guillemot	*Cepphus* spp.
540	13	Puffins	*Lunda* spp., *Fratercula* spp.
541	13	Small alcids (murrelets, aukelets)	
542	13	Phalaropes	Phalaropodidae
543	13	Albatroses	Diomedeidae
544	13	Frigatebirds	Fregatidae
547	13	Gannets, Boobies	Sulidae
545	13	Tropic Birds	Phaephontidae

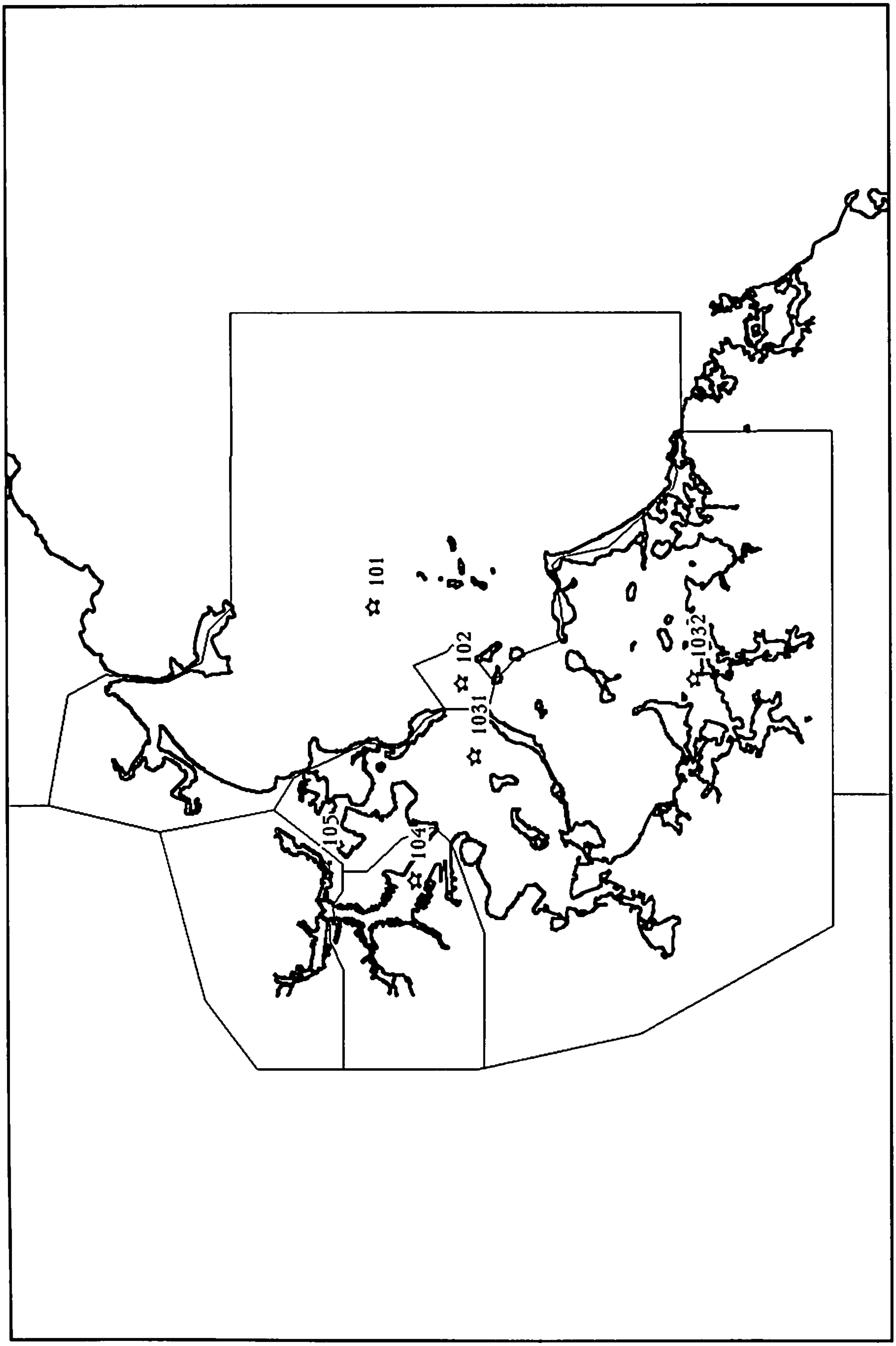
Species Number	Category	Common Name	Scientific Name
546	13	Pelicans	Pelecanidae
548	13	Skimmers	Rynchopidae
599	13	other seabirds	
	RAPTORS		
581	14	Osprey	Pandionidae
582	14	Bald eagles	*Haliaeetus* spp.
583	14	Hawks	Accipitridae
584	14	Owls	Strigiformes
591	14	Kingfishers	Alcedinidae
	MAMMALS		
401	10	Fur Seal	*Callorhinus ursinus*

CATEGORY KEY

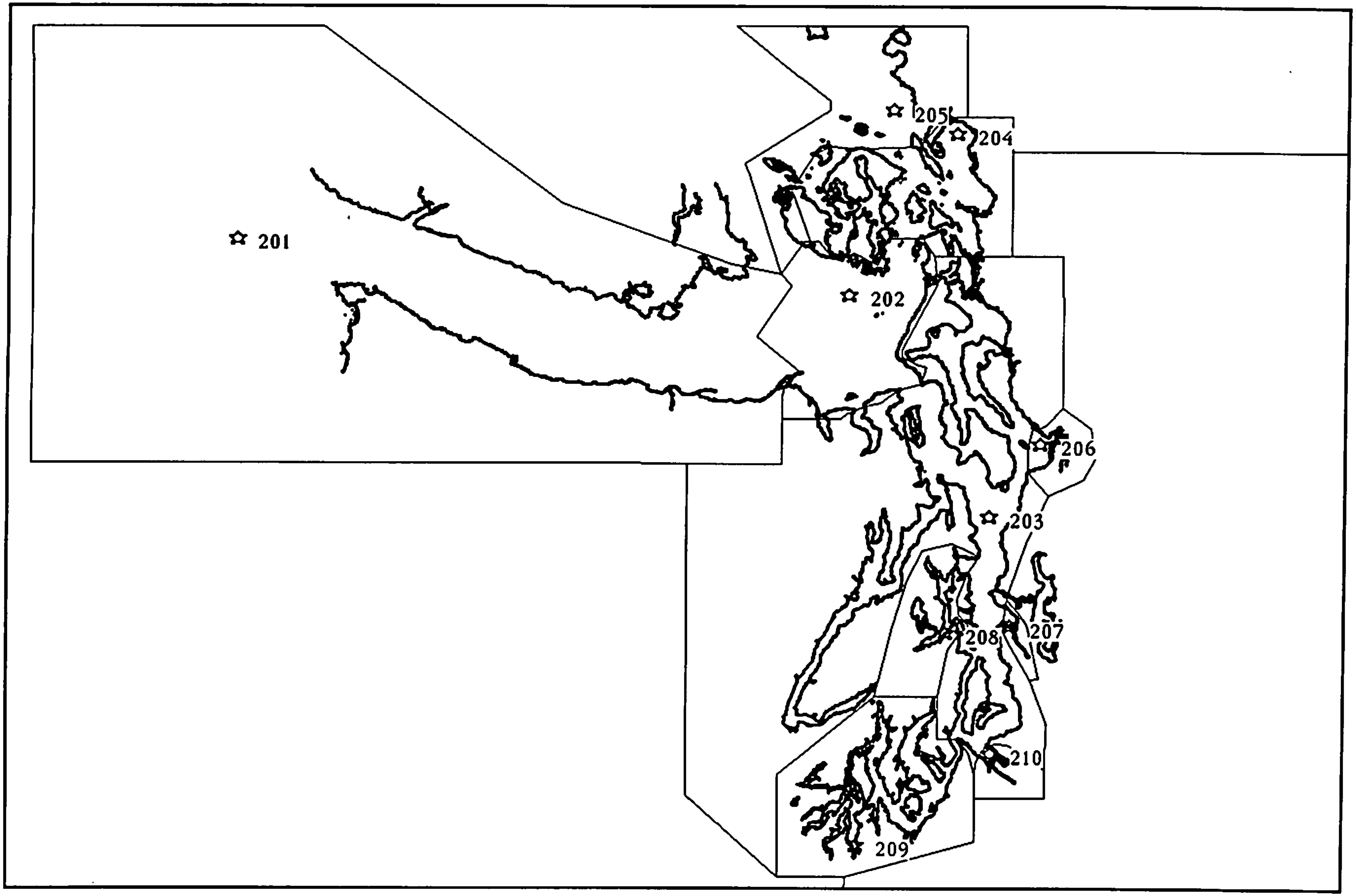
Category Number	Category
1	Anadromous fish
2	Planktivorous fish
3	Piscivorous fish
4	Top carnivorus
5	Demersal fish
6	Semi-demersal fish
7	Mollusks
8	Decapods
9	Squid
10	Mammals
11	Waterfowl
12	Shorebirds
13	Seabirds
14	Raptors

APPENDIX 6-B
STUDY ZONE MAPS SHOWING SPILL SITE LOCATIONS

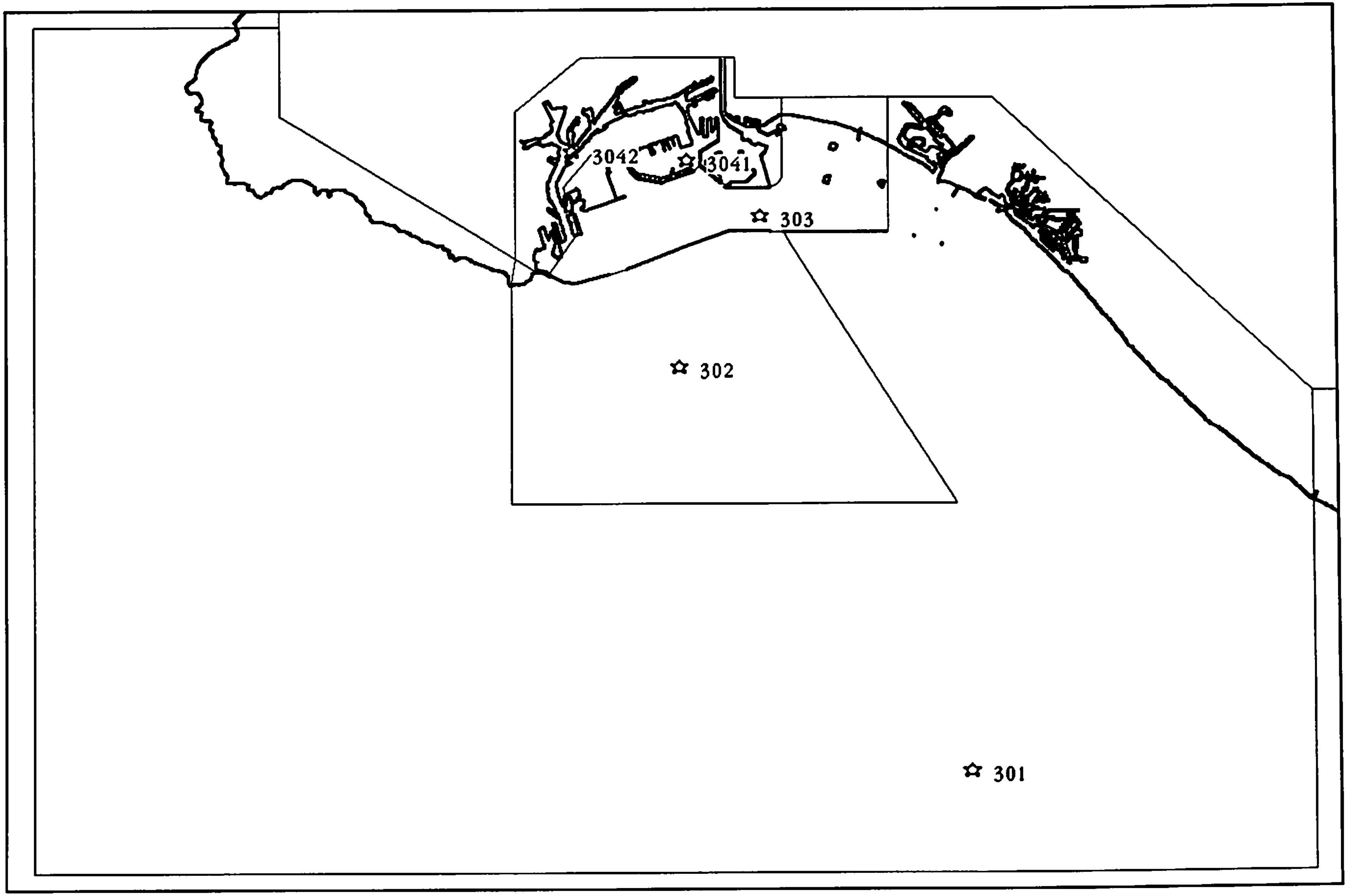
Boston Spill Sites



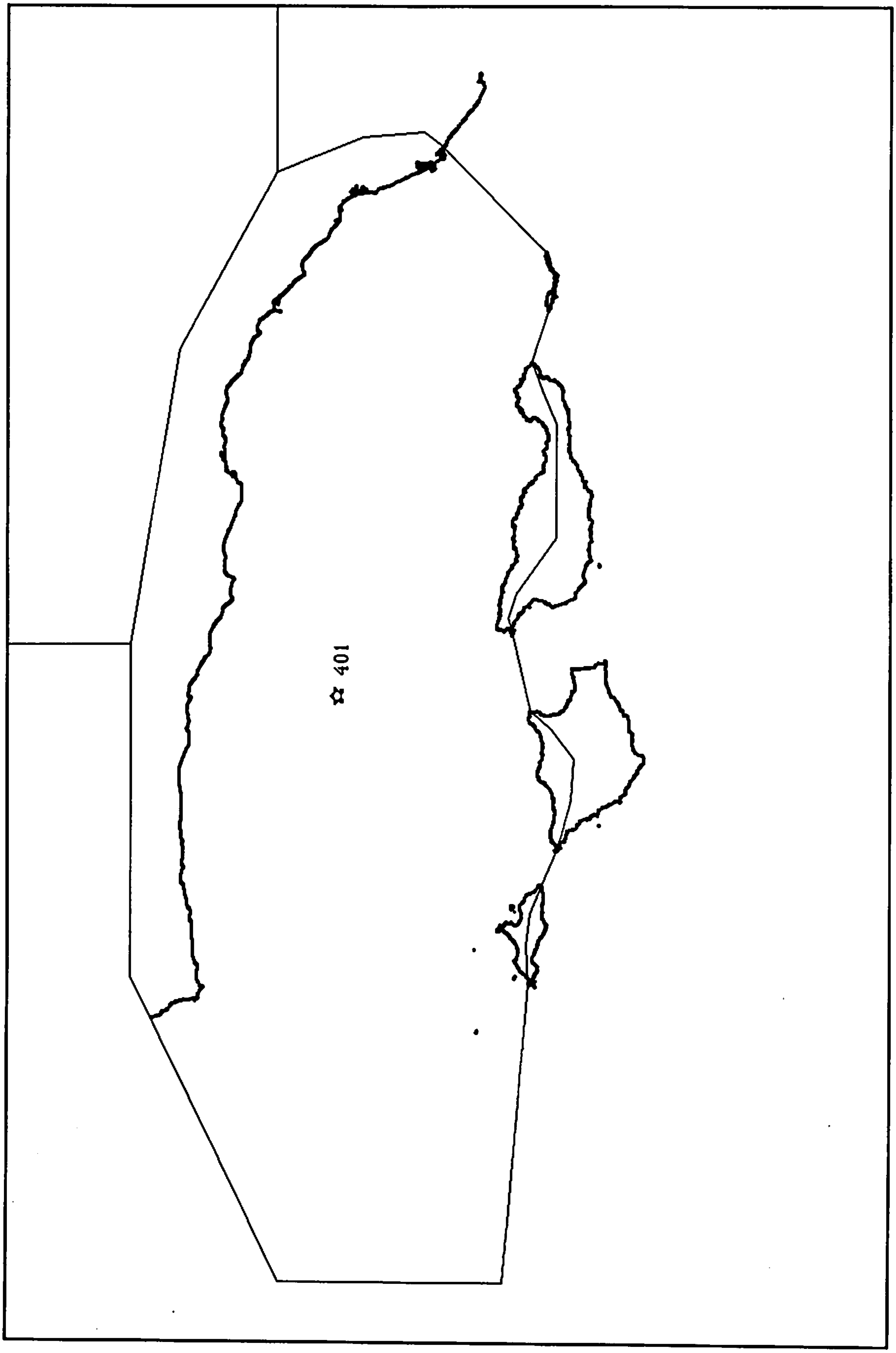
Seattle Spill Sites



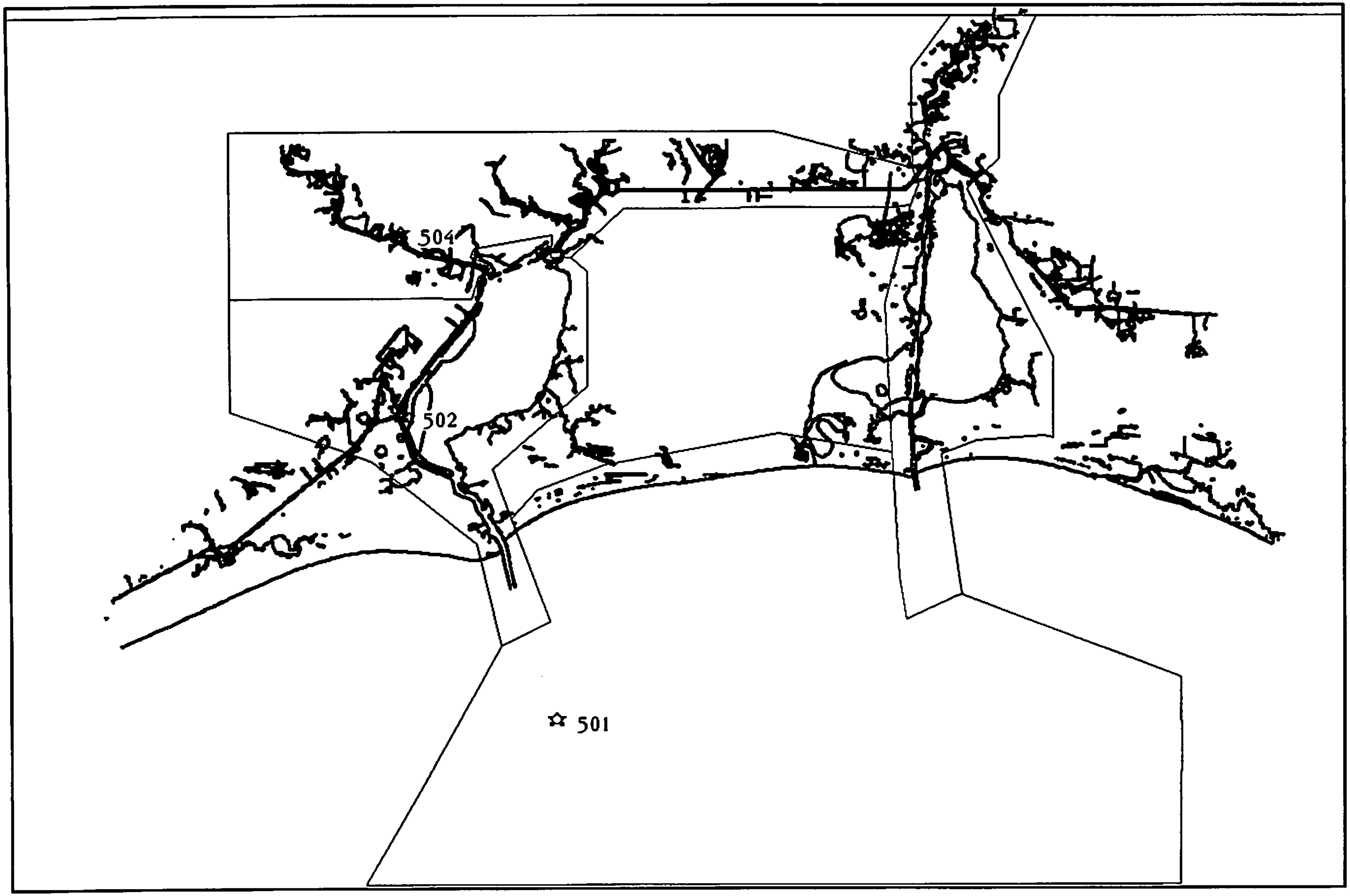
Los Angeles Spill Sites



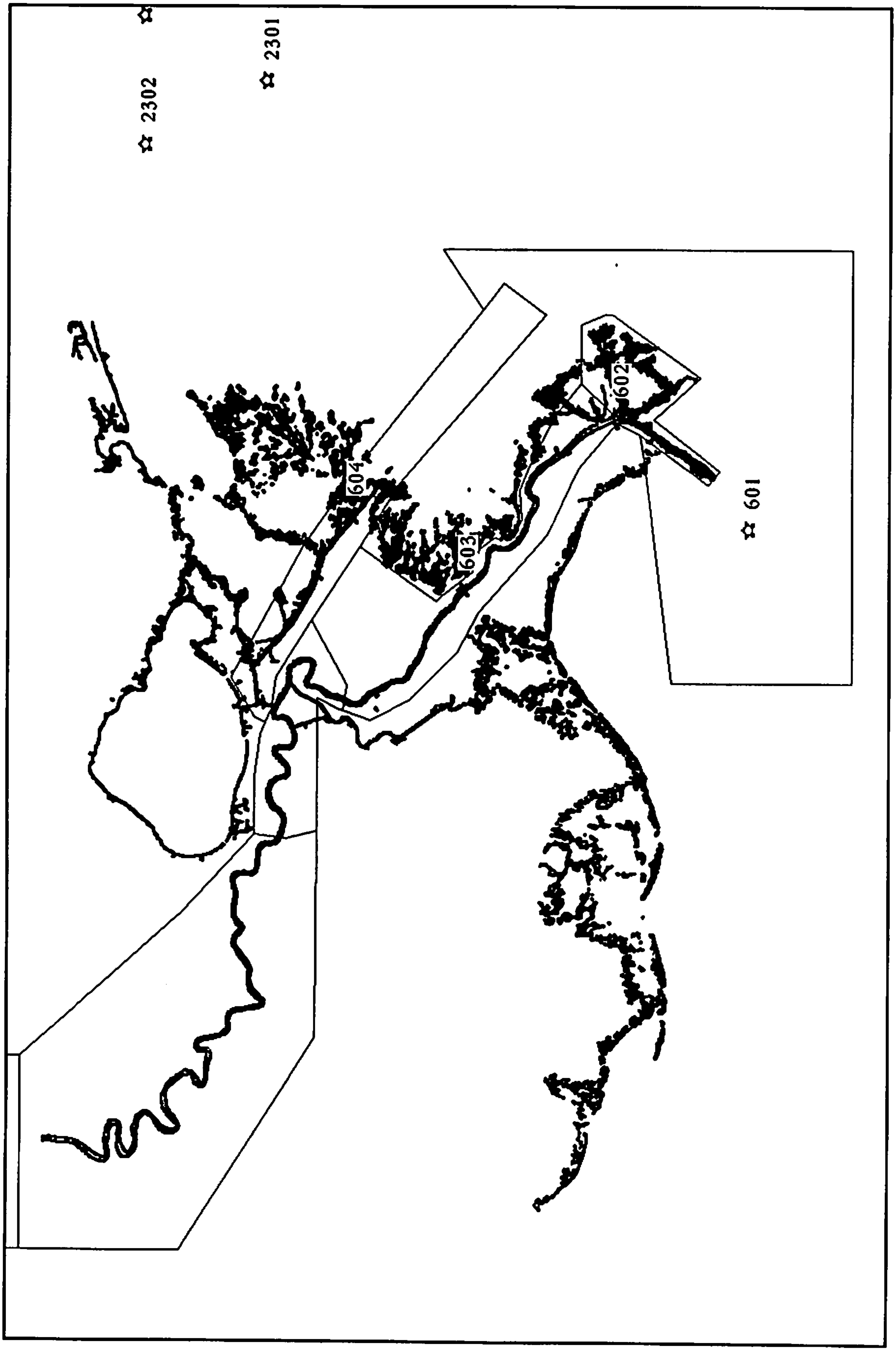
Santa Barbara Spill Sites



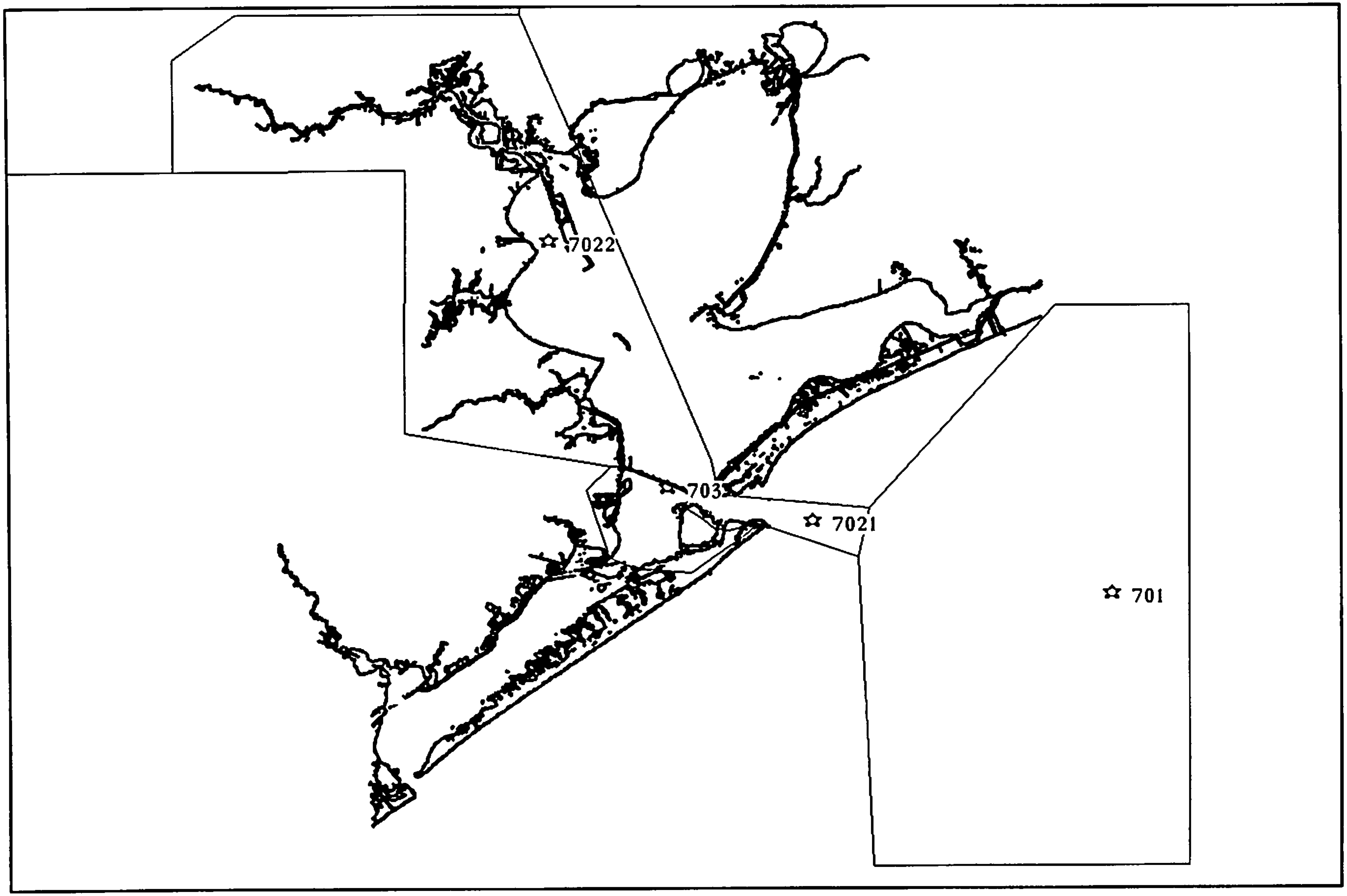
Port Arthur Spill Sites



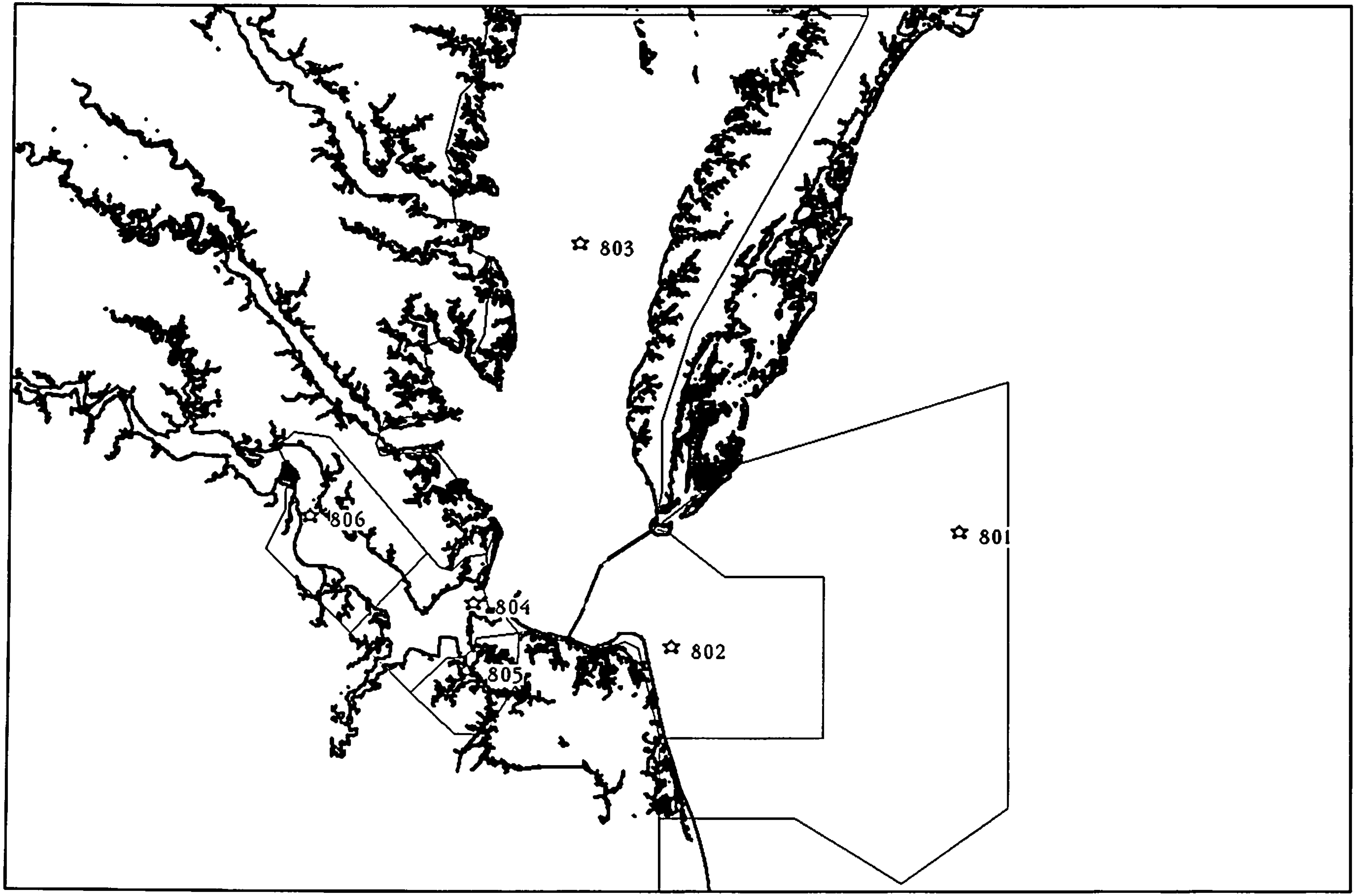
New Orleans Spill Sites



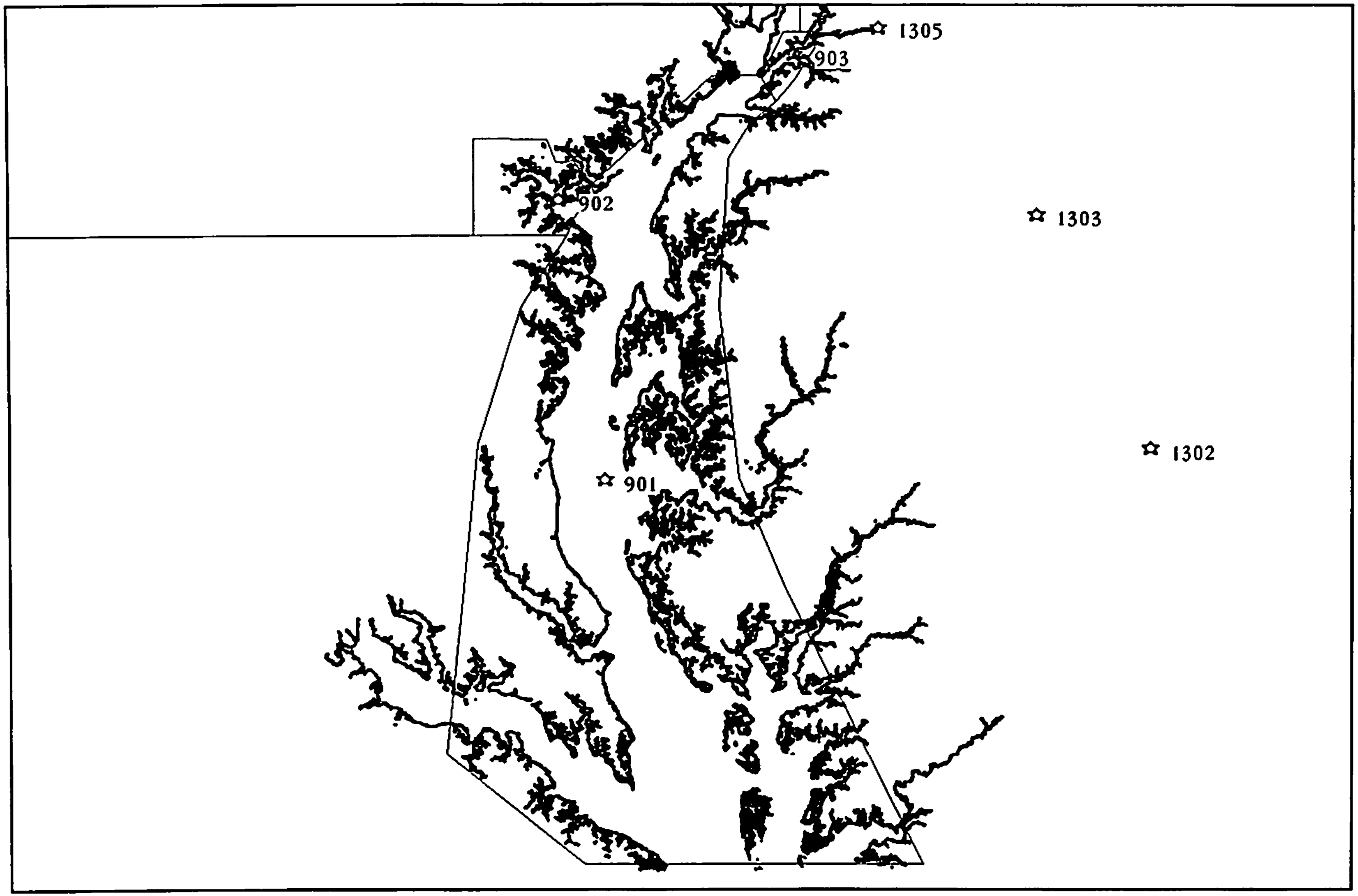
Houston Spill Sites



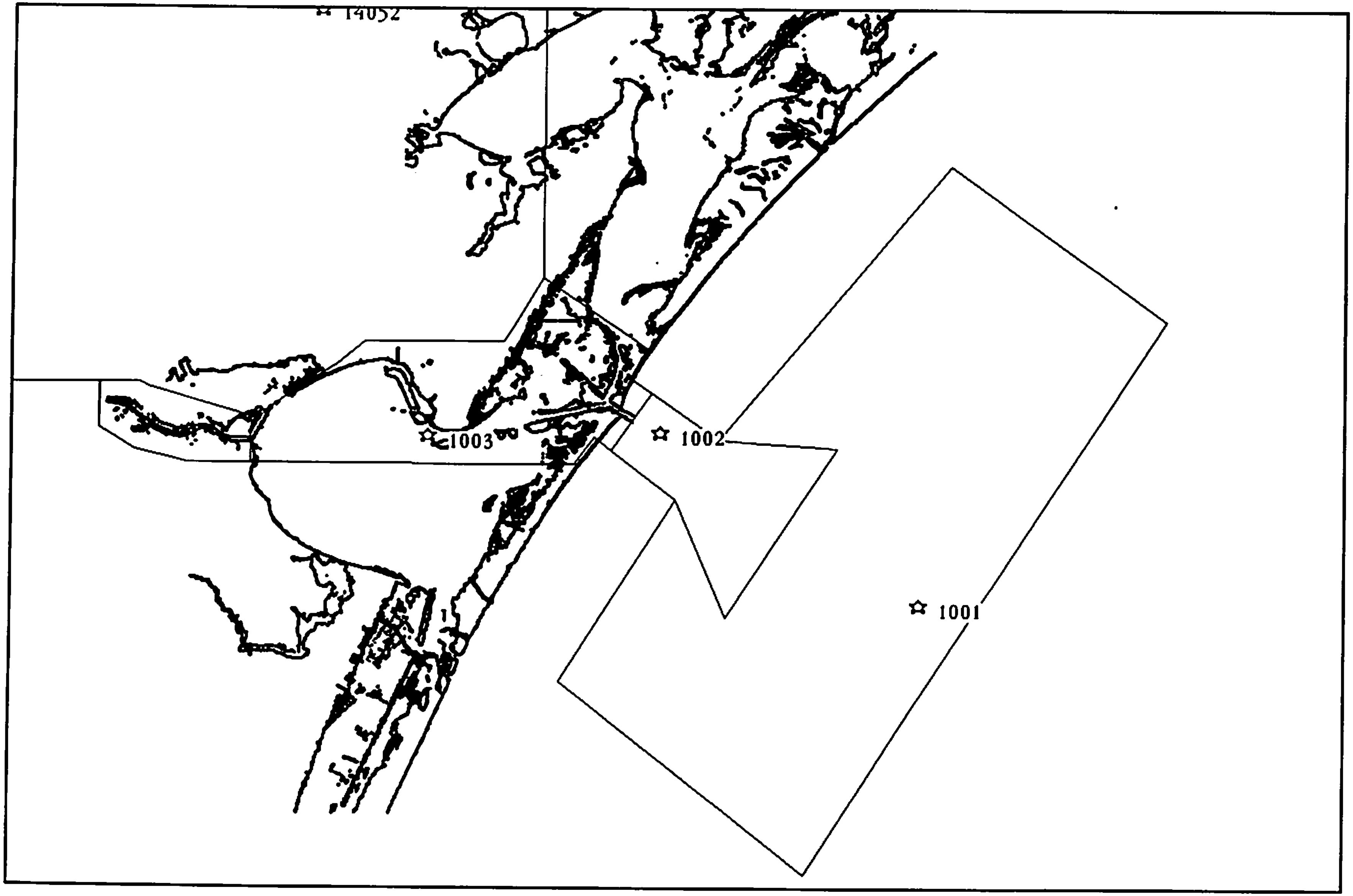
Hampton Roads Spill Sites



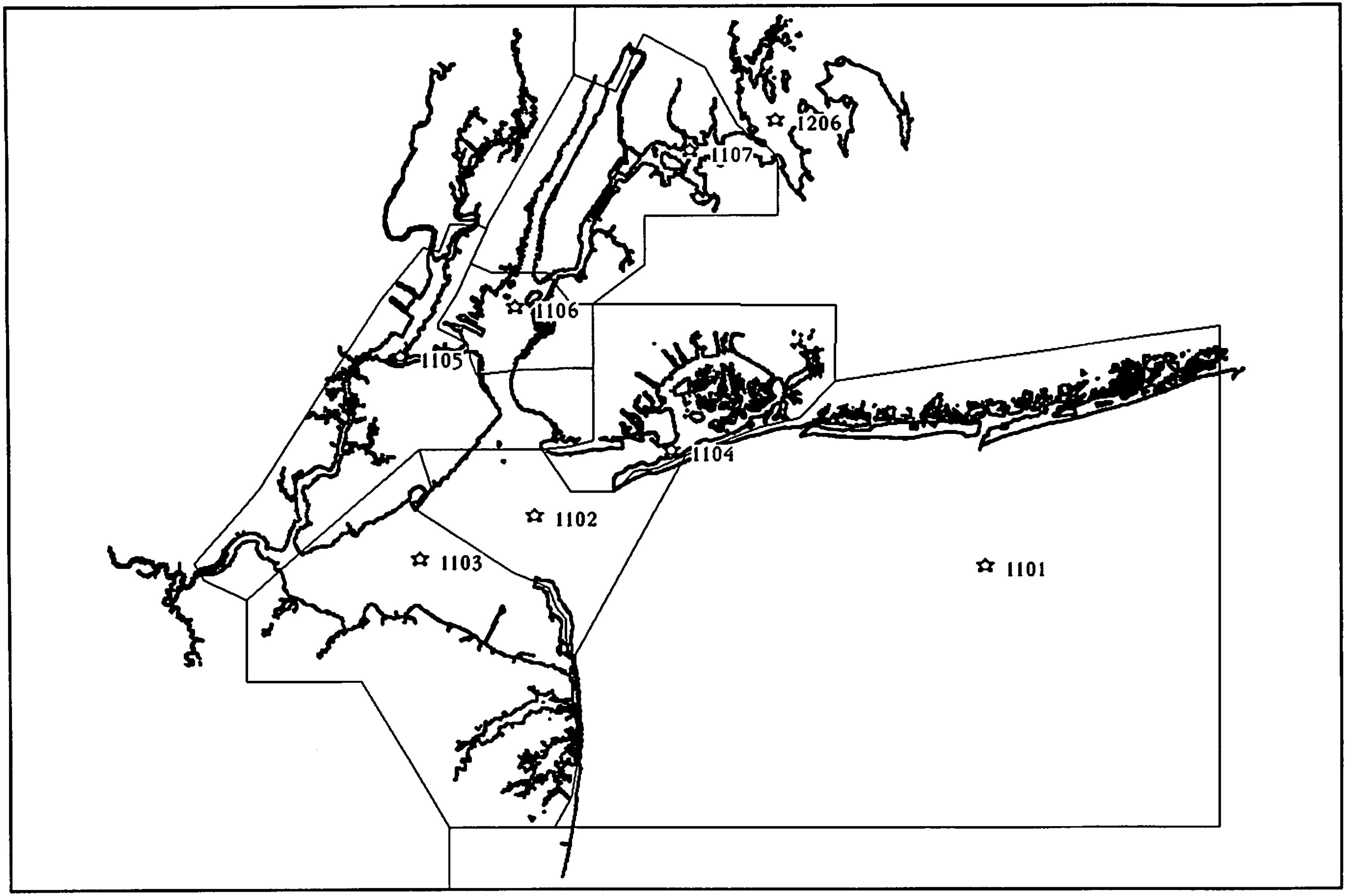
Baltimore Spill Sites



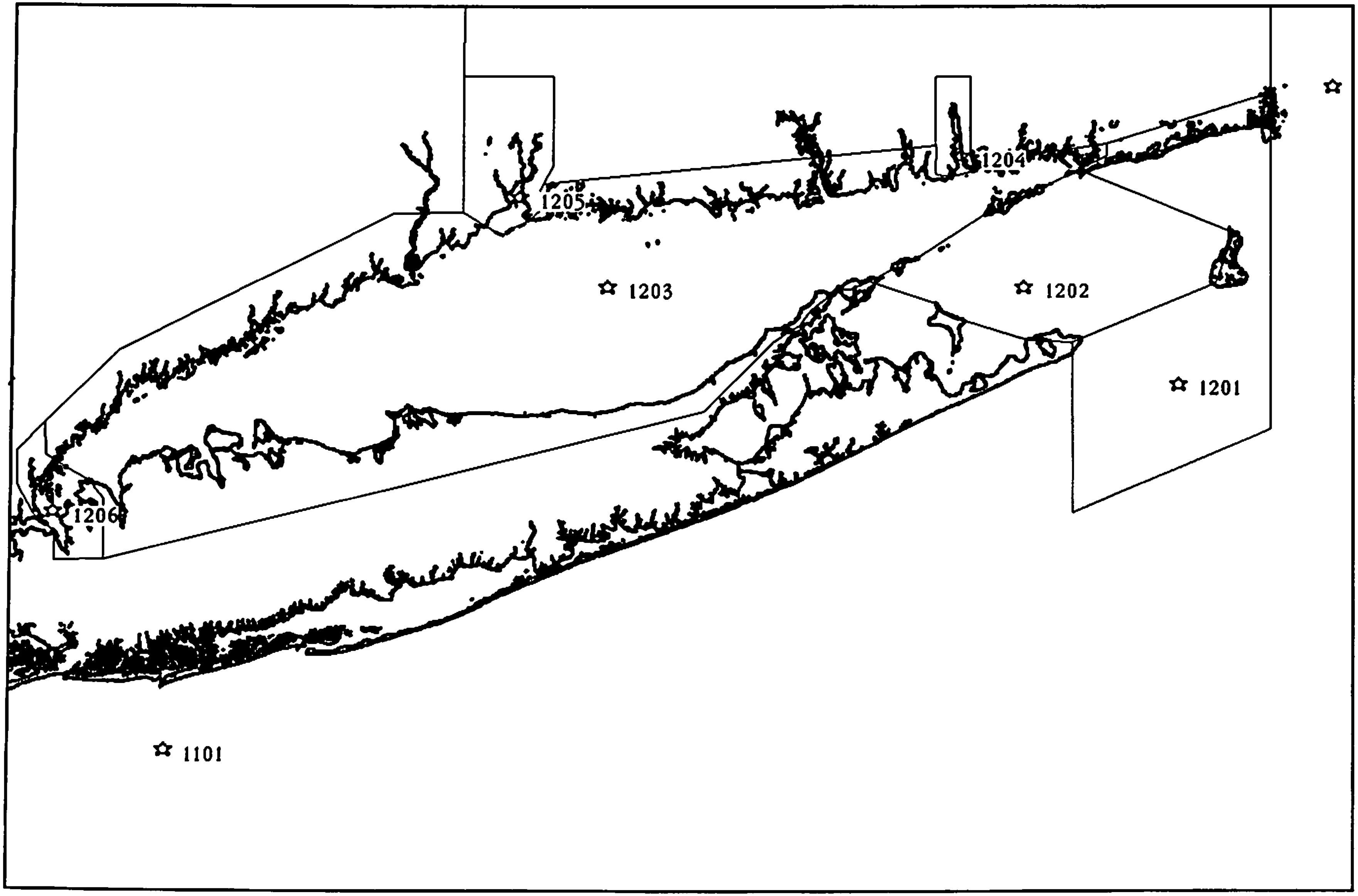
Corpus Christi Spill Sites



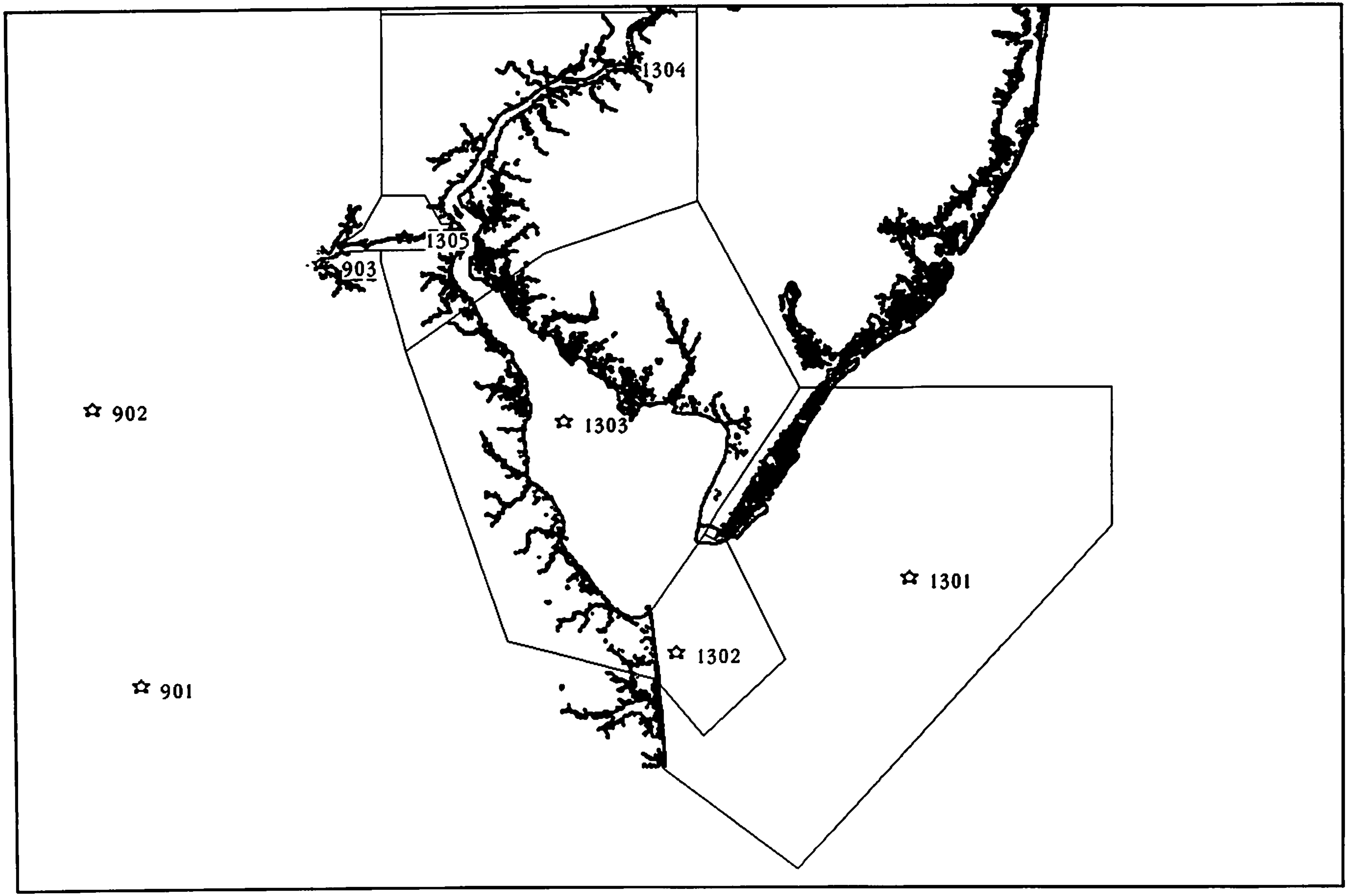
New York City Spill Sites



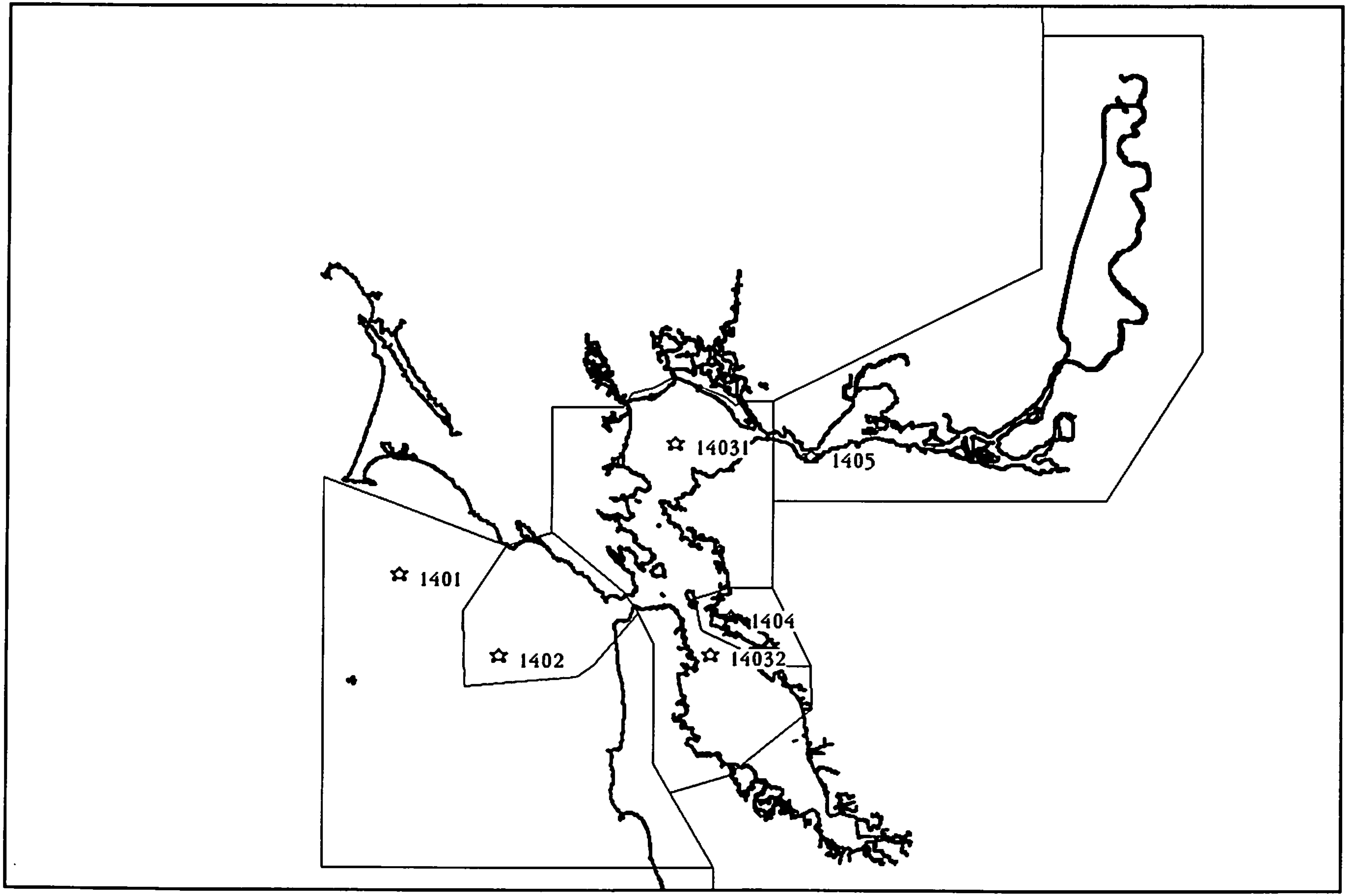
Long Island Sound Spill Sites



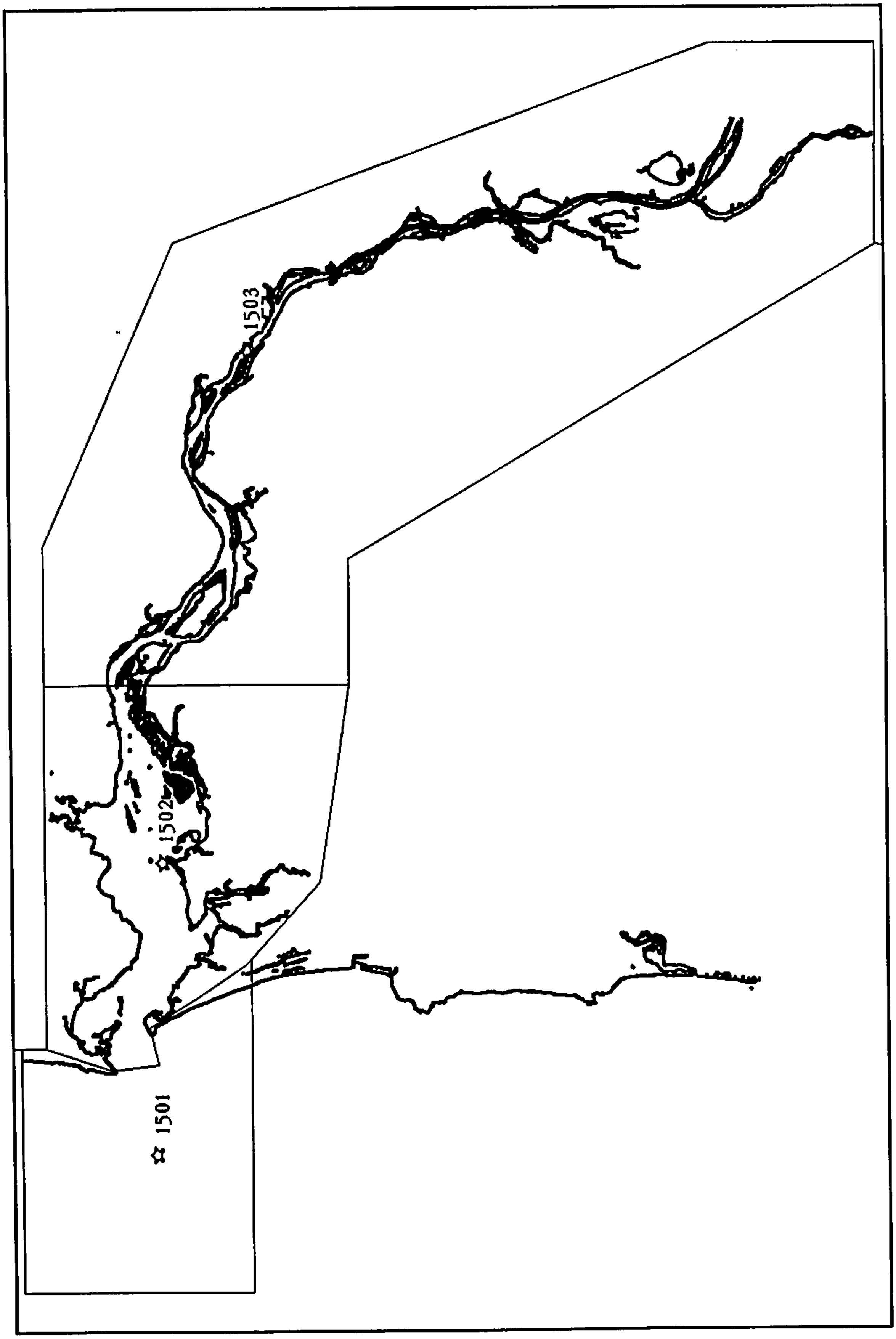
Philadelphia Spill Sites



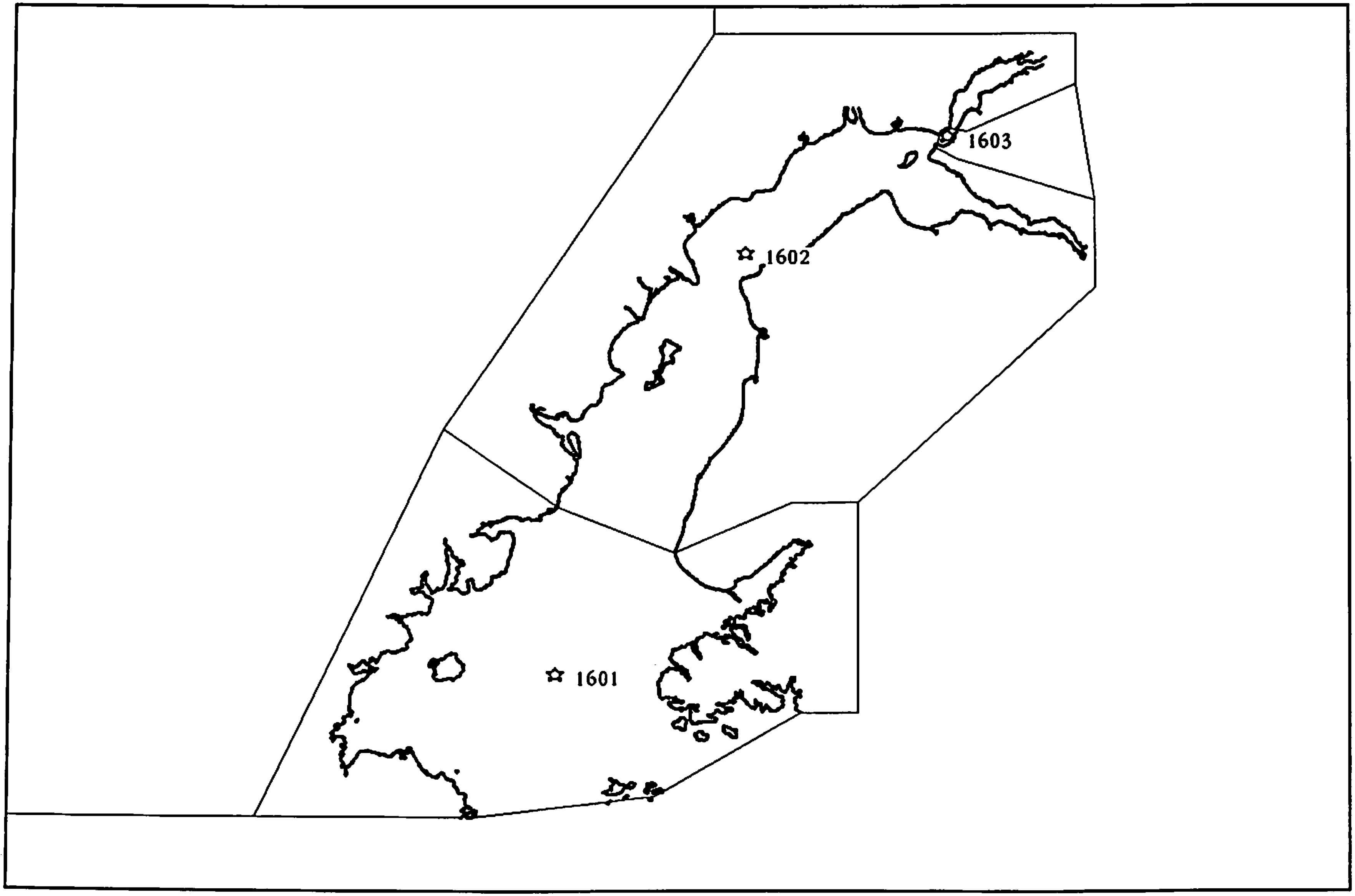
San Francisco Spill Sites



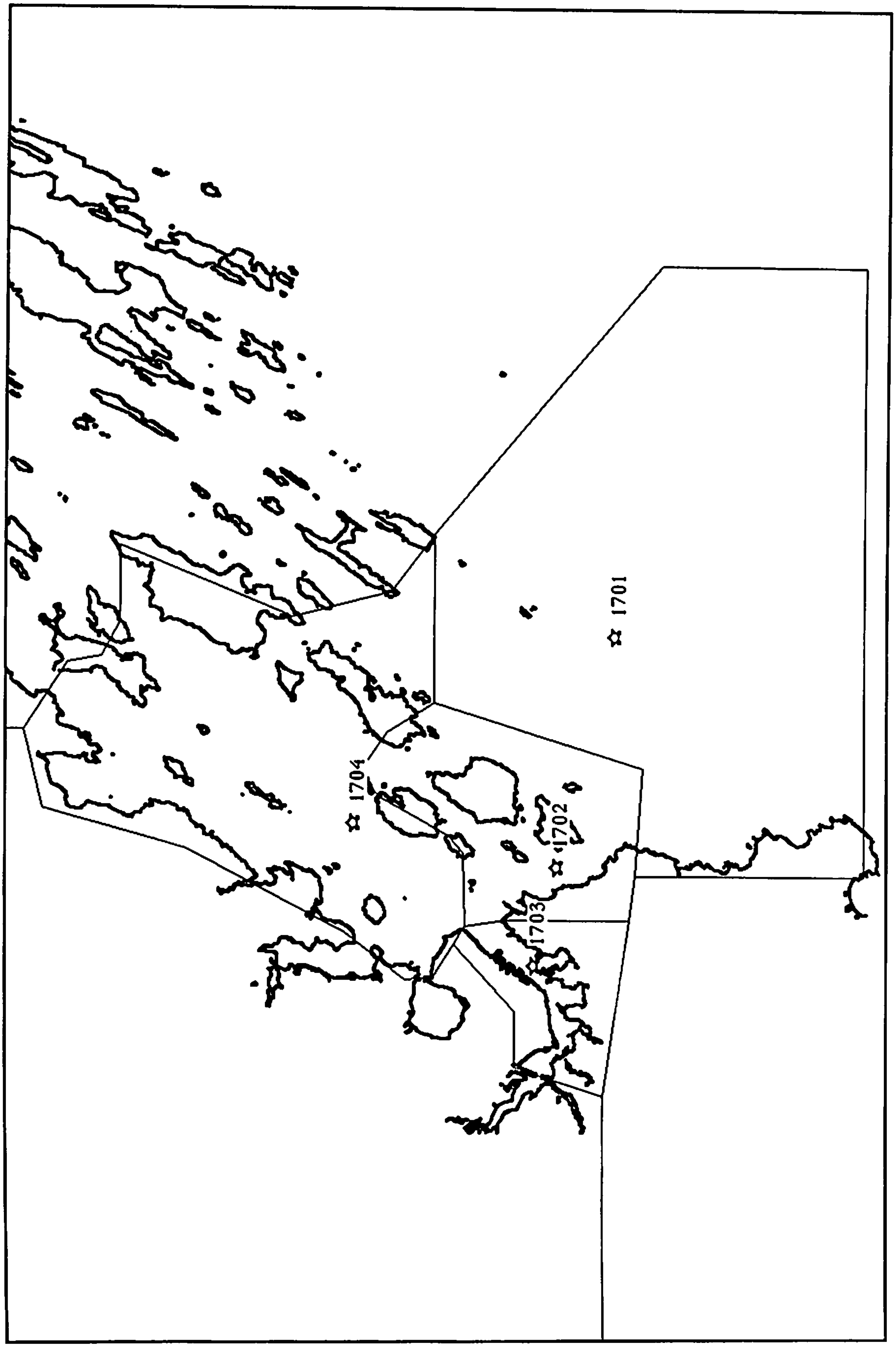
Portland Oregon Spill Sites



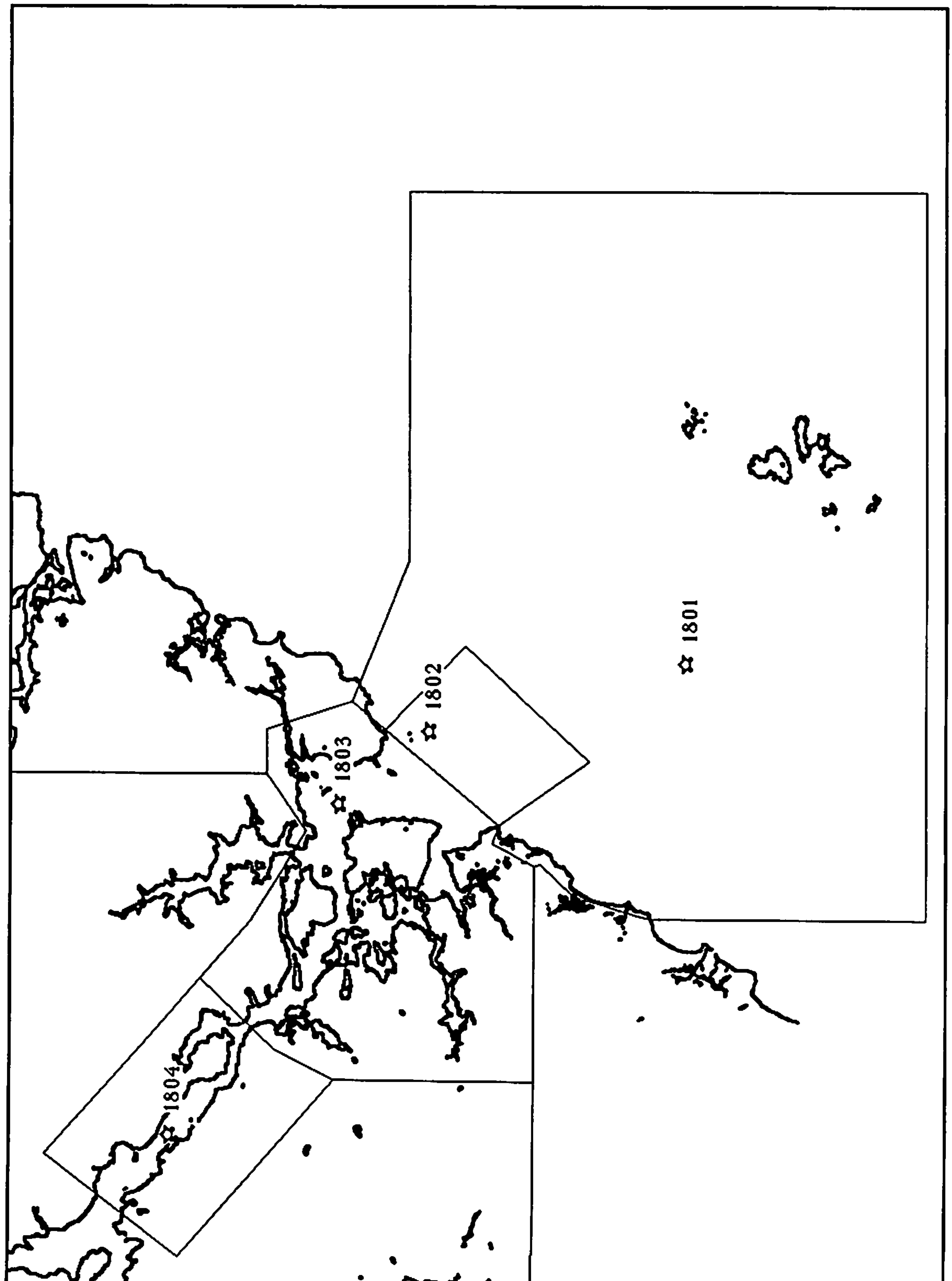
Anchorage Spill Sites



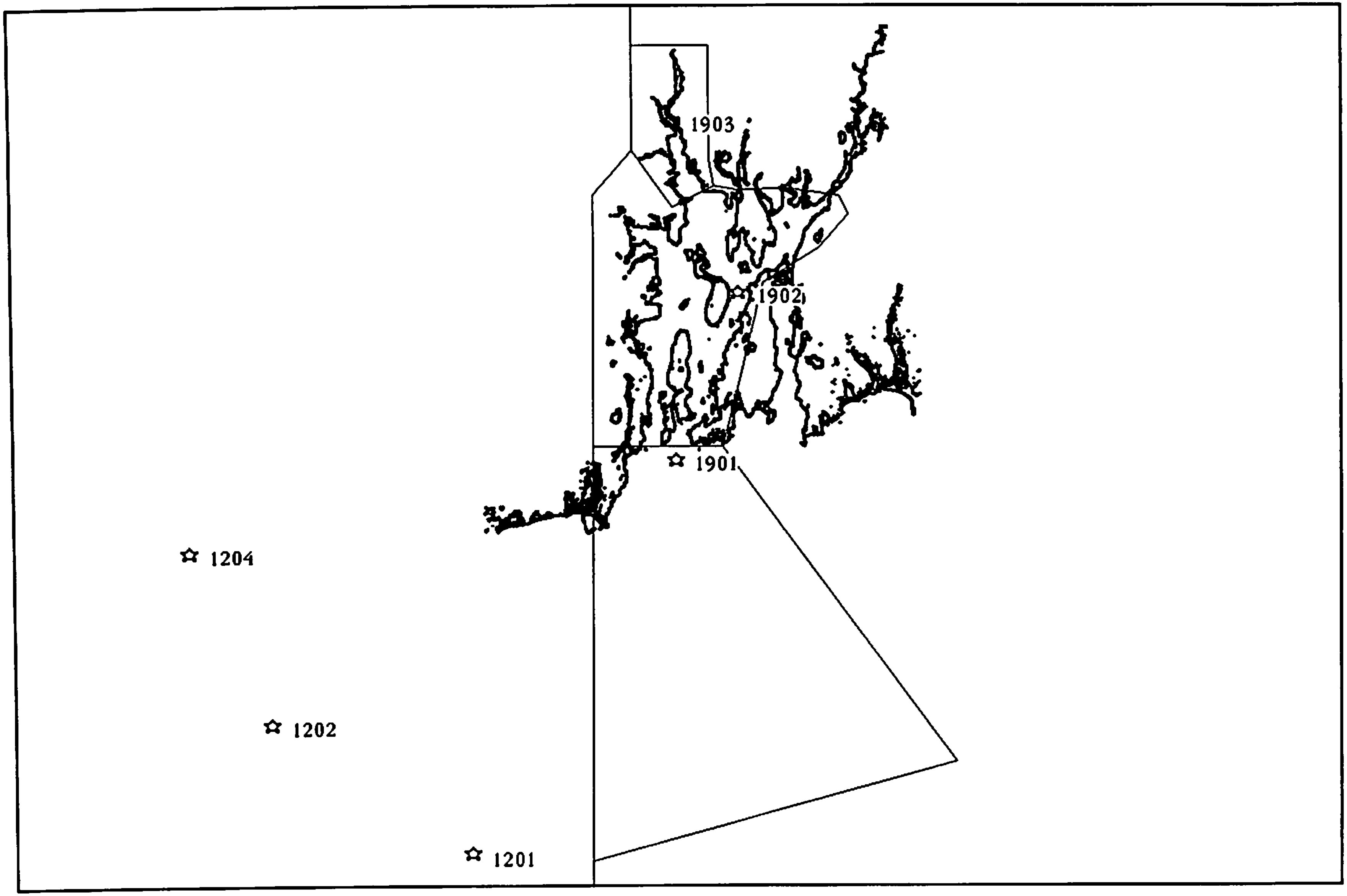
Portland Maine Spill Sites



Portsmouth Spill Sites

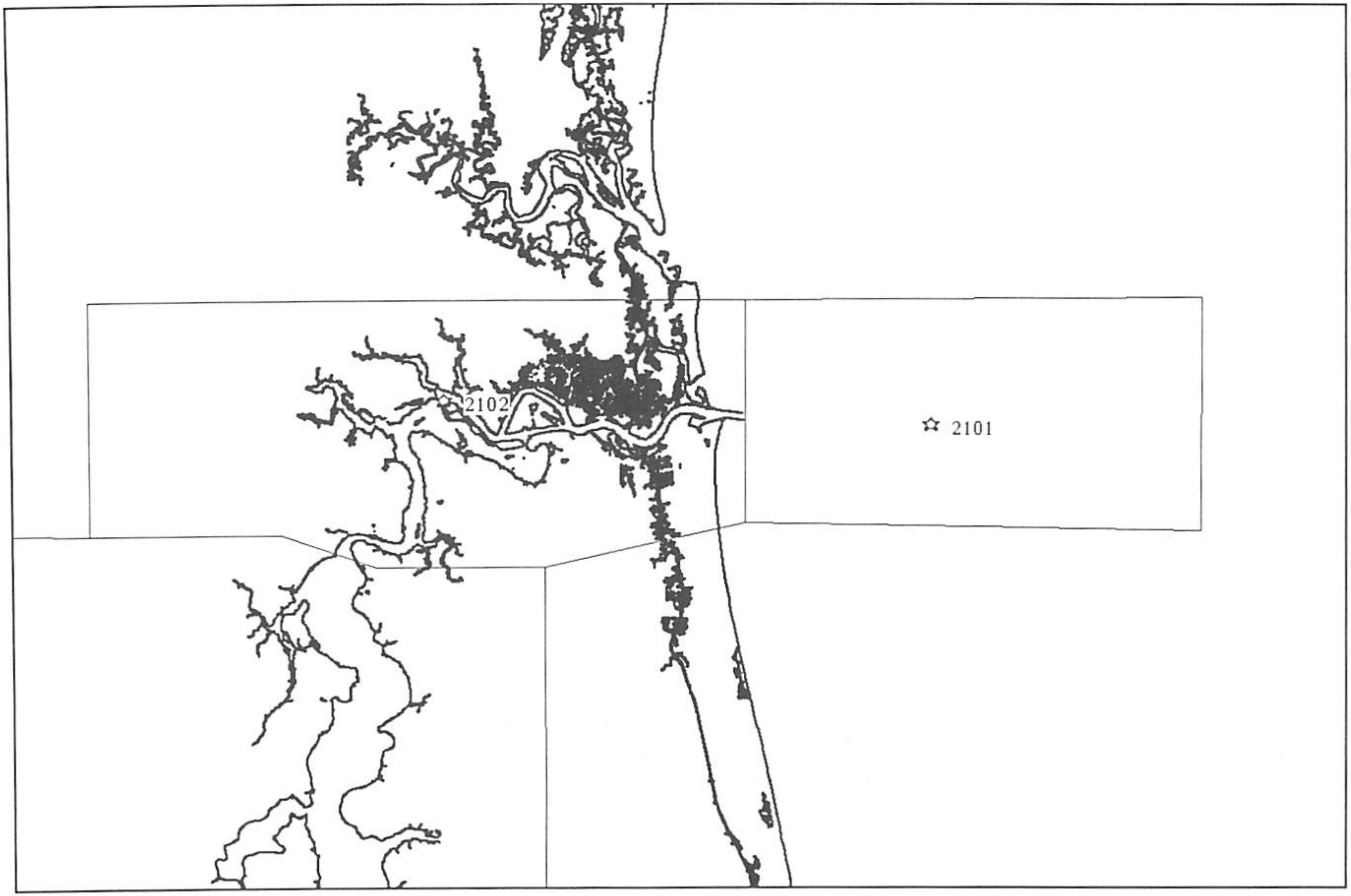


Providence Spill Sites

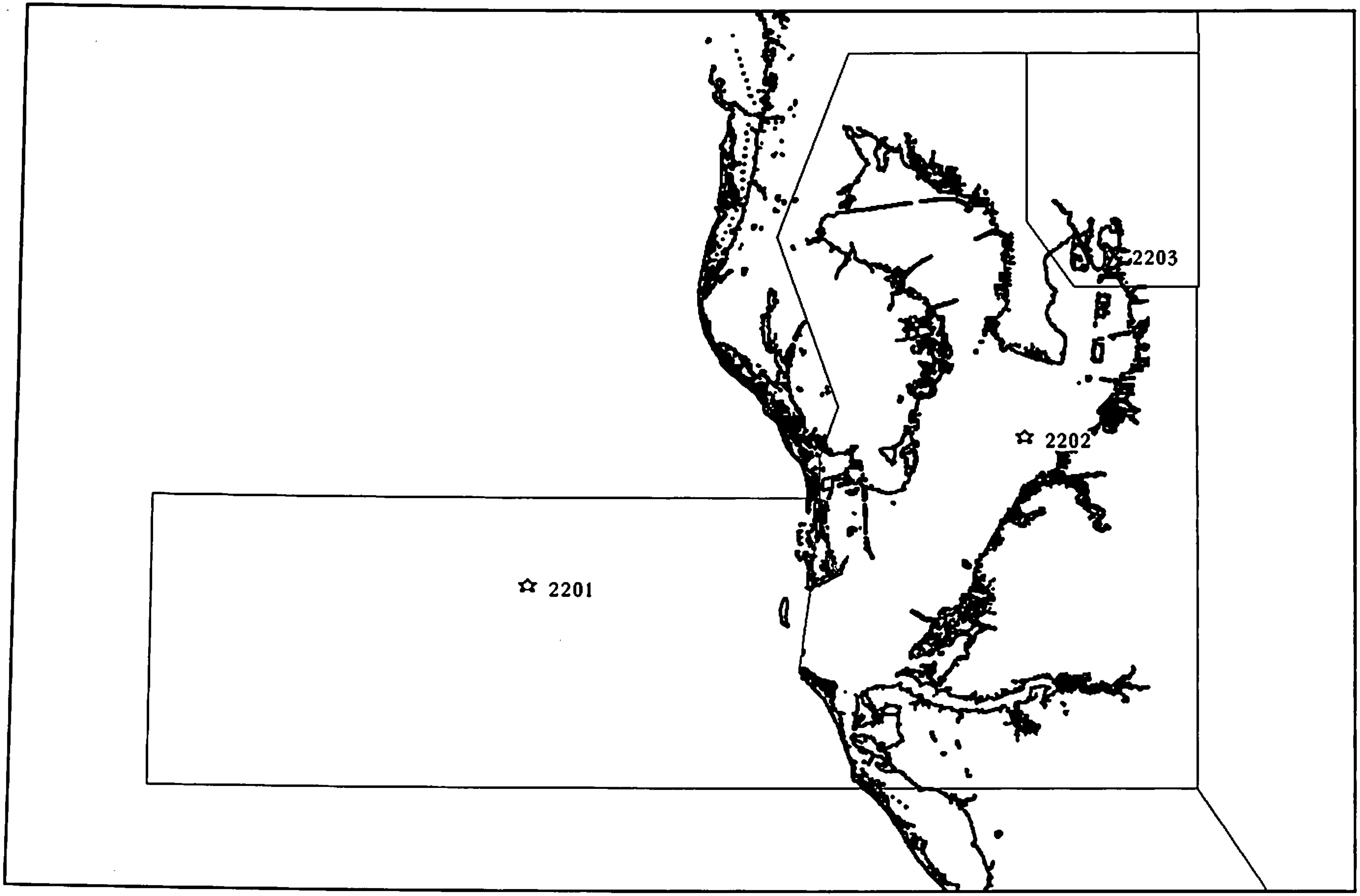


Wilmington Spill Sites

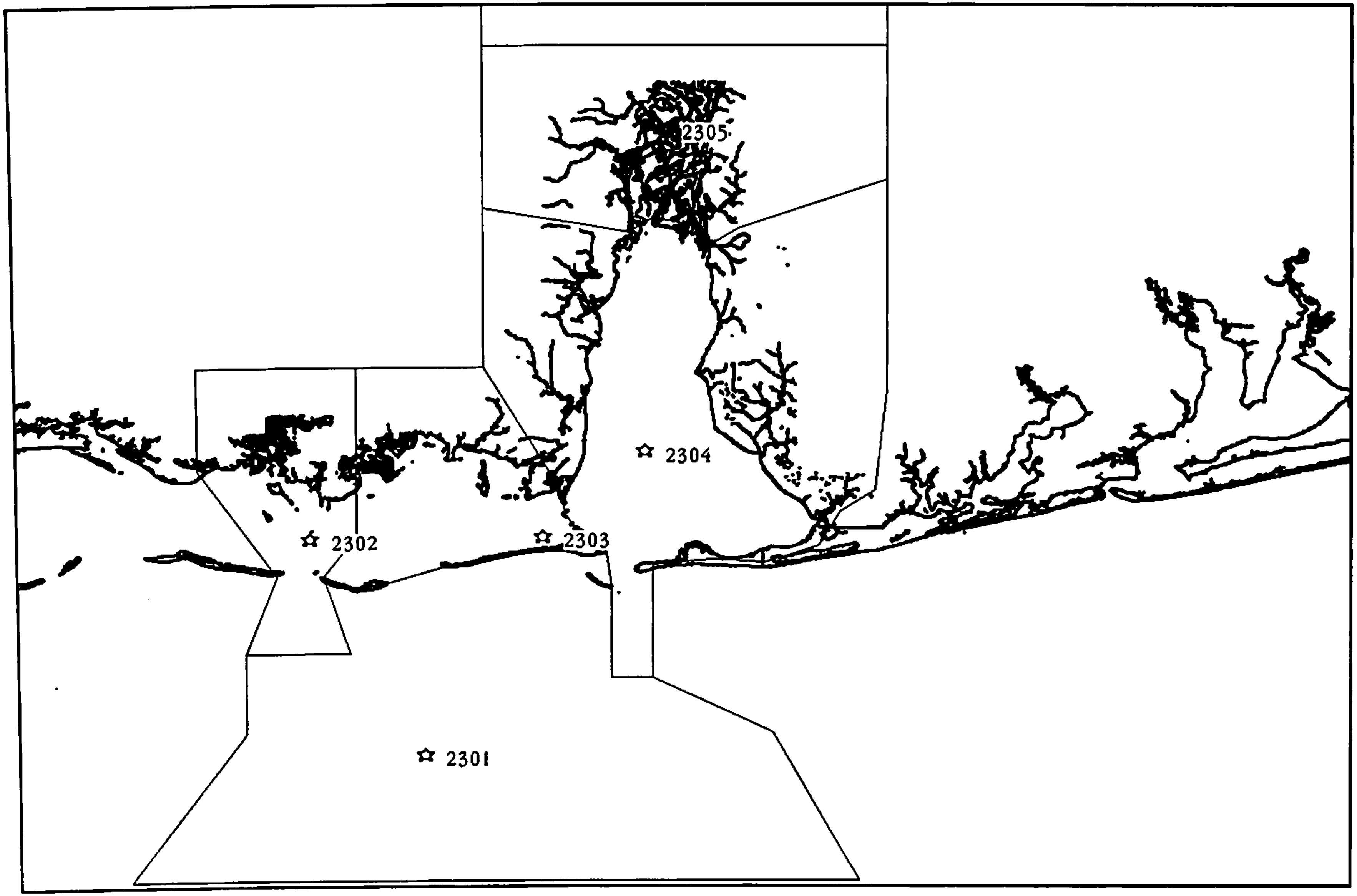
Jacksonville Spill Sites



Tampa Spill Sites



Mobile Spill Sites



APPENDIX 6-C
NRDAM/CME INPUT DATA FOR BOSTON MODEL RUNS

NRDAM Site Specific Input Parameters

Subzone	Site	Salinity Zone	Subtidal Bottom Type	Water Depth in meters	Current Speed m/sec	Tide Speed Parallel m/sec	Border Boundaries in Km -X	+X	-Y	+Y	Land Boundaries 1=Yes 0=No -X	+X	-Y	+Y
Port 1														
1	1	2	1	18.30	.02	.67	3.57	1000.00	3.83	3.83	1	0	1	1
2	1	2	1	13.70	.02	.77	8.70	1000.00	1.48	3.57	1	0	1	1
3	1	2	1	9.10	.02	.36	6.00	1.74	2.26	2.61	1	1	1	1
3	2	2	4	3.70	.02	.41	4.18	14.53	3.39	6.61	1	1	1	1
3	4	2	1	10.97	.02	.36	1.00	4.41	4.94	3.59	1	1	1	1
4	1	1	4	11.30	.02	.21	1.74	1.65	.61	1.13	0	0	1	1
5	1	1	4	10.40	.50	.10	2.34	6.03	1.26	2.00	1	1	1	1
Port 2														
1	1	2	4	61.00	.02	.50	178.71	1000.00	11.75	29.36	1	0	1	1
2	1	2	3	9.10	.02	.46	22.86	1000.00	11.11	38.80	1	0	1	1
3	1	1	4	29.00	.02	.10	4.35	25.92	23.18	76.31	1	1	1	1
4	1	2	4	2.70	.02	.15	4.19	80.50	5.80	46.05	1	1	1	1
5	1	2	4	128.10	.02	.41	6.28	24.96	30.27	38.16	1	1	1	1
6	1	1	4	18.30	.02	.05	7.08	4.51	4.99	5.31	1	1	1	1
7	1	1	4	17.00	.02	.05	2.25	4.03	5.80	15.13	1	1	1	1
8	1	1	4	5.00	.02	.10	8.86	4.19	.97	20.77	1	1	1	1
9	1	1	4	5.49	.02	.15	6.92	35.10	20.93	23.99	1	1	1	1
10	1	1	4	14.00	.02	.15	5.31	7.25	2.42	4.35	1	1	1	1
Port 3														
1	1	2	3	25.30	.02	.10	26.24	1000.00	1000.00	16.42	1	0	0	1
2	1	2	3	20.00	.02	.10	8.86	1000.00	1000.00	17.71	1	0	0	1
3	1	2	4	17.00	.02	.10	3.06	1000.00	1000.00	8.21	1	0	0	1
4	1	2	4	5.79	.02	.10	.97	.48	2.09	1.61	1	1	1	1
4	2	2	4	8.84	.02	.10	.16	.81	.97	1.61	1	1	1	1
Port 4														
1	1	2	4	73.20	.02	.10	32.36	19.48	82.43	1000.00	1	1	1	0
Port 5														
1	1	2	4	10.67	.02	.67	10.95	1000.00	362.03	209.17	1	0	1	1
2	1	1	4	9.14	.02	.67	4.51	9.18	13.69	24.79	1	1	1	1
4	1	1	4	8.84	.02	.67	15.94	11.59	.16	.16	1	1	1	1

NRDAM Seasonal Specific Input Parameters

		Winter			Spring			Summer			Fall		
Subzone	Site	Wind Direction degrees	Wind Speed m/sec	Temperature degree C	Wind Direction degrees	Wind Speed m/sec	Temperature degree C	Wind Direction degrees	Wind Speed m/sec	Temperature degree C	Wind Direction degrees	Wind Speed m/sec	Temperature degree C
Port 1													
1	1	315	5.88	.31	45	5.51	14.63	45	5.09	20.91	45	5.83	6.94
2	1	310	5.88	.31	40	5.51	14.63	40	5.09	20.91	40	5.83	6.94
3	1	315	5.88	.31	45	5.51	14.63	45	5.09	20.91	45	5.83	6.94
3	2	247	5.88	.31	337	5.51	14.63	337	5.09	20.91	337	5.83	6.94
3	4	315	5.88	.31	45	5.51	14.63	45	5.09	20.91	45	5.83	6.94
4	1	0	5.88	.31	90	5.51	14.63	90	5.09	20.91	90	5.83	6.94
5	1	90	5.88	.31	180	5.51	14.63	180	5.09	20.91	180	5.83	6.94
Port 2													
1	1	300	3.95	5.12	300	4.08	12.09	120	3.74	16.81	300	3.78	8.45
2	1	210	3.95	5.12	210	4.08	12.09	30	3.74	16.81	210	3.78	8.45
3	1	0	3.95	5.12	0	4.08	12.09	180	3.74	16.81	0	3.78	8.45
4	1	200	3.95	5.12	200	4.08	12.09	20	3.74	16.81	200	3.78	8.45
5	1	210	3.95	5.12	210	4.08	12.09	30	3.74	16.81	210	3.78	8.45
6	1	210	3.95	5.12	210	4.08	12.09	30	3.74	16.81	210	3.78	8.45
7	1	310	3.95	5.12	310	4.08	12.09	130	3.74	16.81	310	3.78	8.45
8	1	0	3.95	5.12	0	4.08	12.09	180	3.74	16.81	0	3.78	8.45
9	1	0	3.95	5.12	0	4.08	12.09	180	3.74	16.81	0	3.78	8.45
10	1	310	3.95	5.12	310	4.08	12.09	130	3.74	16.81	310	3.78	8.45
Port 3													
1	1	350	2.80	13.63	170	3.35	18.02	170	3.17	22.73	350	2.52	16.42
2	1	340	2.80	13.63	160	3.35	18.02	160	3.17	22.73	340	2.52	16.42
3	1	0	2.80	13.63	180	3.35	18.02	180	3.17	22.73	0	2.52	16.42
4	1	235	2.80	13.63	55	3.35	18.02	55	3.17	22.73	235	2.52	16.42
4	2	40	2.80	13.63	220	3.35	18.02	220	3.17	22.73	40	2.52	16.42
Port 4													
1	1	20	2.67	13.63	20	3.16	18.02	20	2.75	22.73	20	2.33	16.42

NRDAM Scenario Input Parameters for Boston Harbor

Run	Subzone	Site	Commodity Code	Spill Amount	Location	Intertidal Bottom Type	Surface Cleanup	Days Till Cleanup	Intertidal Cleanup	Days Till Cleanup	Price Deflator
Port 1											
0100101	1	1	0- 0- 1	24.43	2		5	.30			129.60
0100102	1	1	0- 0- 1		1	3			40	2	129.60
0100201	1	1	0- 0- 1	275.93	2		5	.30			129.60
0100202	1	1	0- 0- 1		1	3			40	5	129.60
0100301	1	1	0- 0- 1	1532.93	2		5	.30			129.60
0100302	1	1	0- 0- 1		1	3			40	8	129.60
0100401	2	1	0- 0- 1	24.43	2		5	.30			129.60
0100402	2	1	0- 0- 1		1	3			40	2	129.60
0100501	2	1	0- 0- 1	275.93	2		5	.30			129.60
0100502	2	1	0- 0- 1		1	3			40	5	129.60
0100601	2	1	0- 0- 1	1532.93	2		5	.30			129.60
0100602	2	1	0- 0- 1		1	3			40	8	129.60
0100701	3	1	0- 0- 1	24.43	2		5	.30			129.60
0100702	3	1	0- 0- 1		1	3			40	2	129.60
0100801	3	1	0- 0- 1	275.93	2		5	.30			129.60
0100802	3	1	0- 0- 1		1	3			40	5	129.60
0100901	3	1	0- 0- 1	1532.93	2		5	.30			129.60
0100902	3	1	0- 0- 1		1	3			40	8	129.60
0101001	4	1	0- 0- 1	24.43	2		10	.30			129.60
0101002	4	1	0- 0- 1		1	4			40	2	129.60
0101101	4	1	0- 0- 1	275.93	2		10	.30			129.60
0101102	4	1	0- 0- 1		1	4			40	5	129.60
0101201	4	1	0- 0- 1	1532.93	2		10	.30			129.60
0101202	4	1	0- 0- 1		1	4			40	8	129.60
0101301	5	1	0- 0- 1	24.43	2		5	.30			129.60
0101302	5	1	0- 0- 1		1	4			40	2	129.60
0101401	5	1	0- 0- 1	275.93	2		5	.30			129.60
0101402	5	1	0- 0- 1		1	4			40	5	129.60
0101501	5	1	0- 0- 1	1532.93	2		5	.30			129.60
0101502	5	1	0- 0- 1		1	4			40	8	129.60
0101601	5	1	0- 0- 3	25.64	2		5	.30			129.60
0101602	5	1	0- 0- 3		1	4			40	2	129.60

NRDAM Scenario Input Parameters for Boston Harbor

Run	Subzone	Site	Commodity Code	Spill Amount	Location	Intertidal Bottom Type	Surface Cleanup	Days Till Cleanup	Intertidal Cleanup	Days Till Cleanup	Price Deflator
Port 1											
0101701	5	1	0- 0- 3	289.56	2		5	.30			129.60
0101702	5	1	0- 0- 3		1	4			40	5	129.60
0101801	5	1	0- 0- 3	1608.63	2		5	.30			129.60
0101802	5	1	0- 0- 3		1	4			40	8	129.60
0101901	1	1	0- 0- 3	25.64	2		5	.30			129.60
0101902	1	1	0- 0- 3		1	3			40	2	129.60
0102001	1	1	0- 0- 3	289.56	2		5	.30			129.60
0102002	1	1	0- 0- 3		1	3			40	5	129.60
0102101	1	1	0- 0- 3	1608.63	2		5	.30			129.60
0102102	1	1	0- 0- 3		1	3			40	8	129.60
0102201	2	1	0- 0- 3	25.64	2		5	.30			129.60
0102202	2	1	0- 0- 3		1	3			40	2	129.60
0102301	2	1	0- 0- 3	289.56	2		5	.30			129.60
0102302	2	1	0- 0- 3		1	3			40	5	129.60
0102401	2	1	0- 0- 3	1608.63	2		5	.30			129.60
0102402	2	1	0- 0- 3		1	3			40	8	129.60
0102501	3	1	0- 0- 3	25.64	2		5	.30			129.60
0102502	3	1	0- 0- 3		1	3			40	2	129.60
0102601	3	1	0- 0- 3	289.56	2		5	.30			129.60
0102602	3	1	0- 0- 3		1	3			40	5	129.60
0102701	3	1	0- 0- 3	1608.63	2		5	.30			129.60
0102702	3	1	0- 0- 3		1	3			40	8	129.60
0102801	3	2	0- 0- 3	25.64	2		5	.30			129.60
0102802	3	2	0- 0- 3		1	4			40	2	129.60
0102901	3	2	0- 0- 3	289.56	2		5	.30			129.60
0102902	3	2	0- 0- 3		1	4			40	5	129.60
0103001	3	2	0- 0- 3	1608.63	2		5	.30			129.60
0103002	3	2	0- 0- 3		1	4			40	8	129.60
0103101	4	1	0- 0- 3	25.64	2		10	.30			129.60
0103102	4	1	0- 0- 3		1	4			40	2	129.60
0103201	4	1	0- 0- 3	289.56	2		10	.30			129.60
0103202	4	1	0- 0- 3		1	4			40	5	129.60
0103301	4	1	0- 0- 3	1608.63	2		10	.30			129.60

NRDAM Scenario Input Parameters for Boston Harbor

Run	Subzone	Site	Commodity	Code	Spill Amount	Location	Intertidal Bottom Type	Surface Cleanup	Days Till Cleanup	Intertidal Cleanup	Days Till Cleanup	Price Deflator
Port 1												
0103302	4	1	0- 0-	3		1	4			40	8	129.60
0103401	1	1	0- 0-	2	29.86	2		5	.30			129.60
0103402	1	1	0- 0-	2		1	3			40	2	129.60
0103501	1	1	0- 0-	2	337.25	2		5	.30			129.60
0103502	1	1	0- 0-	2		1	3			40	5	129.60
0103601	1	1	0- 0-	2	1873.58	2		5	.30			129.60
0103602	1	1	0- 0-	2		1	3			40	8	129.60
0103701	2	1	0- 0-	2	29.86	2		5	.30			129.60
0103702	2	1	0- 0-	2		1	3			40	2	129.60
0103801	2	1	0- 0-	2	337.25	2		5	.30			129.60
0103802	2	1	0- 0-	2		1	3			40	5	129.60
0103901	2	1	0- 0-	2	1873.58	2		5	.30			129.60
0103902	2	1	0- 0-	2		1	3			40	8	129.60
0104001	3	1	0- 0-	2	29.86	2		5	.30			129.60
0104002	3	1	0- 0-	2		1	3			40	2	129.60
0104101	3	1	0- 0-	2	337.25	2		5	.30			129.60
0104102	3	1	0- 0-	2		1	3			40	5	129.60
0104201	3	1	0- 0-	2	1873.58	2		5	.30			129.60
0104202	3	1	0- 0-	2		1	3			40	8	129.60
0104301	4	1	0- 0-	2	29.86	2		10	.30			129.60
0104302	4	1	0- 0-	2		1	4			40	2	129.60
0104401	4	1	0- 0-	2	337.25	2		10	.30			129.60
0104402	4	1	0- 0-	2		1	4			40	5	129.60
0104501	4	1	0- 0-	2	1873.58	2		10	.30			129.60
0104502	4	1	0- 0-	2		1	4			40	8	129.60
0104601	1	1	0- 0-	6	24.13	2		5	.30			129.60
0104602	1	1	0- 0-	6		1	3			40	2	129.60
0104701	1	1	0- 0-	6	272.52	2		5	.30			129.60
0104702	1	1	0- 0-	6		1	3			40	5	129.60
0104801	1	1	0- 0-	6	1514.00	2		5	.30			129.60
0104802	1	1	0- 0-	6		1	3			40	8	129.60
0104901	2	1	0- 0-	6	24.13	2		5	.30			129.60
0104902	2	1	0- 0-	6		1	3			40	2	129.60

NRDAM Scenario Input Parameters for Boston Harbor

Run	Subzone	Site	Commodity Code	Spill Amount	Location	Intertidal Bottom Type	Surface Cleanup	Days Till Cleanup	Intertidal Cleanup	Days Till Cleanup	Price Deflator
Port 1											
0105001	2	1	0- 0- 6	272.52	2		5	.30			129.60
0105002	2	1	0- 0- 6		1	3			40	5	129.60
0105101	2	1	0- 0- 6	1514.00	2		5	.30			129.60
0105102	2	1	0- 0- 6		1	3			40	8	129.60
0105201	3	2	0- 0- 6	24.13	2		5	.30			129.60
0105202	3	2	0- 0- 6		1	4			40	2	129.60
0105301	3	2	0- 0- 6	272.52	2		5	.30			129.60
0105302	3	2	0- 0- 6		1	4			40	5	129.60
0105401	3	2	0- 0- 6	1514.00	2		5	.30			129.60
0105402	3	2	0- 0- 6		1	4			40	8	129.60
0105501	5	1	0- 0- 2	29.86	2		5	.30			129.60
0105502	5	1	0- 0- 2		1	4			40	2	129.60
0105601	5	1	0- 0- 2	337.25	2		5	.30			129.60
0105602	5	1	0- 0- 2		1	4			40	5	129.60
0105701	5	1	0- 0- 2	1873.58	2		5	.30			129.60
0105702	5	1	0- 0- 2		1	4			40	8	129.60
0105801	3	4	0- 0- 1	24.43	2		5	.30			129.60
0105802	3	4	0- 0- 1		1	3			40	2	129.60
0105901	3	4	0- 0- 1	275.93	2		5	.30			129.60
0105902	3	4	0- 0- 1		1	3			40	5	129.60
0106001	3	4	0- 0- 1	1532.93	2		5	.30			129.60
0106002	3	4	0- 0- 1		1	3			40	8	129.60
0106101	3	4	0- 0- 3	25.64	2		5	.30			129.60
0106102	3	4	0- 0- 3		1	3			40	2	129.60
0106201	3	4	0- 0- 3	289.56	2		5	.30			129.60
0106202	3	4	0- 0- 3		1	3			40	5	129.60
0106301	3	4	0- 0- 3	1608.63	2		5	.30			129.60
0106302	3	4	0- 0- 3		1	3			40	8	129.60
0106401	3	4	0- 0- 2	29.86	2		5	.30			129.60
0106402	3	4	0- 0- 2		1	3			40	2	129.60
0106501	3	4	0- 0- 2	337.25	2		5	.30			129.60
0106502	3	4	0- 0- 2		1	3			40	5	129.60
0106601	3	4	0- 0- 2	1873.58	2		5	.30			129.60

NRDAM Scenario Input Parameters for Boston Harbor

Run	Subzone	Site	Commodity Code	Spill Amount	Location	Intertidal Bottom Type	Surface Cleanup	Days Till Cleanup	Intertidal Cleanup	Days Till Cleanup	Price Deflator
Port 1											
0106602	3	4	0- 0- 2		1	3			40	8	129.60
0113901	4	1	0- 0- 6	24.13	2		10	.30			129.60
0113902	4	1	0- 0- 6		1	4			40	2	129.60
0114001	4	1	0- 0- 6	272.52	2		10	.30			129.60
0114002	4	1	0- 0- 6		1	4			40	5	129.60
0114101	4	1	0- 0- 6	1514.00	2		10	.30			129.60
0114102	4	1	0- 0- 6		1	4			40	8	129.60
0114201	5	1	0- 0- 6	24.13	2		5	.30			129.60
0114202	5	1	0- 0- 6		1	4			40	2	129.60
0114301	5	1	0- 0- 6	272.52	2		5	.30			129.60
0114302	5	1	0- 0- 6		1	4			40	5	129.60
0114401	5	1	0- 0- 6	1514.00	2		5	.30			129.60
0114402	5	1	0- 0- 6		1	4			40	8	129.60
0114501	3	4	0- 0- 6	24.13	2		10	.30			129.60
0114502	3	4	0- 0- 6		1	4			40	2	129.60
0114601	3	4	0- 0- 6	272.52	2		10	.30			129.60
0114602	3	4	0- 0- 6		1	4			40	5	129.60
0114701	3	4	0- 0- 6	1514.00	2		10	.30			129.60
0114702	3	4	0- 0- 6		1	4			40	8	129.60

APPENDIX 6-D
DETAILED NATURAL RESOURCES LOSSES FOR BOSTON

Catch Lost for Fish and Invertebrates in Boston Harbor

Commodity Type: 0-0-1

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	2604.67	46701.32	10531.93	11926.26	24531.46	200533.25	107.00	1910.95	964.81	299,811.63
11	MEDIUM	217.83	3926.70	890.81	1062.59	3535.73	29228.10	11.66	8.24	139.16	39,020.81
11	SMALL	5.84	107.73	24.60	31.83	87.22	717.83	.50	.16	3.48	979.18
21	LARGE	3235.64	56237.69	12796.72	14238.55	29430.51	240641.70	176.25	4761.31	1148.73	362,667.09
21	MEDIUM	335.69	6256.56	1401.62	1700.47	4853.66	39891.64	21.90	388.23	196.71	55,046.46
21	SMALL	7.69	153.15	34.71	43.59	123.71	1029.61	1.07	18.70	5.00	1,417.23
31	LARGE	2276.14	32532.05	7693.79	534.57	19134.24	158433.80	4035.28	24159.19	244.20	249,043.25
31	MEDIUM	343.48	5024.35	1172.93	65.36	4570.06	37758.78	561.81	3346.58	59.04	52,902.39
31	SMALL	8.99	153.15	34.94	1.90	162.44	1304.89	35.33	206.37	1.97	1,909.95
41	LARGE	5128.14	52522.72	12398.56	583.99	32132.55	249157.89	8269.84	25591.05	365.39	386,150.11
41	MEDIUM	649.54	7212.57	1662.25	63.72	6730.85	52244.80	1479.86	3446.54	76.51	73,566.65
41	SMALL	14.43	201.45	42.22	1.59	191.74	1463.57	81.57	198.07	2.23	2,196.86
51	LARGE	4628.72	74752.37	16524.38	850.42	38014.57	303195.15	6407.61	10128.10	458.25	454,959.54
51	MEDIUM	473.62	7811.48	1664.94	83.86	7070.52	56050.59	1029.37	710.99	82.51	74,977.87
51	SMALL	11.57	223.07	44.56	2.38	190.89	1480.63	48.17	20.36	2.12	2,023.73

Commodity Type: 0-0-2

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	0.00	.06	.02	.10	.06	.38	389.66	23193.40	0.00	23,583.67
11	MEDIUM	0.00	0.00	0.00	0.00	0.00	0.00	70.17	4178.02	0.00	4,248.19
11	SMALL	0.00	0.00	0.00	0.00	0.00	0.00	6.29	374.88	0.00	381.17
21	LARGE	0.00	.11	.04	.12	.10	.60	395.13	23516.56	0.00	23,912.66
21	MEDIUM	0.00	0.00	0.00	0.00	0.00	0.00	71.09	4233.33	0.00	4,304.42
21	SMALL	0.00	0.00	0.00	0.00	0.00	0.00	6.36	378.43	0.00	384.79
31	LARGE	0.00	0.00	0.00	0.00	62.65	.06	5193.30	31093.11	0.00	36,349.11
31	MEDIUM	0.00	0.00	0.00	0.00	11.25	.01	932.22	5579.81	0.00	6,523.27
31	SMALL	0.00	0.00	0.00	0.00	.99	0.00	82.44	493.45	0.00	576.88
41	LARGE	0.00	.24	.02	0.00	87.34	.16	6876.80	39281.48	0.00	46,246.03
41	MEDIUM	0.00	.02	0.00	0.00	15.68	.01	1235.35	7058.58	0.00	8,309.62
41	SMALL	0.00	0.00	0.00	0.00	1.38	0.00	109.28	624.37	0.00	735.02
51	LARGE	0.00	1.80	.15	0.00	136.97	1.17	6478.40	31647.27	0.00	38,265.74
51	MEDIUM	0.00	.04	0.00	0.00	24.56	.02	1165.55	5698.54	0.00	6,888.70
51	SMALL	0.00	0.00	0.00	0.00	2.18	0.00	104.19	509.39	0.00	615.76

Catch Lost for Fish and Invertebrates in Boston Harbor

Commodity Type: 0-0-3

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	15640.96	237280.78	55378.40	55650.04	84943.73	709341.18	741.47	16452.74	3091.87	1,178,521.16
11	MEDIUM	2758.69	44921.44	10314.68	11362.71	24886.39	204668.68	133.27	2436.72	952.09	302,434.66
11	SMALL	81.03	1479.55	337.07	394.70	1186.78	10356.58	9.48	191.54	41.19	14,077.90
21	LARGE	19087.47	260329.02	63643.35	56125.83	88330.26	754098.58	880.06	17641.47	2949.55	1,263,085.57
21	MEDIUM	3436.77	49775.06	12033.79	11856.09	26420.68	220586.45	156.83	2731.20	947.12	327,943.98
21	SMALL	114.28	2103.87	489.90	530.50	1450.41	12397.15	11.13	216.04	53.70	17,366.97
31	LARGE	1872.25	26655.34	6362.21	515.70	15843.03	133835.06	4805.12	28391.36	211.64	218,491.70
31	MEDIUM	562.86	7264.77	1754.61	136.97	6133.50	52002.64	857.99	4945.96	84.12	73,743.40
31	SMALL	57.64	826.18	197.60	16.07	887.04	7766.81	74.49	407.50	12.53	10,245.85
32	LARGE	56328.66	718014.68	174334.03	10445.76	245304.49	2026537.50	87446.42	236117.77	3383.84	3,557,913.14
32	MEDIUM	9602.54	139946.91	33171.90	1752.17	65762.59	537939.45	9553.47	25983.57	896.22	824,608.81
32	SMALL	392.64	6865.09	1559.42	81.60	4079.12	33759.23	81.41	287.40	53.37	47,159.26
41	LARGE	6823.78	57923.80	14270.56	617.81	35724.61	273746.45	10092.99	35148.74	403.63	434,752.36
41	MEDIUM	1662.73	14943.78	3605.26	173.06	13647.29	105038.99	2690.21	6066.85	156.02	147,984.19
41	SMALL	167.53	1641.01	384.09	19.79	1699.24	13421.10	399.12	484.79	21.74	18,238.39
51	LARGE	20664.87	271874.00	64717.46	4563.74	94898.07	783040.50	20329.81	25429.45	1411.23	1,286,929.12
51	MEDIUM	4448.27	60439.26	14144.30	908.43	30585.48	249055.02	5445.78	4012.59	434.40	369,473.51
51	SMALL	193.47	3165.11	688.16	43.33	2773.52	22737.00	576.15	308.11	39.96	30,524.80

Commodity Type: 0-0-6

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	24704.54	367162.08	85189.56	88139.07	116142.96	965043.23	813.70	1472.27	4261.37	1,652,928.77
11	MEDIUM	3320.29	49141.14	11460.44	11919.42	24372.41	202513.95	99.92	119.87	886.41	303,833.84
11	SMALL	140.39	2390.61	550.84	574.16	2052.50	17135.99	6.05	3.54	77.37	22,931.44
21	LARGE	26176.87	441767.40	98702.49	111084.61	146635.40	1199290.08	1041.13	1964.37	5714.75	2,032,377.09
21	MEDIUM	4198.94	62245.38	14460.63	15044.09	29561.11	244248.53	125.10	136.72	1081.52	371,102.01
21	SMALL	226.31	3468.09	807.85	868.02	2823.12	23342.75	7.89	4.57	107.68	31,656.27
32	LARGE	64358.36	882857.90	206187.80	12184.70	278959.23	2276514.75	208687.33	543414.55	3281.49	4,476,446.09
32	MEDIUM	11247.13	159040.57	36974.28	2077.59	71826.37	585657.23	10785.08	27847.57	855.72	906,311.53
32	SMALL	550.02	7767.12	1808.38	105.42	6311.49	51835.58	22.98	29.87	77.26	68,508.11
41	LARGE	107203.11	1566510.00	359275.05	21855.21	467299.85	3819809.91	25724.70	54526.44	5466.82	6,427,671.08
41	MEDIUM	15506.13	224895.86	51963.94	3177.18	93744.58	766521.20	2054.83	1081.69	1127.51	1,160,072.91
41	SMALL	628.08	9336.54	2154.23	129.99	8323.85	67904.77	214.12	26.87	101.44	88,819.88
51	LARGE	46514.29	706035.38	158170.67	9251.22	212358.83	1705162.75	39866.93	33959.54	2491.46	2,913,811.06
51	MEDIUM	6525.99	98592.08	22071.05	1273.31	42193.22	338012.05	5527.22	351.71	499.59	515,046.21
51	SMALL	295.15	4485.09	988.35	64.57	4102.64	32889.98	503.97	8.36	49.86	43,387.97

Value Lost for Fish and Invertebrates in Boston Harbor

Commodity Type: 0-0-1

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	176.62	17861.44	13711.15	1967.80	18395.79	54620.44	98.30	1055.50	297.59	108,184.61
11	MEDIUM	14.77	1483.97	1172.05	172.09	2651.06	7958.43	5.04	8.62	42.92	13,508.93
11	SMALL	.40	40.05	32.83	5.01	65.35	195.04	.23	.21	1.08	340.18
21	LARGE	219.41	21324.40	16799.56	2351.76	22069.74	65549.20	207.75	2564.50	354.31	131,440.63
21	MEDIUM	22.76	2419.45	1809.46	277.58	3639.63	10866.33	20.03	209.92	60.67	19,325.81
21	SMALL	.52	57.09	46.25	6.92	92.69	279.95	.97	10.01	1.55	495.94
31	LARGE	154.34	11643.20	10541.21	133.93	14308.45	43125.01	15046.72	12765.52	75.32	107,793.71
31	MEDIUM	23.29	1852.16	1575.50	16.37	3414.69	10273.20	2061.17	1769.55	18.21	21,004.13
31	SMALL	.62	56.85	46.64	.47	121.05	354.18	130.80	108.96	.61	820.17
41	LARGE	396.37	10424.89	17387.13	114.30	25267.90	56512.41	27654.71	13512.12	112.70	151,382.52
41	MEDIUM	50.75	1171.83	2397.61	12.47	5280.49	11670.88	4754.68	1818.96	23.60	27,181.26
41	SMALL	1.13	30.98	61.11	.31	149.18	318.93	265.39	104.45	.69	932.14
51	LARGE	401.90	11115.99	27231.78	166.46	29617.61	56794.13	19999.62	5338.80	141.34	150,807.61
51	MEDIUM	41.29	1238.84	2743.51	16.42	5471.30	10497.41	3012.24	374.81	25.45	23,421.26
51	SMALL	1.00	33.53	73.33	.47	147.06	276.89	138.12	10.73	.65	681.77

Commodity Type: 0-0-2

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	0.00	.02	.03	.01	.03	.09	811.68	12220.11	0.00	13,031.97
11	MEDIUM	0.00	0.00	0.00	0.00	0.00	0.00	146.20	2201.30	0.00	2,347.49
11	SMALL	0.00	0.00	0.00	0.00	0.00	0.00	13.12	197.51	0.00	210.63
21	LARGE	0.00	.03	.05	.01	.06	.14	822.98	12390.37	0.00	13,213.65
21	MEDIUM	0.00	0.00	0.00	0.00	0.00	0.00	148.12	2230.44	0.00	2,378.56
21	SMALL	0.00	0.00	0.00	0.00	0.00	0.00	13.25	199.39	0.00	212.64
31	LARGE	0.00	0.00	0.00	0.00	55.06	.01	19762.12	16382.29	0.00	36,199.47
31	MEDIUM	0.00	0.00	0.00	0.00	9.89	0.00	3547.44	2939.87	0.00	6,497.20
31	SMALL	0.00	0.00	0.00	0.00	.86	0.00	313.71	260.00	0.00	574.57
41	LARGE	0.00	.00	.02	0.00	75.78	.02	26228.07	20696.57	0.00	47,000.47
41	MEDIUM	0.00	0.00	0.00	0.00	13.61	0.00	4711.67	3719.01	0.00	8,444.29
41	SMALL	0.00	0.00	0.00	0.00	1.19	0.00	416.78	328.97	0.00	746.95
51	LARGE	0.00	.03	.21	0.00	104.83	.18	24874.49	16674.25	0.00	41,653.98
51	MEDIUM	0.00	0.00	0.00	0.00	18.79	0.00	4476.28	3002.43	0.00	7,497.50
51	SMALL	0.00	0.00	0.00	0.00	1.67	0.00	400.14	268.39	0.00	670.20

Value Lost for Fish and Invertebrates in Boston Harbor

Commodity Type: 0-0-3

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	1060.61	87158.41	74453.10	9281.98	63688.27	193127.08	775.43	9193.38	953.66	439,691.90
11	MEDIUM	187.06	16904.08	13618.89	1874.49	18660.99	55740.79	124.17	1351.45	293.66	108,755.56
11	SMALL	5.50	551.27	448.25	63.68	889.58	2818.56	9.27	102.63	12.71	4,901.44
21	LARGE	1294.32	89523.13	89838.72	9409.34	66222.73	205282.14	874.81	9863.40	909.76	473,218.35
21	MEDIUM	233.05	17481.05	16796.07	1954.71	19809.38	60054.62	143.18	1509.74	292.13	118,273.90
21	SMALL	7.74	754.00	673.66	85.83	1087.17	3373.07	10.68	116.00	16.57	6,124.71
31	LARGE	126.96	9293.25	8859.19	129.20	11842.96	36425.79	17997.57	14989.79	65.28	99,729.99
31	MEDIUM	38.17	2551.31	2430.72	34.32	4581.16	14148.81	3146.35	2617.50	25.94	29,574.27
31	SMALL	3.91	286.71	275.88	4.02	661.08	2111.44	259.62	216.24	3.87	3,822.76
32	LARGE	3823.31	307235.20	114411.05	3353.09	120318.54	673092.75	54121.75	328033.86	1043.71	1,605,433.26
32	MEDIUM	651.97	60715.56	20660.01	562.45	32242.79	178617.45	6507.04	35333.36	276.43	335,567.06
32	SMALL	26.70	2990.72	973.74	26.20	1996.77	11197.56	199.34	199.66	16.46	17,627.14
41	LARGE	507.82	13343.65	19664.54	120.93	28002.17	63762.89	34346.90	18566.30	124.49	178,439.69
41	MEDIUM	124.44	3210.79	5013.75	33.87	10718.04	24352.66	8551.66	3209.33	48.12	55,262.67
41	SMALL	12.72	284.26	551.18	3.88	1357.61	2979.37	1194.25	256.40	6.70	6,646.36
51	LARGE	1813.05	15969.15	105980.85	893.27	76429.21	146665.47	62062.00	13426.84	435.28	423,675.12
51	MEDIUM	389.19	3874.98	23160.73	177.81	24350.21	46643.80	16000.88	2118.13	133.99	116,849.70
51	SMALL	16.76	264.16	1127.47	8.48	2218.35	4256.26	1666.19	162.45	12.33	9,732.44

Commodity Type: 0-0-6

Spill Site	Spill Size	Anadromous	Planktivorous	Piscivorous	Carnivorous	Demersal	Semi-demersal	Mollusks	Decapods	Squid	Total
11	LARGE	1675.21	136802.38	113254.67	14705.09	87083.38	262752.78	396.78	1991.17	1314.38	619,975.82
11	MEDIUM	225.14	18240.65	15284.08	1982.08	18276.60	55163.71	45.99	161.94	273.41	109,653.60
11	SMALL	9.53	876.94	740.39	94.51	1539.16	4667.99	2.61	4.77	23.86	7,959.76
21	LARGE	1775.04	171963.38	126169.40	18504.47	109965.55	326706.03	529.17	2461.60	1762.66	759,837.28
21	MEDIUM	284.73	23241.47	19176.49	2506.99	22168.26	66536.04	58.71	184.70	333.58	134,490.96
21	SMALL	15.34	1288.49	1077.75	143.24	2117.23	6360.58	3.47	6.15	33.21	11,045.46
32	LARGE	4374.29	379762.70	134422.32	3911.29	136857.78	756359.18	97419.08	794650.03	1012.14	2,308,768.80
32	MEDIUM	764.48	68748.27	23605.54	666.91	35235.51	194568.30	5041.93	40856.08	263.94	369,750.95
32	SMALL	37.38	3345.19	1176.01	33.85	3094.75	17215.65	9.40	43.76	23.83	24,979.81
41	LARGE	7524.54	541816.38	481457.91	5335.56	352089.44	1012180.58	33903.33	64964.29	1686.19	2,500,958.22
41	MEDIUM	1098.90	74452.87	70727.17	769.53	70672.28	202505.65	4686.58	1154.46	347.77	426,415.21
41	SMALL	45.35	2854.47	2992.43	30.99	6274.12	17931.07	535.53	27.78	31.29	30,723.01
51	LARGE	4075.33	113406.29	260948.23	1810.76	166280.36	319448.18	122585.90	18770.92	768.47	1,008,094.41
51	MEDIUM	571.44	14798.07	36373.82	249.23	33021.26	63321.53	15460.55	195.11	154.09	164,145.09
51	SMALL	25.90	580.08	1625.41	12.64	3212.33	6161.59	1401.21	4.62	15.38	13,039.14

Catch Lost for Birds and Mammals in Boston Harbor

Commodity Type: 0-0-1

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	50.62	2154.28	634.80	.01	2,839.71
11	MEDIUM	0.00	2.34	5.73	246.68	0.00	254.75
11	SMALL	0.00	.09	0.00	107.13	0.00	107.22
21	LARGE	0.00	4.34	2081.24	184.61	0.00	2,270.18
21	MEDIUM	0.00	.76	28.35	89.56	0.00	118.66
21	SMALL	0.00	0.00	1.22	41.39	0.00	42.61
31	LARGE	0.00	4.72	26770.69	16.08	3.00	26,794.49
31	MEDIUM	0.00	3.58	3648.07	11.60	2.15	3,665.40
31	SMALL	0.00	1.90	240.41	6.83	1.22	250.37
41	LARGE	0.00	63.83	26854.24	24.73	26.62	26,969.42
41	MEDIUM	0.00	40.25	3688.37	15.91	16.25	3,760.77
41	SMALL	0.00	30.04	235.08	7.25	8.11	280.49
51	LARGE	0.00	1.98	8192.00	75.03	0.00	8,269.01
51	MEDIUM	0.00	.94	309.53	42.57	0.00	353.05
51	SMALL	0.00	.09	1.55	10.04	0.00	11.67

Commodity Type: 0-0-2

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	27.93	25153.46	444.66	0.00	25,626.05
11	MEDIUM	0.00	4.68	4529.74	154.71	0.00	4,689.12
11	SMALL	0.00	.75	406.18	51.33	0.00	458.25
21	LARGE	0.00	2.36	25164.09	134.14	0.00	25,300.59
21	MEDIUM	0.00	.60	4529.10	55.88	0.00	4,585.57
21	SMALL	0.00	.11	406.09	18.76	0.00	424.96
31	LARGE	0.00	4.70	36169.65	15.93	2.75	36,193.02
31	MEDIUM	0.00	3.11	6494.11	10.51	1.82	6,509.55
31	SMALL	0.00	.97	574.31	3.95	.62	579.84
41	LARGE	0.00	55.60	39944.13	21.97	21.52	40,043.23
41	MEDIUM	0.00	28.58	7176.13	11.53	10.08	7,226.31
41	SMALL	0.00	10.05	634.64	3.67	3.44	651.80
51	LARGE	0.00	1.25	34192.11	52.26	0.00	34,245.62
51	MEDIUM	0.00	.46	6156.85	23.53	0.00	6,180.84
51	SMALL	0.00	.14	552.03	7.33	0.00	559.49

Commodity Type: 0-0-3

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	56.50	16753.31	716.61	.01	17,526.43
11	MEDIUM	0.00	12.42	2574.82	312.84	0.00	2,900.07
11	SMALL	0.00	1.77	210.06	140.31	0.00	352.14
21	LARGE	0.00	5.28	16680.91	205.54	0.00	16,891.72
21	MEDIUM	0.00	1.49	2547.33	109.38	0.00	2,658.20
21	SMALL	0.00	.35	208.50	50.72	0.00	259.57
31	LARGE	0.00	4.71	32800.54	16.08	2.91	32,824.24
31	MEDIUM	0.00	3.59	5719.84	11.72	2.16	5,737.31
31	SMALL	0.00	1.96	466.88	7.16	1.26	477.26
32	LARGE	0.00	21.90	18403.78	627.38	21.13	19,074.18
32	MEDIUM	0.00	17.33	2834.70	382.60	11.70	3,246.33
32	SMALL	0.00	2.60	234.80	101.87	1.78	341.05
41	LARGE	0.00	64.98	35873.99	25.53	27.36	35,991.86
41	MEDIUM	0.00	42.04	6211.24	16.93	17.37	6,287.57
41	SMALL	0.00	22.02	498.24	7.73	8.68	536.67
51	LARGE	0.00	2.34	25275.62	84.60	0.00	25,362.56
51	MEDIUM	0.00	1.15	3897.25	49.66	0.00	3,948.06
51	SMALL	0.00	.34	310.40	17.51	0.00	328.24

Catch Lost for Birds and Mammals in Boston Harbor

Commodity Type: 0-0-6

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	0.00	0.00	216.69	0.00	216.69
11	MEDIUM	0.00	0.00	0.00	84.80	0.00	84.80
11	SMALL	0.00	0.00	0.00	18.18	0.00	18.18
21	LARGE	0.00	0.00	15.55	77.67	0.00	93.23
21	MEDIUM	0.00	0.00	0.00	21.25	0.00	21.25
21	SMALL	0.00	0.00	0.00	7.45	0.00	7.45
32	LARGE	0.00	13.45	0.00	113.63	51.20	178.28
32	MEDIUM	0.00	0.00	0.00	35.17	5.67	40.83
32	SMALL	0.00	0.00	0.00	13.85	.21	14.06
41	LARGE	0.00	195.80	9117.34	226.07	174.87	9,714.07
41	MEDIUM	0.00	74.30	143.40	96.64	29.27	343.61
41	SMALL	0.00	20.84	2.29	23.19	5.15	51.46
51	LARGE	0.00	.33	86.28	70.47	0.00	157.08
51	MEDIUM	0.00	.03	.04	30.64	0.00	30.70
51	SMALL	0.00	0.00	0.00	10.38	0.00	10.38

Commodity Type: 0-0-1

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	295.89	9431.92	3834.41	1.47	13,563.69
11	MEDIUM	0.00	16.45	22.55	1489.38	0.00	1,528.38
11	SMALL	0.00	.62	0.00	646.15	0.00	646.77
21	LARGE	0.00	27.88	9068.37	1095.20	0.00	10,191.45
21	MEDIUM	0.00	5.34	119.98	531.32	0.00	656.64
21	SMALL	0.00	0.00	4.93	245.57	0.00	250.50
31	LARGE	0.00	30.34	117210.05	97.55	405.49	117,743.43
31	MEDIUM	0.00	23.03	15971.63	70.35	290.50	16,355.51
31	SMALL	0.00	13.40	1010.23	41.44	164.47	1,229.53
41.	LARGE	0.00	373.54	117526.46	146.66	3593.81	121,640.47
41	MEDIUM	0.00	239.31	16139.88	94.36	2193.04	18,666.59
41	SMALL	0.00	181.75	987.37	43.01	1095.34	2,307.47
51	LARGE	0.00	13.96	35875.67	445.09	0.00	36,334.72
51	MEDIUM	0.00	6.63	1307.16	252.55	0.00	1,566.35
51	SMALL	0.00	.61	6.46	59.56	0.00	66.62

Commodity Type: 0-0-2

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	86.74	110150.08	2685.45	0.00	112,922.28
11	MEDIUM	0.00	14.63	19836.28	934.22	0.00	20,785.13
11	SMALL	0.00	2.55	1706.65	309.66	0.00	2,018.86
21	LARGE	0.00	16.61	110196.15	795.82	0.00	111,008.58
21	MEDIUM	0.00	2.02	19833.32	331.53	0.00	20,166.86
21	SMALL	0.00	.35	1706.28	111.31	0.00	1,817.94
31	LARGE	0.00	14.59	158392.01	96.59	371.02	158,874.21
31	MEDIUM	0.00	9.67	28438.66	63.76	245.93	28,758.02
31	SMALL	0.00	3.28	2468.41	23.92	83.46	2,579.06
41	LARGE	0.00	159.69	174833.96	130.34	2905.59	178,029.57
41	MEDIUM	0.00	84.03	31409.67	68.41	1360.97	32,923.08
41	SMALL	0.00	31.22	2726.34	21.77	464.56	3,243.89
51	LARGE	0.00	8.80	149725.35	310.04	0.00	150,044.19
51	MEDIUM	0.00	1.57	26960.43	139.58	0.00	27,101.57
51	SMALL	0.00	.47	2373.10	43.50	0.00	2,417.06

Value Lost for Birds and Mammals in Boston Harbor

Commodity Type: 0-0-3

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	330.45	73357.50	4329.10	1.63	78,018.68
11	MEDIUM	0.00	76.65	11275.77	1889.43	0.00	13,241.85
11	SMALL	0.00	12.47	882.73	846.54	0.00	1,741.74
21	LARGE	0.00	33.91	73040.43	1219.37	0.00	74,293.71
21	MEDIUM	0.00	10.46	11154.68	648.91	0.00	11,814.04
21	SMALL	0.00	2.46	876.11	300.88	0.00	1,179.45
31	LARGE	0.00	30.30	143635.51	97.54	393.31	144,156.66
31	MEDIUM	0.00	23.13	25047.66	71.08	291.97	25,433.83
31	SMALL	0.00	13.79	1961.64	43.44	170.48	2,189.35
32	LARGE	0.00	132.09	80585.17	3806.99	2852.25	87,376.50
32	MEDIUM	0.00	104.27	12413.63	2322.07	1579.26	16,419.22
32	SMALL	0.00	18.35	986.66	618.22	240.13	1,863.36
41	LARGE	0.00	380.24	157019.01	151.45	3693.32	161,244.02
41	MEDIUM	0.00	249.87	27186.55	100.46	2344.97	29,881.83
41	SMALL	0.00	132.38	2092.33	45.86	1171.42	3,441.98
51	LARGE	0.00	16.49	110672.43	501.88	0.00	111,190.80
51	MEDIUM	0.00	8.08	17065.08	294.61	0.00	17,367.77
51	SMALL	0.00	2.37	1304.25	103.85	0.00	1,410.47

Commodity Type: 0-0-6

Spill Site	Spill Size	Mammals	Waterfowl	Shorebirds	Seabirds	Raptors	Total
11	LARGE	0.00	0.00	0.00	1307.35	0.00	1,307.35
11	MEDIUM	0.00	0.00	0.00	511.90	0.00	511.90
11	SMALL	0.00	0.00	0.00	109.74	0.00	109.74
21	LARGE	0.00	0.00	66.49	460.80	0.00	527.29
21	MEDIUM	0.00	0.00	0.00	126.03	0.00	126.03
21	SMALL	0.00	0.00	0.00	44.19	0.00	44.19
32	LARGE	0.00	82.05	0.00	689.41	6912.33	7,683.78
32	MEDIUM	0.00	0.00	0.00	213.35	764.86	978.21
32	SMALL	0.00	0.00	0.00	84.05	28.76	112.81
41	LARGE	0.00	1135.14	39835.35	1370.64	23606.98	65,948.11
41	MEDIUM	0.00	441.94	594.60	585.76	3951.03	5,573.32
41	SMALL	0.00	129.95	9.00	140.33	695.11	974.38
51	LARGE	0.00	2.34	375.44	418.09	0.00	795.86
51	MEDIUM	0.00	.18	.11	181.77	0.00	182.06
51	SMALL	0.00	0.00	0.00	61.60	0.00	61.60

APPENDIX 6-E
BIBLIOGRAPHY FOR COMPILATION OF PORT-SPECIFIC SPECIES DATA BASES

Ahlstrom, E.H., 1966. Distribution and abundance of sardine and anchovy larvae in the California current region off California and Baja California, 1951-64: A summary. U.S. Fish Wildl. Serv., Special Scientific Rep. Fisheries No. 534, 71 p.

Ahlstrom, E.H., 1969. Distributional atlas of fish larvae in the California current region: Jack mackerel, *Trachurus symmetricus*, and Pacific hake, *Merluccius productus* 1951 through 1966. CalCOFI no 11.

Ahlstrom, E.H. and H.G. Moser, 1975. Distributional atlas of fish larvae in the California current region: flat fishes, 1955 through 1960. CalCOFI No 23. 207 p.

Ahlstrom, E.H., H.G. Moser, and E.M. Sandknop, 1978. Distributional atlas of fish larvae in the California current region: Rockfishes, *Sebastes* spp., 1950 through 1975. CalCOFI Atlas, No. 26.

Alton, M.S., 1972. Characteristics of the demersal fish fauna inhabiting the outer continental shelf and slope off the Northern Oregon Coast. IN The Columbia River Estuary and adjacent ocean waters. Ed. A.T. Pruter and D.L. Alvers. p. 553-634.

Ault, J.S., 1985. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) --black, green and red abalones. U.S. Army Corps of Engineers, TR EL-82-4. 19 p.

Bolton, M.L. and R.E. Loveland, 1989. Reproductive risk: high mortality associated with spawning by horseshoe crabs (*Limulus polyphemus*) in Delaware Bay, USA. Mar. Bio. 101:143-151.

Bonar, S.A., G.B. Pauley and G.L. Thomas, 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) pink salmon. U.S. Fish. Wildl. Serv., Biol. Rep. 82(11.88) U.S. Army Corps of Engineers TR EL-82-4. 18 p.

Boreman, J. and R.J. Seagraves, 1984. Status of weakfish along the Atlantic Coast, 1984. Woods Hole Laboratory Reference Document no. 84-19.

Bryant, T.L. and J.R. Pennock, 1988. The Delaware Estuary: Rediscovering a forgotten resource. Univ. Del. Sea Grant Program. 144 p.

Burger, J. 1983. Jamaica Bay Studies III: Abiotic determinants of distribution and abundance of gulls (*Larus*). Est. Coast. Shelf Sci. 16:191-216.

California Department of Fish and Game, 1969a. Progress report on wildlife affected by the Santa Barbara Channel oil spill January 28- March 31, 1969. State of California, Dept. Fish. Game, Terminal Island, Marine Resource Operations.

California Department of Fish and Game, 1969b. Second progress report on wildlife affected by the Santa Barbara Channel Oil spill April 1- May 31, 1969. State of California, Dept. Fish. Game, Terminal Island, Marine Resource Operations.

Cheney, D.P. and T.F. Mumford, Jr., 1986. Shellfish and seaweed harvests of Puget Sound. Washington Sea Grant, University of Washington Press. 164 p.

Chesmore, A.P., S.A. Testaverde, and F.P. Richards, 1971. A study of the marine resources of Dorchester Bay. Mass. Dept. of Natural Resources, Div. Mar. Fish. 44 p.

Conte, M.H., R.G. Otto, P.E. Miller, 1978. Short-term variability in surface catches of ichthyoplankton in the upper Chesapeake Bay. Chesapeake Bay Institute, The John Hopkins University. Reference 78-4. Special Report 64. 22 p.

Darnell, R.M., R.E. Detenbaugh and D. Moore. 1982. Northwestern Gulf Shelf Bio-Atlas, 1983. Minerals Management Service, Department of Interior, Metaire, LA. Open File Report 82-04.

Dovel, W.L. 1981. Ichthyoplankton of the lower Hudson Estuary, New York. New York Fish. Game. J. 28(1): 21-39.

Dugas, R.J., 1977. Oyster distribution and density of the productive portion of the state seed grounds in Southeastern Louisiana. Louisiana Dept. of Wildl. Fish, Tech. Bull. No. 23. 27p.

Durbin, A.G. and E.G. Durbin, 1990. Zooplankton and ichthyoplankton in Narragansett Bay: Status and trends, Part 2: Ichthyoplankton. Narragansett Bay Project, Current Report #NBP-90-27.

Epifanio, C.E., C.C. Valenti, and A.E. Pembroke, 1984. Dispersal and recruitment of blue crab larvae in Delaware Bay, USA. Est. Coast. Shelf Sci. 18: 1-12.

Epifanio, C.E., A.K. Masse, and R.W. Garvine, 1989. Transport of blue crab larvae by surface currents off Delaware Bay, USA. Mar. Ecol. Prog. Ser. 54: 35-41.

Estrella, B. 1990. Mass. Div. of Fish., Sandwich, MA. personal communication.

Ettinger, W.S. and R.W. Blye, jr., 1981. Occurrence of the blue crab *Callinectes sapidus* in the tidal freshwater reaches of the Delaware and Schuylkill Rivers in 1976. J. Crustacean Biology 1(2):177-182.

Fay, C.W., R.J. Neues, and G.B. Pardue, 1983a. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic): Atlantic silversides. U.S. Fish Wildl. Serv. Div. Biol. Serv. FWS/OBS-82/11.10. U.S. Army Corps of Engineers, TR EL-82-4. 15 p.

Fay, C.W., R.J. Neues and G.B. Pardue, 1983b. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic): Bay Scallop. U.S. Fish Wildl. Serv. Div. Biol. Serv. FWS/OBS-82/11.12. U.S. Army Corps of Engineers, TR EL-82-4. 17 p.

Fefer, S.I. and P.A. Schetting, 1980. An ecological characterization of coastal Maine. FWS/OBS-80/29, Atlas Map 4, fish and wildlife, Region 1, Map 5.

Fisherman's Report, 1990. Bottom trawl survey, Cape Hatteras- Western Scotian Shelf. March 5- April 18, 1990. R/V Delaware II. NMFS, Northeast Fisheries Center.

Fisherman's Report, 1989a. Bottom trawl survey, Cape Hatteras- Western Scotian Shelf. February 27- April 13, 1989. R/V Delaware II. NMFS, Northeast Fisheries Center.

Fisherman's Report, 1989b. Bottom trawl survey, Cape Hatterras- Western Scotian Shelf, September 11- November 2, 1989. R/V Delaware II. NMFS, Northeast Fisheries Center.

Flomar, L.C., 1990. U.S. Environmental Protection Agency ERL-Gulf Breeze, personal communication. (Fish life history and weights of Gulf of Mexico fishes).

Flores-Coto, C., F. Barva-Torres, and J. Sanchez-Robles, 1983. Seasonal diversity, abundance and distribution of ichthyoplankton in Tamiahua Lagoon, Western Gulf of Mexico. Amer. Fish. Soc. Trans. 112:247-256.

Fogarty, M.J., M.A. Hyman and C.A. Griscom, 1979. The seasonal distribution of lobster (*Homarus americanus*) larvae in Block Island Sound 1978. Office of Federal Aid, NMFS, State Fish Pier, Gloucester, MA. Project 3-286-R. 33 p.

Gifford, D. 1990. Alyeska Tactical Oilspill Model, Biological Data Base. 1990 ASA Report to Alyeska Pipeline Co.

Gonyea, G.P. 1985. Abundance of Pacific herring in central and southern Puget Sound. State of Washington, Dept. Fish. Tech. Rep No. 87. 77 p.

Goodwin, L. and B. Pease, 1987. The distribution of geoduck (*Panope abrupta*) size, density, and quality in relation to habitat characteristics such as geographic area water depth, sediment type and associated flora and fauna in Puget Sound, Washington. State of Washington, Dept. Fish. Tech. Rep. No. 102. 44 p.

Gosselink, J.G., 1984. The ecology of delta marshes of coastal Louisiana: A community profile. U.S. Fish Wildl. Serv. FWS/OBS-84/09. 134 p.

Hammerschmidt, P.S., 1985. Relative blue crab abundance in Texas coastal waters. J. Shellfish Res. 5(1):9-11.

Harbors Environmental Projects, 1979. Ecological changes in Outer Los Angeles- Long Beach Harbors following initiation of secondary waste treatment and cessation of fish cannery waste effluent. Ed. D.F. Soule and M. Oguri. IN Marine Studies of San Pedro Bay, CA. Part 16. Sea Grant SCU-T-79-001. 597 p.

Hatch, J. 1990. University of Mass.- Boston. Dept. of Biology. personal communication.

Henny, C.J., M.M. Smith, and V.D. Stolts, 1974. The 1973 distribution and abundance of breeding ospreys in the Chesapeake Bay. Ches. Sci. 15:125-133.

Herman, S.S., 1963. Planktonic fish eggs and larvae of Narragansett Bay. Limnol. Ocean. 8(1):103-109.

Hewitt, R., 1980. Distributional atlas of fish larvae in the California current region: northern anchovy: *Engraulis mordax* (Girara), 1966 through 1979. CalCOFI Atlas, No. 28. 101 p.

Holland, G.A., 1969. Age, growth, and mortality of races of english sole (*Parophrys vetulus*) in Puget Sound, Washington. Pac. Mar. Fish. Comm. Bull. 7: 35-50.

Hornick, H.T., 1988. Stock assessment of blue crabs (*Callinectes sapidus*) and weakfish (*Cynoscion regalis*) in Maryland's Chesapeake Bay. Final Report FY 1986. A cooperative agreement between NOAA and the State of Maryland for the conduct of a cooperative program to assess the status of the fishery resources of the Cheaspeake Bay.

Hornig, S., A. Sterling and S.D. Smith, 1989. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest):

ghost shrimp and blue mud shrimp. U.S. Fish. Wildl. Serv., Biol. Rep. 82(11.93). U.S. Army Corps of Engineers. TR EL-82-4. 14 p.

Houde, E.D. and J.A. Loudal, 1984. Seasonality of occurrence, foods and food preferences of ichthyoplankton in Biscayne Bay, FL. Estuar. Coast. Shelf Sci. 18: 403-419.

Hyle, R.A., 1971. Fishes of pond and creek systems. IN Structure and functioning of estuarine ecosystems exposed to treated sewage waters. ED. E.J. Kuenzler and A.F. Chestnut. Sea Grant NCU-Q-71-001, 285-296 p.

Jeffries, S.J. and M.L. Johnson, 1990. Population status of the harbor seal, *Phoca vitulina richardsi* in the water of the State of Washington: 1975-1980. Final Report to the U.S. Marine Mammal Commission for Contract MM7AC030. 69 p.

Kassner, J. 1987. Hard clam (*Mercenaria mercenaria*) abundance in eastern Great South Bay, Long Island, New York: population distribution and structure. J. Shellfish Res. 7(1):165-166.

Kelley, S., J.V. Gartner jr, W.J. Richards and L. Ejsymont, 1990. SEAMAP 1986-ICHTHYOPLANKTON: Larval distribution and abundance of Engraulidiae, Carangidae, Clupeidae, Gobiidae, Lutjanidae, Serranidae, Coryphaenidae, Istiophoridae, and Scombridae in the Gulf of Mexico. NMFS-SEFC-245. 45 p.

Keller, A. 1990. Alyeska Tactical Oilspill Model, Biological Data Base. 1990 ASA Report to Alyeska Pipeline Co.

Kleckner, R.C. and J.D. McCleaves, 1982. Entry of migrating American eel leptocephali into the Gulf Stream system. Helgolander Meeresuntersuchungen 35: 329-339.

Loeb, V.J., P.E. Smith, and H.G. Moser, 1983. Ichthyoplankton and zooplankton abundance patterns in the California current area, 1975. CalCOFI Vol 24. 109-164 p.

Lombardo, R., 1982. A review of commercial fisheries data: Tampa Bay, Florida. IN Proceedings : Tampa Bay Area Scientific information Symposium. Eds. S.F. Treat, J.L. Simon, R.R. Lewis III, R.L. Whitman Jr. Florida Sea Grant, Rep. No. 65. 614-634 p.

Lux, F.E. and G.F. Kelly, 1978. Fisheries resources of the Cape Cod and Massachusetts Bay Region. Environmental Assessment Report 5-78. Laboratory Reference No. 78-15. NMFS, Northeast Fisheries Center.

Lux, F.E. and G.F. Kelly, 1982. Ichthyoplankton studies of Cape Cod and Massachusetts Bay, 1976-77. Northeast Fisheries Center, NMFS, Woods Hole Laboratory, reference document No. 81-43.

Lyczhowski-Laroche, J. and S.L. Richardson, 1979. Winter-spring abundance of larval english sole, *Parophrys vetulus*, between the Columbia River and Cape Blanco, Oregon during 1972-1975 with notes on occurrences of three other Pleuronectids. Estuar. Coast. Mar. Sci. 8:455-476.

Mathews, K.R., B.S. Miller, and T.P. Quinn, 1986. Movement studies of nearshore demersal rockfishes in Puget Sound, Washington. IN Proceedings of the International Rockfish Symposium. Alaska Sea Grant Report. No. 87-2.

McGowan, M.F., 1986. Northern anchovy, *Engraulis mordax*, spawning in San Francisco Bay, California, 1978-79, relative to hydrography and zooplankton prey of adults and larvae. Fish. Bull. 84(4):879-894.

McGowan, M.F. and W.J. Richards, 1989. Bluefin tuna, *Thunnus thynnus*, larvae in the Gulf Stream off the southeastern United States: satellite and shipboard observations of their environment. Fish. Bull. 87:615-631.

Mearns, A.J., D.R. Young, R.J. Olson and H.A. Schafer, 1981. Trophic structure and the cesium-potassium ratio in pelagic ecosystems. CalCOFI Vol. 22, p. 99-110.

McEachron, J.D., J.H. Finucane, and L.S. Hall. Distribution, seasonality and abundance of king and spanish mackerel larvae in the Northwestern Gulf of Mexico (Pisces: Scombridae). Northeast Gulf Science 4(1):1-16.

Miller, R.E., S.D. Sulkin, and R.L. Lippson, 1975. Composition and seasonal abundance of the blue crab, *Callinectes sapidus* Rathun, in the Chesapeake and Delaware Canal and adjacent waters. Chesapeake Sci. 16(1): 27-31.

Monaco, M.E., D.M. Nelson, T.E. Czapla, and M.E. Paltillo, 1989. Distribution and abundance of fishes and invertebrates in Texas estuaries. ELMR Report No. 3 Strategic Assessment Branch, NOS/NOAA Rockville, MD. 107 p.

Monteleone, D.M., W.T. Peterson, and G.C. Williams, 1987. Interannual fluctuation is the density of sand lance *Ammodytes americanus*, larvae in Long Island Sound, 1951-1983. Estuaries 10(3):254-264.

Moulton, L.L. and B.S. Miller, 1987. Characterization of Puget Sound marine fishes: survey of available data. Washington Sea Grant Program. FRI-UW-8716.

NUSCo (Northeast Utilities Service Company), 1984. Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station, Waterford, Connecticut. Annual Report, 1983.

Olney, J.E., 1983. Eggs and early larvae of the bay anchovy, *Anchoa mitchilli*, and the weakfish, *Cynoscion regalis*, in lower Cheapeake Bay with notes on associated ichthyoplankton. Estuaries 6(1):20-35.

Onuf, C.P. M.L. Quammen, G.P. Shaffer, C.H. Peterson, J.W. Chapman, J. Cermak, and R.W. Holmes, 1978. An analysis of the values of central and southern California coastal wetlands, IN Wetland functions and values: The state of our understanding. Eds. P.E, Greeson, J.R. Clark and J.E. Clark, p. 186-199.

Oviatt, C.A. and S.W. Nixon, 1973. The demersal fish of Narragansett Bay: an analysis of community structure, distribution, and abundance. Est. Coast. Mar. Sci. 1:361-378.

Palmisano, A.W., 1973. Habitat preference of waterfowl and fur animals in the Northern Gulf Coast marshes. IN Coastal Marsh and Estuary Management Symposium Proceedings, Second. Ed. R.H. Chabreck. 163-190 p.

Parnell, J.F. and R.F. Soots, Jr. 1979. Atlas of colonial waterbirds of North Carolina estuaries. UNC Sea Grant NCU-C-79-001. 269 p.

Patten, B.G., 1973. Biological information on copper rockfish in Puget Sound, Washington. Amer. Fish. Soc. Trans. 102(2):412-416.

Paul, R.T. and G.E. Woolfenden, 1982. Current Status and recent trends in bird populations of Tampa Bay. IN Proceedings: Tampa Bay Area Scientific information Symposium. Eds. S.F. Treat, J.L. Simon, R.R. Lewis III, R.L. Whitman Jr. Florida Sea Grant, Rep. No. 65. 426-447 pp.

Pearcy, W.G., M.J. Hosie, and S.L. Richarson, 1977. Distribution and duration of pelagic life of larvae of dover sole, *microstomus pacificus*; rex sole, *Glyptocephlus zachirus*; and petrale sole, *Epsetta jordani*, in waters off Oregon. Fish. Bull. 75(1): 173-183

Pearcy, W.G. 1980. Distribution and ecology of oceanic animals off Oregon. IN The Columbia River Estuary and adjacent ocean waters. Eds. A.T. Pruter and D.L. Alverson. 351-373pp.

Perry, M.C., 1987. Waterfowl of Cheapeake Bay. IN Contaminant problems and management of living Chesapeake Bay Resources, Ed S.K. Majumdar, L.W. Hall Jr., and H.M. Austin. 94-115 p.

Portnoy, J.W., 1977. Nesting colonies of seabirds and wading birds. Coastal Louisiana, Mississippi, and Alabama. U.S. Fish Wildl. Ser. FWS/OBS-77/07. 126 p.

Powers, K.D., 1983. Pelagic distribution of marine birds off the northeastern United States. NOAA Tech. MEM. NMFS-F/NEC-27. 201 p.

Powles, H. and B.W. Stender, 1976. Observations on composition, seasonality and distribution of ichthyoplankton from MARMAP cruises in the South Atlantic Bight in 1973. South Carolina Marine Resources Center, Tech. Rep. Ser. #11, 47 pp.

Pruter, A.T., 1954. Age and growth of the Oregon sable fish, *Anoplopoma fimbria*. Pac. Mar. Fish. Comm. 3: 122-128.

Richarson, S.L. and W.G. Pearcy, 1977. Coastal and oceanic fish larvae in all area of upwelling off Yaquina Bay, Oregon. Fish. Bull. 75(1):125-145.

Shaw, R.F., J.H. Cowan Jr. and T.L. Tillman, 1985. Distribution and density of *Brevooria patronus* (gulf menhaden) eggs and larvae in the continental shelf waters of Western Louisiana. Bull. Mar. Sci. 36(1):96-103.

Sager, D.R., 1987. Distribution of larval gizzard shad in the upper Cape Fear River, North Carolina. Amer. Fish. Society Symposium 2: 174-178.

Science Applications, Inc. 1979. Lower Cook Inlet interim synthesis report, environmental assessment of the Alaskan continental shelf. NOAA-OCSEAP, 241 p.

Shuler, V.J., 1971. An ecological study of the Delaware River in the vicinity of Artificial Island, progress report for the period January - December, 1970. Ichthyological Associates, Delaware Progress Report 3 (Part I). Ithaca, N.Y.

Smith, J.W. and C.A. Wenner, 1985. Biology of the southern kingfish in the South Atlantic Bight. Amer. Fish. Soc. Trans. 114: 356-366.

Smith, W.G., 1988. A comparison of informational content from trawl and ichthyoplankton surveys. IN An analysis and evaluation of ichthyoplankton survey data from the N.E. continental shelf ecosystem. Ed. W.G. Smith. NOAA Tech. Mem. NMFS-F/NEC-57. p. 19-25.

Solomon, F. and M.L. Mills, 1983. Location, harvest, and economic values of salmon, bait fish, ground fish, and shellfish resources, summarized from the WDF-sponsored testimony in the northern Tier pipeline case (proposed cross sound route) with updated figures of 1979 and 1980. State of Washington, Dept. Fish., Tech. Rep, No. 76. 136 p.

Sowls, A.L., A.R. DeFange, J.W. Nelson, and G.S. Lester 1980. Catalog of California seabird colonies. Bureau of Land Management, U.S. Fish. Wildl. Serv. FWS/OBS-80/37. 371 p.

Stanley, J.G., 1982. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic): hard clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.41) U.S. Army Corps of Engineer, TR EL-82-4. 24 p.

Stephens, J.S. jr, C. Terry, and M.J. Allen, 1973. Abundance, distribution, seasonality and productivity of the fish populations in Los Angeles Harbor, 1972-73. Marine Studies of San Pedro Bay, California. Part IV. Ed. D. Soule and M. Oguri. Sea Grant SCU-T-74-003. 101 p.

Sullivan, L.F., 1985. Standing stock of juvenile brown shrimp, *Penaeus aztecus* in Texas coastal ponds. Fish. Bull. 83(4): 677-681.

Sykes, J.E. and J.H. Finucane, 1965. Occurrence in Tampa Bay, Florida of immature species dominant in Gulf of Mexico commercial fisheries. Fish. Bull. 65(2): 369-379.

Townsend, D.W., 1984. Comparison of inshore zooplankton and ichthyoplankton populations of the Gulf of Maine. Mar. Eco. Prog. Ser. 15: 79-90.

Texas Instruments Incorporated, 1976. Fisheries survey of the Hudson River, March - December, 1973. Volume IV. Prepared for Consolidated Edison Company of New York, Inc.

Van Cleve, R. and S.Z. El-Sayed, 1969. Age, growth, and productivity of an English sole (*Parophyrys vetulus*) population in Puget Sound, Washington. Pac. Mar. Fish. Comm. Bull. 7:52-71.

Waldron, K.D., 1972. Fish larvae collected from the northeastern Pacific Ocean and Puget Sound during April and May 1967. NOAA Technical Report, NMFS SSRF-663. 16 p.

Wang, J.C.S., 1971. A report on fishes taken in the Chesapeake and Delaware Canal and contiguous waters. IN An ecological study of the Delaware River in the vicinity of Artificial Island. Part II. 108 p.

Weinberg, K.L., M.E. Wilkins and T.A. Dark, 1984. The 1983 Pacific west coast bottom trawl survey of ground fish resources: Estimates of distribution, abundance, age, and length composition. NOAA Technical Memorandum NMFS-F/NWC-70. 376 p.

Weiss, W.R. and T.D. Phillips, 1982. The meroplankton of Tampa Bay. IN Proceedings : Tampa Bay Area Scientific Information Symposium. Eds. S.F. Treat, J.L. Simon, R.R. Lewis III, R.L. Whitman Jr. Florida Sea Grant, Rep. No. 65. 345-383 p.

Wenner, E.L. and C.A. Wenner, 1988. Seasonal composition, distribution, and relative abundance of decapod and stomatopod crustaceans from coastal habitats, southeastern United States. Fish. Bull. 87:155-176.

Wenner, C.A. and G.R. Sedberry, 1989. Species composition, distribution and relative abundance of fishes in the coastal habitat off the southeastern United States. NOAA Tech. Rep. NMFS 79, 49 p.

Werner, C.A., C.A. Barans, B.W. Stender and F.J. Berry, 1979. Results of MARMAP otter trawl investigations in the South Atlantic Bight IV, winter-early spring, 1975. South Carolina Marine Resources Center, Technical Report 44. 59 p.

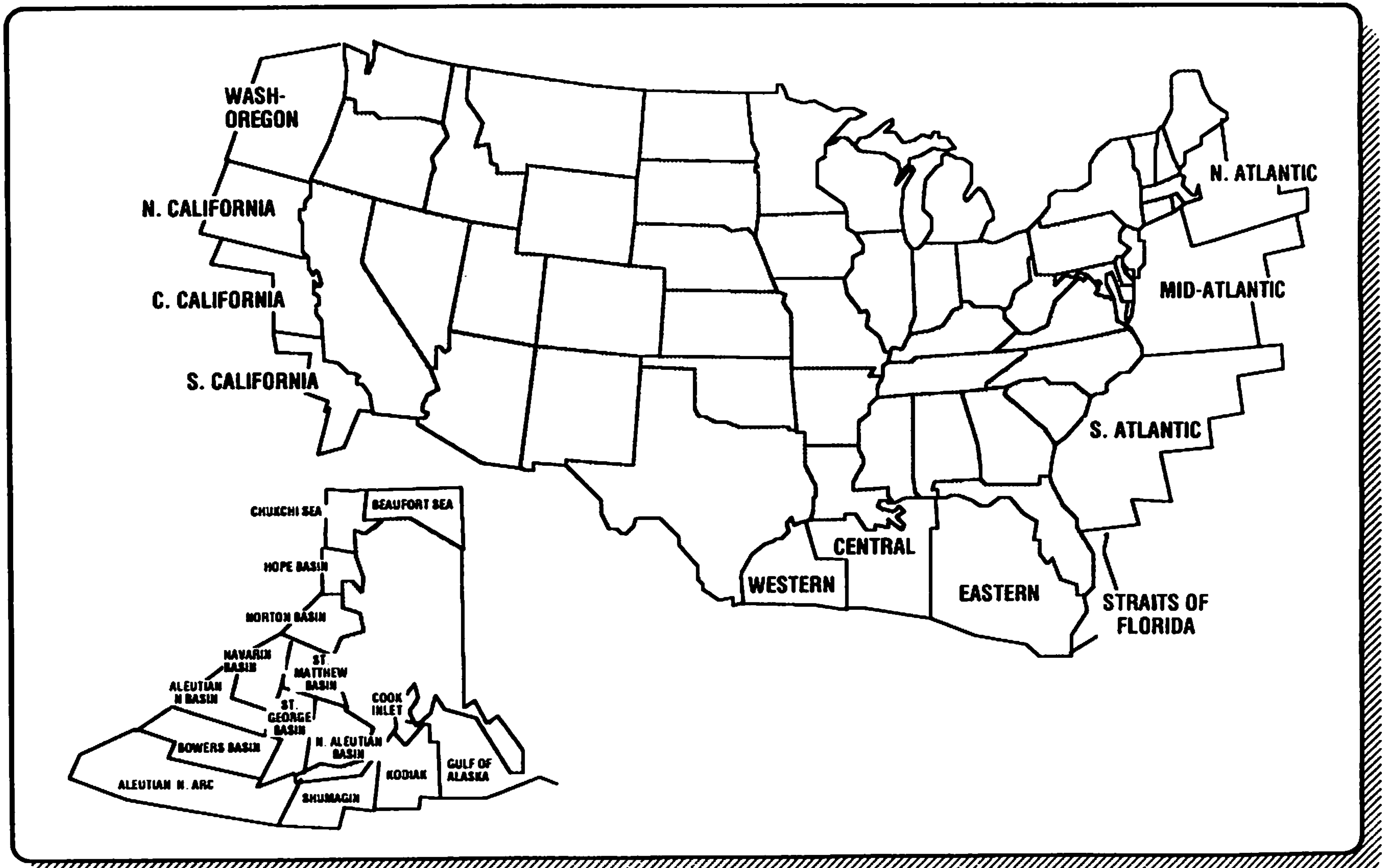
Werner, C.A., C.A. Barans, B.W. Stender and F.J. Berry, 1979. Results of MARMAP otter trawl investigations in the South Atlantic Bight V, summer 1975. South Carolina Marine Resources Center, Technical Report 45. 57 p.

Wheatland, S.B., 1955. Oceanography of Long Island Sound, 1952-1954 VII. pleagic fish eggs and larvae. Bull. of Bingham Oceanographic Collection 15:234-310.

Wilkens, E.P.H. and R.M. Lewis, 1971. Abundance and distribution of young Atlantic menhaden, *Brevoortia tyrannus*, in the White Oak River Estuary, North Carolina. Fish Bull. 69(4): 783-789.

APPENDIX 6-F
MAP OF OCS PLANNING AREAS

Location of Planning Areas For 5-Year OCS Oil And Gas Leasing Program



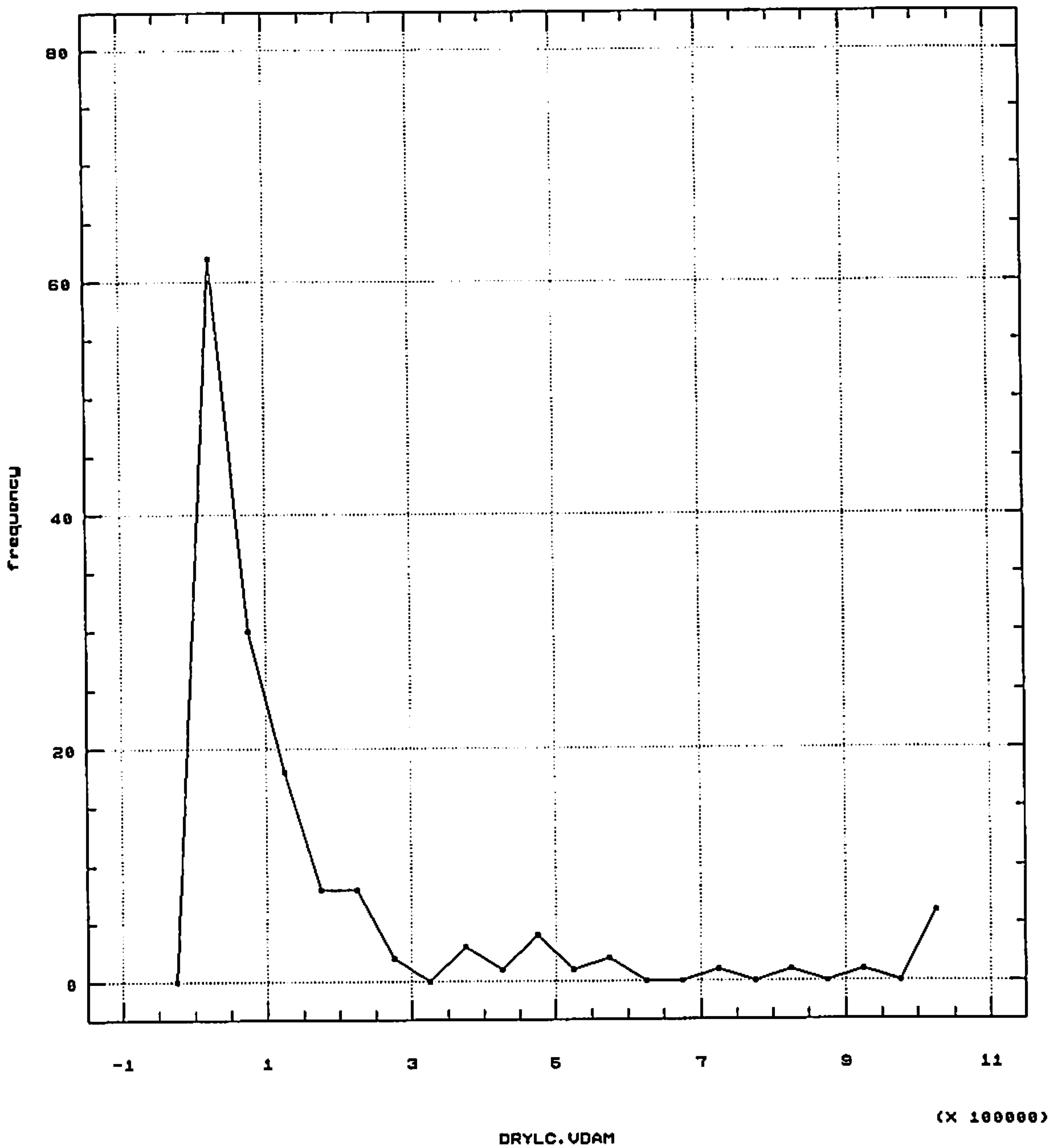
APPENDIX 6-G
WORKSHEET FOR DEVELOPMENT OF PROPERTY VALUE LOSSES BY STUDY ZONE

PORT NAME	LOSS PER BARREL OIL	LOSS PER BRL PRODUCT	VALUE PER FRONT FT	% PRIVATE	LOSS PER FT	FT PER BARREL
Boston	614	460	3,500	40%	38.4	16
Puget Sound	2,104	1,578	6,000	80%	131.5	16
Los Angeles	10,522	7,891	30,000	80%	657.6	16
Santa Barbara	10,522	7,891	30,000	80%	657.6	16
Port Arthur	140	105	800	40%	8.8	16
New Orleans	70	53	400	40%	4.4	16
Houston/Galveston	526	395	1,500	80%	32.9	16
Chesapeake South	701	526	2,000	80%	43.8	16
Chesapeake North	701	526	2,000	80%	43.8	16
Corpus Christi	701	526	2,000	80%	43.8	16
New York City	614	460	3,500	40%	38.4	16
Long Island Sound	1,228	921	3,500	80%	76.7	16
Philadelphia/Del Bay	701	526	2,000	80%	43.8	16
San Francisco	1,403	1,052	8,000	40%	87.7	16
Portland, OR	2,104	1,578	6,000	80%	131.5	16
Cook Inlet	140	105	400	80%	8.8	16
Portland, ME	701	526	2,000	80%	43.8	16
Portsmouth	701	526	2,000	80%	43.8	16
Providence	1,228	921	3,500	80%	76.7	16
Wilmington	526	395	1,500	80%	32.9	16
Jacksonville	526	395	1,500	80%	32.9	16
Tampa	2,104	1,578	6,000	80%	131.5	16
Mobile	526	395	1,500	80%	32.9	16

APPENDIX 6-H
SAMPLE GRAPHS AND TABLES FOR THREE VESSEL TYPES USED IN VESSEL DAMAGE ANALYSIS

Frequency Polygon

EXAMPLE OF TABULATIONS AND GRAPHS FOR LARGE DRY CARGO VESSEL COLLISIONS



Percentiles

Data vector: DRYLC.VDAM

Percentages		Percentiles
50	=	62500
85	=	248175
99	=	3.65

DRYLGC - P. 1 Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below	.0E0000			0	.00000	0	.000
1	.0E0000	5.0E0004	25000.00	62	.41892	62	.419
2	5.0E0004	1.0E0005	75000.00	30	.20270	92	.622
3	1.0E0005	1.5E0005	125000.00	18	.12162	110	.743
4	1.5E0005	2.0E0005	175000.00	8	.05405	118	.797
5	2.0E0005	2.5E0005	225000.00	8	.05405	126	.851
6	2.5E0005	3.0E0005	275000.00	2	.01351	128	.865
7	3.0E0005	3.5E0005	325000.00	0	.00000	128	.865
8	3.5E0005	4.0E0005	375000.00	3	.02027	131	.885
9	4.0E0005	4.5E0005	425000.00	1	.00676	132	.892
10	4.5E0005	5.0E0005	475000.00	4	.02703	136	.919
11	5.0E0005	5.5E0005	525000.00	1	.00676	137	.926
12	5.5E0005	6.0E0005	575000.00	2	.01351	139	.939
13	6.0E0005	6.5E0005	625000.00	0	.00000	139	.939

Mean = 219995 Standard Deviation = 625552 Median = 62500

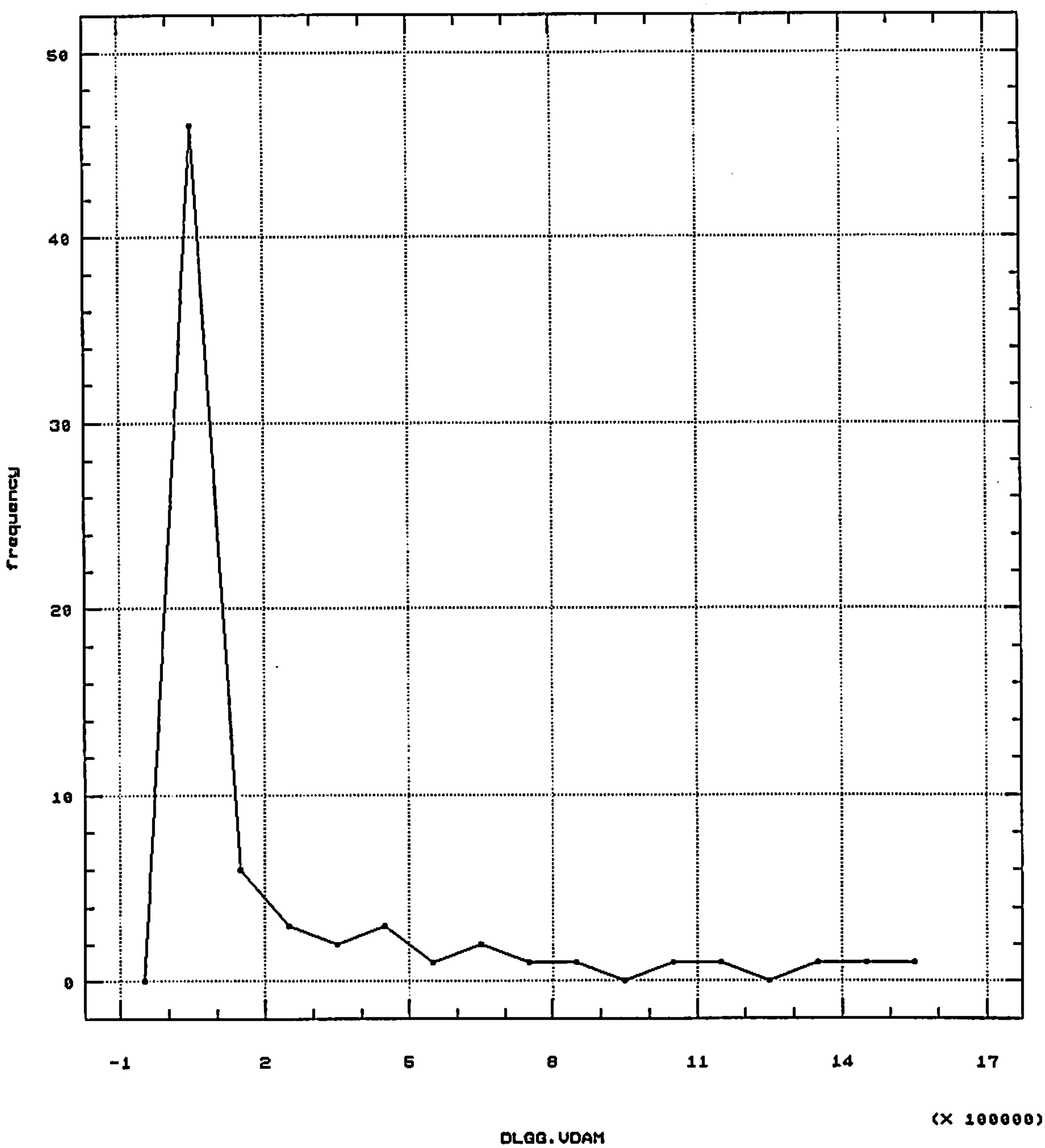
DRYLGC, P. 2 Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
14	6.5E0005	7.0E0005	675000.00	0	.00000	139	.939
15	7.0E0005	7.5E0005	725000.00	1	.00676	140	.946
16	7.5E0005	8.0E0005	775000.00	0	.00000	140	.946
17	8.0E0005	8.5E0005	825000.00	1	.00676	141	.953
18	8.5E0005	9.0E0005	875000.00	0	.00000	141	.953
19	9.0E0005	9.5E0005	925000.00	1	.00676	142	.959
20	9.5E0005	1.0E0006	975000.00	0	.00000	142	.959
above	1.0E0006			6	.04054	148	1.000

Mean = 219995 Standard Deviation = 625552 Median = 62500

Frequency Polygon

EXAMPLE OF TABULATIONS AND GRAPHS FOR LARGE DRY CARGO VESSEL GROUNDINGS



Percentiles

Data vector: DLGG.VDAM

Percentages		Percentiles
95	=	1.12
35	=	23140
80	=	344688

DLGG Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.0E0000		0	.0000	0	.000
1	.0E0000	1.0E0005	5.0E0004	46	.6571	46	.657
2	1.0E0005	2.0E0005	1.5E0005	6	.0857	52	.743
3	2.0E0005	3.0E0005	2.5E0005	3	.0429	55	.786
4	3.0E0005	4.0E0005	3.5E0005	2	.0286	57	.814
5	4.0E0005	5.0E0005	4.5E0005	3	.0429	60	.857
6	5.0E0005	6.0E0005	5.5E0005	1	.0143	61	.871
7	6.0E0005	7.0E0005	6.5E0005	2	.0286	63	.900
8	7.0E0005	8.0E0005	7.5E0005	1	.0143	64	.914
9	8.0E0005	9.0E0005	8.5E0005	1	.0143	65	.929
10	9.0E0005	1.0E0006	9.5E0005	0	.0000	65	.929
11	1.0E0006	1.1E0006	1.1E0006	1	.0143	66	.943
12	1.1E0006	1.2E0006	1.2E0006	1	.0143	67	.957
13	1.2E0006	1.3E0006	1.3E0006	0	.0000	67	.957

Mean = 213864 Standard Deviation = 377929 Median = 45755.5

DLGG, P. 2 Frequency Tabulation

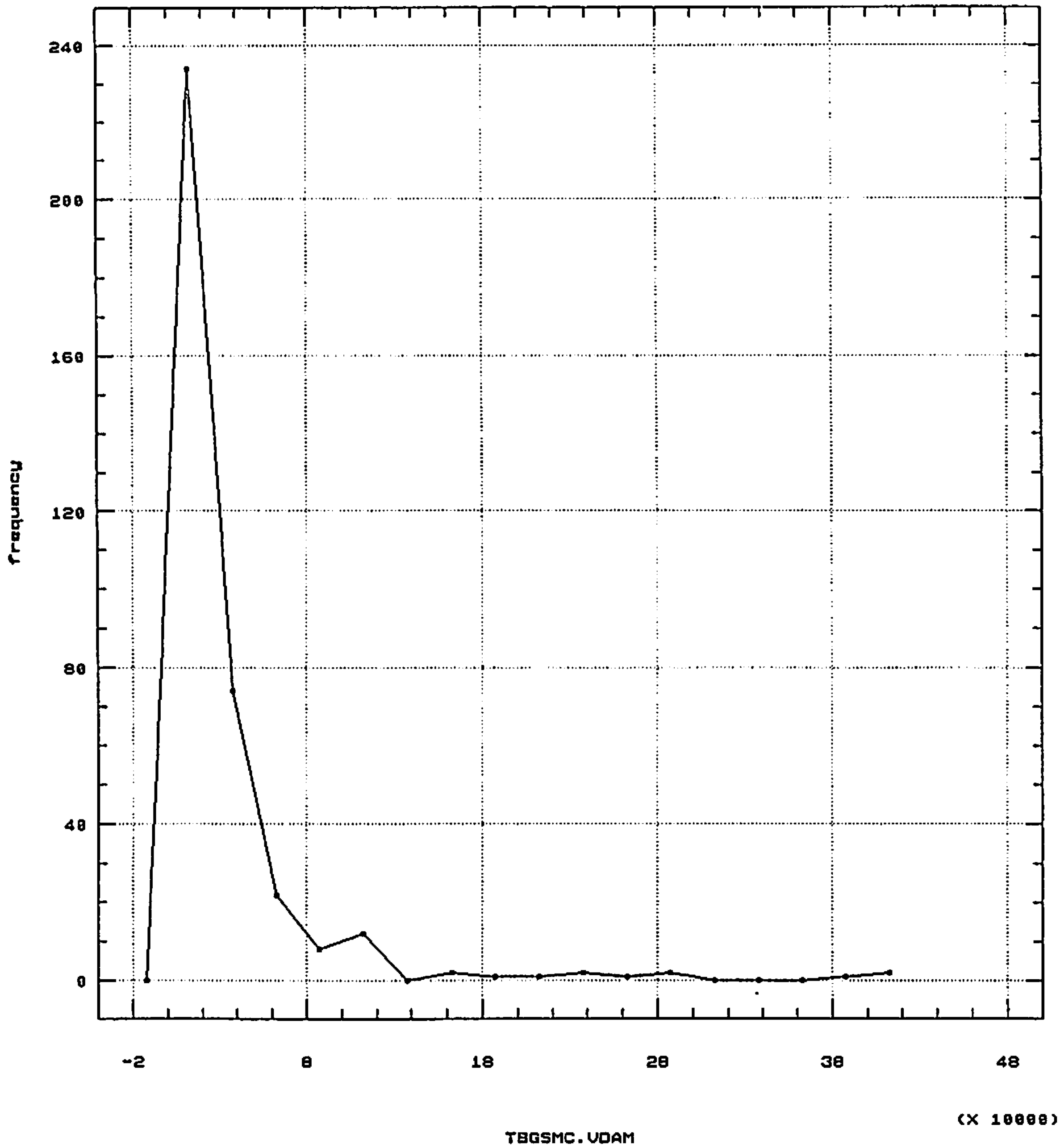
Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
14	1.3E0006	1.4E0006	1.4E0006	1	.0143	68	.971
15	1.4E0006	1.5E0006	1.5E0006	1	.0143	69	.986
above	1.5E0006			1	.0143	70	1.000

Mean = 213864 Standard Deviation = 377929 Median = 45755.5

Variable:	DLGG.VDAM
Sample size	70
Average	213864
Median	45755.7
Mode	23140
Geometric mean	41686.3
Variance	1.42831E11
Standard deviation	377929
Standard error	45171.2
Minimum	210.2
Maximum	1.8E6
Range	1.79979E6
Lower quartile	11270
Upper quartile	206910
Interquartile range	195640

Frequency Polygon

EXAMPLE OF TABULATIONS AND GRAPHS FOR SMALL TANK BARGE COLLISIONS



Percentiles

Data vector: TBGSMC.VDAM

Percentages		Percentiles
70	=	30000
95	=	112700
99	=	294500

TKBGSMC, P. 1 Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
at or below		.00		0	.00000	0	.000
1	.00	25000.00	12500.00	234	.64641	234	.646
2	25000.00	50000.00	37500.00	74	.20442	308	.851
3	50000.00	75000.00	62500.00	22	.06077	330	.912
4	75000.00	100000.00	87500.00	8	.02210	338	.934
5	100000.00	125000.00	112500.00	12	.03315	350	.967
6	125000.00	150000.00	137500.00	0	.00000	350	.967
7	150000.00	175000.00	162500.00	2	.00552	352	.972
8	175000.00	200000.00	187500.00	1	.00276	353	.975
9	200000.00	225000.00	212500.00	1	.00276	354	.978
10	225000.00	250000.00	237500.00	2	.00552	356	.983
11	250000.00	275000.00	262500.00	1	.00276	357	.986
12	275000.00	300000.00	287500.00	2	.00552	359	.992
13	300000.00	325000.00	312500.00	0	.00000	359	.992

Mean = 35950.7 Standard Deviation = 105758 Median = 15043.8

TKBGSMC, P, 2 Frequency Tabulation

Class	Lower Limit	Upper Limit	Midpoint	Frequency	Relative Frequency	Cumulative Frequency	Cum. Rel. Frequency
14	325000.00	350000.00	337500.00	0	.00000	359	.992
15	350000.00	375000.00	362500.00	0	.00000	359	.992
16	375000.00	400000.00	387500.00	1	.00276	360	.994
above	400000.00			2	.00552	362	1.000

Mean = 35950.7 Standard Deviation = 105758 Median = 15043.8

APPENDIX 6-I
SEVERITY RANGES FOR VESSEL DAMAGE BY VESSEL TYPE

RANGE OF VESSEL DAMAGES
(000)

VESSEL TYPE	VESSEL DRAFT	CASUALTY TYPE	SEVERITY	RANGE/K
DRY BARGE	<19		T	N/A
DRY BARGE	<19	C	L	<50
DRY BARGE	<19	C	M	50-150
DRY BARGE	<19	C	S	>150
DRY BARGE	<19	G	L	<25
DRY BARGE	<19	G	M	25-100
DRY BARGE	<19	G	S	>100
DRY BARGE	>18		T	N/A
DRY BARGE	>18	C	L	<75
DRY BARGE	>18	C	M	75-200
DRY BARGE	>18	C	S	>200
DRY BARGE	>18	G	L	<75
DRY BARGE	>18	G	M	75-200
DRY BARGE	>18	G	S	>200
DRY CARGO	19-29		T	N/A
DRY CARGO	19-29	C	L	<100
DRY CARGO	19-29	C	M	100-500
DRY CARGO	19-29	C	S	>500
DRY CARGO	19-29	G	L	<100
DRY CARGO	19-29	G	M	100-500
DRY CARGO	19-29	G	S	>500
DRY CARGO	<19		T	N/A
DRY CARGO	<19	C	L	30
DRY CARGO	<19	C	M	30-100
DRY CARGO	<19	C	S	>100
DRY CARGO	<19	G	L	<100
DRY CARGO	<19	G	M	100-400
DRY CARGO	<19	G	S	>400
DRY CARGO	>30		T	N/A
DRY CARGO	>30	C	L	<150
DRY CARGO	>30	C	M	150-500
DRY CARGO	>30	C	S	>500
DRY CARGO	>30	G	L	<100
DRY CARGO	>30	G	M	100-1000
DRY CARGO	>30	G	S	>1000
FISHING			T	N/A
FISHING		C	L	<25
FISHING		C	M	25-100
FISHING		C	S	>100
FISHING		G	L	<25
FISHING		G	M	25-200
FISHING		G	S	>200
OTHER			T	N/A
OTHER		C	L	<50

RANGE OF VESSEL DAMAGES (Cont.)
(000)

VESSEL TYPE	VESSEL DRAFT	CASUALTY TYPE	SEVERITY	RANGE/K
OTHER		C	M	50-150
OTHER		C	S	>150
OTHER		G	L	<50
OTHER		G	M	50-250
OTHER		G	S	>250
PASS/FERRY	<19		T	N/A
PASS/FERRY	<19	C	L	<50
PASS/FERRY	<19	C	M	50-200
PASS/FERRY	<19	C	S	>200
PASS/FERRY	<19	G	L	<100
PASS/FERRY	<19	G	M	100-500
PASS/FERRY	<19	G	S	>500
PASS/FERRY	>18		T	N/A
PASS/FERRY	>18	C	L	<100
PASS/FERRY	>18	C	M	100-500
PASS/FERRY	>18	C	S	>500
PASS/FERRY	>18	G	L	<100
PASS/FERRY	>18	G	M	100-500
PASS/FERRY	>18	G	S	>500
TANK BARGE	<19		T	N/A
TANK BARGE	<19	C	L	<50
TANK BARGE	<19	C	M	50-200
TANK BARGE	<19	C	S	>200
TANK BARGE	<19	G	L	<50
TANK BARGE	<19	G	M	50-250
TANK BARGE	<19	G	S	>250
TANK BARGE	>18		T	N/A
TANK BARGE	>18	C	L	<100
TANK BARGE	>18	C	M	100-300
TANK BARGE	>18	C	S	>300
TANK BARGE	>18	G	L	<100
TANK BARGE	>18	G	M	100-400
TANK BARGE	>18	G	S	>400
TANKER	19-30		T	N/A
TANKER	19-30	C	L	<150
TANKER	19-30	C	M	150-500
TANKER	19-30	C	S	>500
TANKER	19-30	G	L	<100
TANKER	19-30	G	M	100-500
TANKER	19-30	G	S	>500
TANKER	<19		T	N/A
TANKER	<19	C	L	<75
TANKER	<19	C	M	75-150
TANKER	<19	C	S	>150
TANKER	<19	G	L	<100

RANGE OF VESSEL DAMAGES (Cont.)
(000)

VESSEL TYPE	VESSEL DRAFT	CASUALTY TYPE	SEVERITY	RANGE/K
TANKER	<19	G	M	100-300
TANKER	<19	G	S	>300
TANKER	>30		T	N/A
TANKER	>30	C	L	<100
TANKER	>30	C	M	100-200
TANKER	>30	C	S	>200
TANKER	>30	G	L	<100
TANKER	>30	G	M	100-800
TANKER	>30	G	S	>800
TOWBOAT			T	N/A
TOWBOAT		C	L	<50
TOWBOAT		C	M	50-200
TOWBOAT		C	S	>200
TOWBOAT		G	L	<50
TOWBOAT		G	M	50-200
TOWBOAT		G	S	>200

APPENDIX 6-J
BREAKDOWN OF ANCILLARY COSTS RESULTING FROM DAMAGE TO VESSELS IN CASUALTIES

TABLE 3

3/16/91

ANCILLARY COSTS OF CASUALTIES

VESSEL TYPE	VESSEL DRAFT	CASUALTY TYPE	SEVERITY	TOWDAYS	TOWCOST	DRYDOCK	GF/TC	ANCOST
DRY BARGE	<19		T	1	3,500.00	0.00	0.00	3,500.00
DRY BARGE	<19	C	L	0	0.00	0.00	0.00	0.00
DRY BARGE	<19	C	M	1	2,000.00	0.00	0.00	2,000.00
DRY BARGE	<19	C	S	2	4,000.00	3,150.00	0.00	7,150.00
DRY BARGE	<19	G	L	1	2,000.00	0.00	0.00	2,000.00
DRY BARGE	<19	G	M	2	4,000.00	2,150.00	0.00	6,150.00
DRY BARGE	<19	G	S	2	4,000.00	3,150.00	0.00	7,150.00
DRY BARGE	>18		T	2	7,000.00	0.00	0.00	7,000.00
DRY BARGE	>18	C	L	1	0.00	0.00	0.00	0.00
DRY BARGE	>18	C	M	2	3,500.00	0.00	0.00	3,500.00
DRY BARGE	>18	C	S	2	7,000.00	6,750.00	0.00	13,750.00
DRY BARGE	>18	G	L	1	3,500.00	0.00	0.00	3,500.00
DRY BARGE	>18	G	M	2	7,000.00	4,100.00	0.00	11,100.00
DRY BARGE	>18	G	S	2	7,000.00	6,750.00	0.00	13,750.00
DRY CARGO	19-29		T	3	21,000.00	0.00	0.00	21,000.00
DRY CARGO	19-29	C	L	0	0.00	0.00	0.00	0.00
DRY CARGO	19-29	C	M	1	7,000.00	0.00	23,000.00	30,000.00
DRY CARGO	19-29	C	S	2	15,000.00	153,750.00	23,000.00	191,750.00
DRY CARGO	19-29	G	L	1	7,000.00	0.00	0.00	7,000.00
DRY CARGO	19-29	G	M	2	14,000.00	27,750.00	23,000.00	64,750.00
DRY CARGO	19-29	G	S	2	14,000.00	48,750.00	23,000.00	85,750.00
DRY CARGO	<19		T	2	14,000.00	0.00	0.00	14,000.00
DRY CARGO	<19	C	L	0	0.00	0.00	0.00	0.00
DRY CARGO	<19	C	M	1	7,000.00	0.00	18,700.00	25,700.00
DRY CARGO	<19	C	S	2	14,000.00	9,400.00	18,700.00	42,100.00
DRY CARGO	<19	G	L	1	7,000.00	0.00	0.00	7,000.00
DRY CARGO	<19	G	M	2	14,000.00	4,400.00	18,700.00	37,100.00
DRY CARGO	<19	G	S	2	14,000.00	12,400.00	18,700.00	45,100.00
DRY CARGO	>30		T	3	21,000.00	0.00	0.00	21,000.00
DRY CARGO	>30	C	L	0	0.00	0.00	0.00	0.00

3/16/91

TABLE 3

ANCILLARY COSTS OF CASUALTIES

VESSEL TYPE	VESSEL DRAFT	CASUALTY TYPE	SEVERITY	TOWDAYS	TOWCOST	DRYDOCK	GF/TC	ANCOST
DRY CARGO	>30	C	M	1	7,000.00	0.00	32,500.00	39,500.00
DRY CARGO	>30	C	S	2	14,000.00	536,000.00	32,500.00	582,500.00
DRY CARGO	>30	G	L	1	7,000.00	0.00	0.00	7,000.00
DRY CARGO	>30	G	M	2	14,000.00	86,000.00	32,500.00	132,500.00
DRY CARGO	>30	G	S	3	21,000.00	226,000.00	32,500.00	279,500.00
FISHING			T	2	7,000.00	0.00	0.00	7,000.00
FISHING		C	L	0	0.00	0.00	0.00	0.00
FISHING		C	M	1	3,500.00	0.00	2,700.00	6,200.00
FISHING		C	S	2	7,000.00	18,400.00	2,700.00	28,100.00
FISHING		G	L	1	3,500.00	0.00	0.00	3,500.00
FISHING		G	M	1	3,500.00	18,400.00	2,700.00	24,600.00
FISHING		G	S	2	7,000.00	36,000.00	2,700.00	45,700.00
OTHER			T	2	7,000.00	0.00	0.00	7,000.00
OTHER		C	L	0	0.00	0.00	0.00	0.00
OTHER		C	M	1	3,500.00	0.00	5,000.00	8,500.00
OTHER		C	S	2	7,000.00	13,271.00	5,000.00	25,271.00
OTHER		G	L	1	3,500.00	0.00	0.00	3,500.00
OTHER		G	M	1	3,500.00	4,711.00	5,000.00	13,211.00
OTHER		G	S	2	7,000.00	17,563.00	5,000.00	29,563.00
PASS/FERRY	<19		T	3	10,500.00	0.00	0.00	10,500.00
PASS/FERRY	<19	C	L	0	0.00	0.00	0.00	0.00
PASS/FERRY	<19	C	M	1	7,000.00	0.00	18,700.00	25,700.00
PASS/FERRY	<19	C	S	2	14,000.00	12,300.00	18,700.00	45,000.00
PASS/FERRY	<19	G	L	1	7,000.00	0.00	0.00	7,000.00
PASS/FERRY	<19	G	M	1	7,000.00	5,500.00	18,700.00	31,200.00
PASS/FERRY	<19	G	S	2	14,000.00	8,400.00	18,700.00	41,100.00
PASS/FERRY	>18		T	4	21,000.00	0.00	0.00	21,000.00
PASS/FERRY	>18	C	L	0	0.00	0.00	0.00	0.00
PASS/FERRY	>18	C	M	1	7,000.00	0.00	23,000.00	30,000.00
PASS/FERRY	>18	C	S	2	14,000.00	43,000.00	23,000.00	80,000.00
PASS/FERRY	>18	G	L	1	7,000.00	0.00	0.00	7,000.00

TABLE 3

3/16/91

ANCILLARY COSTS OF CASUALTIES

VESSEL TYPE	VESSEL DRAFT	CASUALTY TYPE	SEVERITY	TOWDAYS	TOWCOST	DRYDOCK	GF/TC	ANCOST
PASS/FERRY	>18	G	M	2	14,000.00	6,000.00	23,000.00	43,000.00
PASS/FERRY	>18	G	S	3	21,000.00	43,000.00	23,000.00	87,000.00
TANK BARGE	<19		T	3	10,500.00	0.00	0.00	10,500.00
TANK BARGE	<19	C	L	0	0.00	0.00	0.00	0.00
TANK BARGE	<19	C	M	2	7,000.00	0.00	15,500.00	22,500.00
TANK BARGE	<19	C	S	3	10,500.00	6,963.00	15,500.00	32,963.00
TANK BARGE	<19	G	L	2	7,000.00	0.00	0.00	7,000.00
TANK BARGE	<19	G	M	3	10,500.00	2,200.00	15,500.00	28,200.00
TANK BARGE	<19	G	S	3	10,500.00	17,005.00	15,500.00	43,005.00
TANK BARGE	>18		T	3	21,000.00	0.00	0.00	21,000.00
TANK BARGE	>18	C	L	1	3,500.00	0.00	0.00	3,500.00
TANK BARGE	>18	C	M	2	7,000.00	0.00	33,000.00	40,000.00
TANK BARGE	>18	C	S	3	10,500.00	9,400.00	33,000.00	52,900.00
TANK BARGE	>18	G	L	2	7,000.00	0.00	0.00	7,000.00
TANK BARGE	>18	G	M	3	10,500.00	0.00	33,000.00	43,500.00
TANK BARGE	>18	G	S	3	10,500.00	22,000.00	33,000.00	65,500.00
TANKER	19-30		T	4	28,000.00	0.00	0.00	28,000.00
TANKER	19-30	C	L	0	0.00	0.00	0.00	0.00
TANKER	19-30	C	M	1	7,000.00	0.00	33,000.00	40,000.00
TANKER	19-30	C	S	3	21,000.00	183,000.00	33,000.00	237,000.00
TANKER	19-30	G	L	1	7,000.00	0.00	0.00	7,000.00
TANKER	19-30	G	M	3	21,000.00	40,500.00	33,000.00	94,500.00
TANKER	19-30	G	S	4	28,000.00	123,000.00	33,000.00	184,000.00
TANKER	<19		T	3	10,500.00	0.00	0.00	10,500.00
TANKER	<19	C	L	0	0.00	0.00	0.00	0.00
TANKER	<19	C	M	2	7,000.00	0.00	22,000.00	29,000.00
TANKER	<19	C	S	3	10,500.00	6,400.00	22,000.00	38,900.00
TANKER	<19	G	L	2	7,000.00	0.00	0.00	7,000.00
TANKER	<19	G	M	3	10,500.00	5,400.00	22,000.00	37,900.00
TANKER	<19	G	S	3	10,500.00	10,400.00	22,000.00	42,900.00
TANKER	>30		T	6	42,000.00	0.00	0.00	42,000.00

TABLE 3

3/16/91

ANCILLARY COSTS OF CASUALTIES

VESSEL TYPE	VESSEL DRAFT	CASUALTY TYPE	SEVERITY	TOWDAYS	TOWCOST	DRYDOCK	GF/TC	ANCOST
TANKER	>30	C	L	0	0.00	0.00	0.00	0.00
TANKER	>30	C	M	2	14,000.00	0.00	44,000.00	58,000.00
TANKER	>30	C	S	5	35,000.00	318,000.00	44,000.00	397,000.00
TANKER	>30	G	L	2	14,000.00	0.00	0.00	14,000.00
TANKER	>30	G	M	4	28,000.00	98,000.00	44,000.00	170,000.00
TANKER	>30	G	S	5	35,000.00	688,000.00	44,000.00	767,000.00
TOWBOAT			T	2	7,000.00	0.00	0.00	7,000.00
TOWBOAT		C	L	0	0.00	0.00	0.00	0.00
TOWBOAT		C	M	1	3,500.00	0.00	2,500.00	6,000.00
TOWBOAT		C	S	2	7,000.00	5,280.00	2,500.00	14,780.00
TOWBOAT		G	L	1	3,500.00	0.00	0.00	3,500.00
TOWBOAT		G	M	1	3,500.00	2,480.00	2,500.00	8,480.00
TOWBOAT		G	S	2	7,000.00	5,280.00	2,500.00	14,780.00

APPENDIX 6-K
ORIGINAL DATA SOURCE FOR COST OF INJURY RESULTING FROM A CASUALTY

Costs Per Police-Reported Injury, By Body Region and MAIS, at a 4% Discount Rate

	Cases	Hosp/ Med @	Voc Rehab	HH Prod	Wages	Insur Admin #Cost	Empl	Emerg Svcs *	Travel Delay	Legal/ Court	SubTotl 1988 $	Prop Damage	Total 1988 $	Pain & Suffer	Grand Total
Spinal Cord															
All	939	302048	2262	39510	163034	51793	3627	709	125	84956	648064	5327	653391	739474	1392865
MAIS 1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MAIS 2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MAIS 3	397	20425	165	12870	46777	7824	2540	404	125	14080	105210	4328	109538	211101	320639
MAIS 4	111	437470	2567	68259	200080	72730	3831	919	125	118837	904818	6267	911085	446659	1357744
MAIS 5	431	526579	4116	56645	260578	86902	4575	935	125	141516	1081971	6005	1087976	1442268	2530244
Brain															
All	585688	4766	31	1517	5418	1345	484	175	125	1841	15702	2590	18292	69041	87333
MAIS 1	436683	774	10	477	1624	460	178	121	125	385	4154	2451	6605	2923	9528
MAIS 2	121774	3729	78	1829	6483	1267	1017	269	125	1489	16286	2524	18810	149449	168259
MAIS 3	15608	14016	153	7901	28645	5098	2330	404	125	8943	67615	4328	71943	325671	397614
MAIS 4	6693	72166	183	13771	50569	14631	2692	919	125	24465	179521	6267	185788	1055950	1241738
MAIS 5	4930	263147	159	49089	180322	51307	5526	935	125	85634	636244	6005	642249	1786954	2429203
Lower Extremity															
All	162290	9672	84	3787	13450	2703	1280	262	125	4091	35454	3001	38455	107074	145529
MAIS 1	50321	704	8	219	646	348	142	121	125	224	2537	2451	4988	2789	7777
MAIS 2	67505	7803	78	3059	10708	2079	1155	269	125	2497	27773	2524	30297	28019	58316
MAIS 3	43985	22552	180	8886	31927	6284	2747	404	125	10824	83929	4328	88257	345466	433723
MAIS 4	479	32391	157	13049	48170	9262	3578	919	125	16560	124211	6267	130478	313324	443802
MAIS 5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Upper Extremity															
All	153371	3049	35	2471	8816	1493	823	203	125	2077	19092	2687	21779	36414	58193
MAIS 1	83611	598	18	416	1392	419	175	121	125	332	3596	2451	6047	4803	10850
MAIS 2	52541	4638	45	3760	13407	2070	1301	269	125	2626	28241	2524	30765	30879	61644
MAIS 3	17219	10105	90	8519	30860	4944	2511	404	125	8873	66431	4328	70759	206797	277556
MAIS 4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MAIS 5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Trunk, Abdomen															
All	354343	2098	43	925	3214	799	390	173	125	1009	8776	2680	11456	33480	44936
MAIS 1	288278	689	7	240	743	358	150	121	125	239	2672	2451	5123	2607	7730
MAIS 2	32293	3242	168	1932	6628	1228	877	269	125	1449	15918	2524	18442	11994	30436
MAIS 3	25571	9928	219	5091	18267	3480	1786	404	125	5907	45207	4328	49535	252857	302392
MAIS 4	6084	19325	252	7340	27043	5644	2455	919	125	10015	73118	6267	79385	535001	614386
MAIS 5	2117	32503	287	10090	37231	8064	2776	935	125	14159	106170	6005	112175	474268	586443
Face, Other Head, Other Neck															
All	424997	1446	43	699	2432	622	314	136	125	647	6464	2489	8953	9951	18904
MAIS 1	391716	1112	41	393	1323	463	214	121	125	374	4166	2451	6617	4226	10843
MAIS 2	26574	3123	46	2482	8843	1454	1119	269	125	1790	19251	2524	21775	28293	50068
MAIS 3	5900	12340	162	11635	42098	6442	2933	404	125	11771	87910	4328	92238	207783	300021
MAIS 4	791	28769	35	10404	38267	7883	3080	919	125	13991	103473	6267	109740	733320	843060
MAIS 5	16	22134	195	29431	108306	15112	5905	935	125	29098	211241	6005	217246	1023144	1240390
Minor External															
All	1076966.	278	3	200	630	309	100	121	125	186	1952	2451	4403	2114	6517
MAIS 1	1076966.	278	3	200	630	309	100	121	125	186	1952	2451	4403	2114	6517

@ Includes hospital, medical, prescription, attendant, and nursing home services.
\# Includes insurer's legal costs.
* Includes emergency transport, fire, and police services.

APPENDIX 6-L

RELATIONSHIP OF PCAS INJURY CATEGORIES TO INJURY COST CATEGORIES

Injury Category	PCAS "RESULT"	PCAS "BODPART"	PCAS "NATINJ"
Death	DVC		
Multiple Injury		Multiple Injuries Unknown NC	
Minor External		All parts	Abrasion Blister Bruise Cut
Brain		Head	Fracture Concussion Crushed Sprain Strain
Spinal Cord		Back Neck	Fracture Concussion Crushed Sprain Strain
Lower Extremity		Ankle Foot Knee Leg Hip	Remaining natures
Upper Extremity		Arm Finger Hand	Remaining natures
Trunk and Abdomen		Chest Groin Shoulder Stomach Trunk Back	Remaining natures
Face, Other Head, Other Neck		Eye Head Neck	Remaining natures

APPENDIX 6-M
BRIDGE DAMAGE DATA ANALYSIS

There were 38 cases involving 77 vessels, of bridges being rammed as part of addressable casualties during the study period. Such casualties can range from relatively minor damage to a bridge fender system to complete destruction of a bridge span. As a result of bridge rammings, other marine traffic may be impaired in its ability to navigate in the affected waterway. In addition, motor vehicle or rail traffic may be delayed or in some cases unable to use the bridge for an extended time period. By level of severity, the following threshold values were used for bridge rammings:

Bridge Damage Severity	Threshold Value
Severe	$\geq$ $500,000
Moderate	$100,000 - 499,000
Low	< $100,000

The results during the study period were as follows:

Total cases	1084
Total bridge rammings	38 (3.5%)
-with damage > 0	23 (60.5%)
Average bridge damage	
- Severe	$10,784,868 (4 cases)
- Moderate	$254,741 (8 cases)
- Low	$35,196 (11 cases)

APPENDIX 6-N
LIST OF BRIDGES AND CHARACTERISTICS IN VTS STUDY ZONES

CHARACTERISTICS OF BRIDGES BY SUBZONE

SUBZONE	CODE	NAME	SURFACE	TYPE	ONLY ROUTE	HEIGHT	START NODE	END NODE
0103C	1	WASHINGTON STREET	ROAD	BASCULE	NO	33	10609	10610
0105E	2	MYSTIC RIVER/TOBIN	ROAD	FIXED	NO	135	10110	10117
0105E	3	ANDREW P. MCARDLE	ROAD	BASCULE	NO	21	10111	10112
0105E	4	CHELSEA STREET	ROAD	BASCULE	NO	9	10113	10114
0209E	1	ROUTE 16	ROAD	FIXED	YES	180	20315	20316
0502E	1	FOLEY AVENUE	ROAD	FIXED	YES	136	50113	50114
0502E	2	RAINBOW (SHW#87)	ROAD	FIXED	YES	172	50701	50702
0503E	3	KANSAS CITY SOUTHERN	RAIL	LIFT	YES	147	50506	50600
0604E	1	PARIS ROAD	ROAD	FIXED	YES	138	60117	60118
0604E	2	BAYOU YSCLOSKEY/ALLUV	ROAD	LIFT	YES	53	60420	60421
0604E	3	UNDER CONSTRUCTION	ROAD	BASCULE	NO	9	60603	60604
0604E	4	USI RTE #10	ROAD	FIXED	NO	120	60603	60604
0604E	5	SEABROOK RR	RAIL	BASCULE	NO	1	60603	60604
0604E	6	SEABROOK HIGHWAY	ROAD	BASCULE	YES	46	60603	60604
0605F	7	GREATER ORLEANS HW	ROAD	FIXED	NO	150	60942	60943
0605F	8	HUEY P LONG	ROAD	FIXED	NO	133	60951	60952
0605F	9	LULING & DESTREHAN	ROAD	FIXED	NO	133	60961	60962
0605F	10	LOUISIANA (SH#407)	ROAD	LIFT	NO	100	61300	61301
0605F	11	MISSOURI PACIFIC RR	RAIL	LIFT	YES	102.2	61301	61302
0605F	12	LOUISIANNA (SHW#23)	ROAD	LIFT	NO	103	61301	61302
0606F	13	WALLACE	ROAD	FIXED	NO	139	60973	60974
0606F	14	SUNSHINE/SALSBURG	ROAD	FIXED	NO	133	60989	60990
0703D	1	PELICAN ISLAND	ROAD	BASCULE	YES	12	70205	70206
0705E	2	UNDER CONSTRUCTION	ROAD	N/A	NO	25	70118	70119
0705E	3	GREEN BAYOU	ROAD	FIXED	YES	175	70137	70138
0705E	4	INTERSTATE HW#610	ROAD	FIXED	YES	135	70155	70156
0705E	5	INTERSTATE HW#45/75	ROAD	FIXED	YES	73	70419	70420
0705E	6	STATE HW#146	ROAD	FIXED	YES	45	70509	70510
0705E	7	SOUTHERN PACIFIC RR	RAIL	SWING	YES	8	70509	70510
0705E	8	TRI-CITY BEACH ROAD	ROAD	BASCULE	YES	13	71015	71016
0802B	1	CHESAPEAKE BAY	ROAD	FIXED	YES	21	80300	80301
0802B	2	US HW#60	ROAD	FIXED	YES	35	80802	80803
0802B	3	GREAT NECK ROAD	ROAD	FIXED	YES	35	80808	80809
0806C	4	JAMES RIVER	ROAD	LIFT	YES	145	80319	80320
0901C	1	ROUTE #363	ROAD	FIXED	YES	10	90601	90602
0901C	2	LANE MEMORIAL	ROAD	FIXED	NO	186	90914	90915
0901C	3	ROUTE #335	ROAD	SWING	YES	6	91112	91113
0901C	4	INTERSTATE #50	ROAD	SWING	NO	18	91312	91313
0901C	5	ROUTE #33	ROAD	BASCULE	YES	7	91403	91404
0902C	6	FRANCIS SCOTT KEY	ROAD	FOXED	YES	185	91907	91908
1003E	1	ARANSAS PASS	ROAD	FIXED	YES	125	100201	100202
1103C	1		ROAD	BASCULE	YES	35	112105	112106
1103C	2		ROAD	BASCULE	YES	20	112109	112110
1104D	3	BEACH CHANNEL DRIVE	ROAD	LIFT	YES	152	110604	110605
1105E	4	BAYONNE	ROAD	FIXED	YES	138	111607	111608
1105E	5	INTERSTATE #78	ROAD	FIXED	YES	135	111612	111613
1105E	6	CONRAIL	RAIL	LIFT	YES	135	111612	111613
1107E	7	GEORGE WASHINGTON	ROAD	FIXED	YES	195	110119	110120
1107E	8	BROOKLYN	ROAD	FIXED	NO	110	111501	111502
1107E	9	MANHATTAN	ROAD	FIXED	NO	134	111501	111502
1107E	10	WILLIAMSBURG	ROAD	FIXED	NO	133	111502	111503
1107E	11	QUEENSBOROUGH	ROAD	FIXED	YES	131	111504	111505
1107E	12	TRIBOROUGH STREET	ROAD	FIXED	YES	138	111506	111507
1107E	13	CONRAIL	RAIL	FIXED	YES	134	111507	111508
1107E	14	BRONX-WHITESTONE	ROAD	FIXED	YES	135	111511	111512
1107E	15		ROAD	BASCULE	NO	14	111806	111807
1107E	16		ROAD	FIXED	NO	52	111807	111808
1203C	1	CONRAIL	RAIL	BASCULE	YES	11	120801	120802
1203C	2	ROUTE #156	ROAD	SWING	YES	9	120802	120803
1203C	3	UNDER CONSTRUCTION	ROAD	N/A	N/A	N/A	120802	120803
1203C	4	INTERSTATE #95	ROAD	FIXED	YES	81	121305	121306
1203C	5	INTERSTATE #95	ROAD	FIXED	NO	65	121509	121510

CHARACTERISTICS OF BRIDGES BY SUBZONE

SUBZONE	CODE	NAME	SURFACE	TYPE	ONLY ROUTE	HEIGHT	START NODE	END NODE
1203C	6	CONRAIL	RAIL	BASCULE	YES	19	121509	121510
1203C	7	CT TURNPIKE	ROAD	FIXED	NO	65	121601	121602
1203C	8	SEGE AVENUE	ROAD	LIFT	NO	68	122602	122603
1203C	9	CONGRESS STREET	ROAD	BASCULE	NO	8	121603	121604
1203C	10	CRESCENT STREET	ROAD	BASCULE	NO	4	121604	121605
1203C	11	ARTIC STREET	ROAD	FIXED	NO	13	121605	121606
1203C	12	ROUTE #1	ROAD	FIXED	NO	32	121509	121510
1301A	1	CONRAIL	RAIL	SWING	YES	2	131411	131412
1301A	2	AVALON BOULEVARD	ROAD	FIXED	YES	35	131447	131448
1301A	3		ROAD	BASCULE	YES	11	131462	131463
1301A	4	GRASSY SOUND	ROAD	BASCULE	YES	8	131473	131474
1301A	5	OCEAN DRIVE	ROAD	BASCULE	NO	15	131474	131475
1301A	6	CONRAIL	RAIL	BASCULE	YES	6	131480	131481
1301A	7	RIO GRANDE	ROAD	BASCULE	YES	25	131483	131484
1301A	8	MIDDLE THOROUGHFARE	ROAD	BASCULE	YES	23	131489	131490
1301A	9	CONRAIL	RAIL	SWING	YES	4	131506	131507
1301A	10	PENN CENTRAL	ROAD	FIXED	YES	55	131507	131508
1301A	11	SEASHORE ROAD	ROAD	FIXED	YES	55	131507	131508
1301A	12	SEASHORE PARK	ROAD	FIXED	YES	32	131600	131601
1303C	13	ROUTE #553	ROAD	FIXED	YES	25	130520	130521
1304F	14	DELEWARE MEMORIAL	ROAD	FIXED	NO	166	130115	130116
1304F	15	COMMODORE BARRY	ROAD	FIXED	YES	181	130120	130121
1304F	16	WALT WHITMAN	ROAD	FIXED	NO	139	130129	130130
1304F	17	BEJAMIN FRANKLIN	ROAD	FIXED	NO	125	130134	130135
1304F	18	CONRAIL	RAIL	LIFT	YES	49	130138	130139
1304F	19	BETTY ROSS	ROAD	FIXED	NO	113	130140	130141
1304F	20	INTERSTATE #295	ROAD	FIXED	NO	4	130806	130807
1304F	21	CONRAIL	RAIL	FIXED	NO	1	130811	130812
1304F	22	INTERSTATE #495	ROAD	SWING	NO	6	130900	130901
1304F	23	CHRISTINA AVENUE	ROAD	BASCULE	NO	15	130905	130906
1304F	24	WALNUT STREET	ROAD	BASCULE	NO	8	130906	130907
1304F	25	CAUSEWAY	ROAD	BASCULE	NO	19	130906	130907
1304F	26	PLATT MEMORIAL	ROAD	FIXED	YES	135	131101	131102
1304F	27	UNDER CONSTRUCTION	ROAD	N/A	NO	135	131109	131110
1403C	1	VALLEJO HEIGHTS	ROAD	LIFT	NO	100	140312	140600
1403C	2	CARQUINEZ	ROAD	FIXED	NO	146	140309	140700
1405F	3	SUISUN POINT	ROAD	FIXED	NO	135	140704	140800
1405F	4	SOUTHERN PACIFIC RR	RAIL	LIFT	YES	70	140704	140800
1405F	5	PAINTERSVILLE	ROAD	BASCULE	YES	6	141046	141047
1502F	1		ROAD	FIXED	YES	193	150107	150108
1502F	2	LONGVIEW	ROAD	FIXED	NO	185	150140	150141
1502F	3	BNRR	RAIL	SWING	YES	39	150175	150176
1502F	4		ROAD	LIFT	NO	80	150400	150401
1502F	5		ROAD	BASCULE	NO	24	150402	150403
1502F	6		RAIL	BASCULE	YES	25	151002	151003
1502F	7		ROAD	FIXED	YES	63	151003	151004
1502F	8	SAUVIE ISLAND	ROAD	FIXED	YES	78	151236	151237
1502F	9		RAIL	FIXED	YES	28	151302	151303
1502F	10		ROAD	FIXED	NO	34	151311	131312
1502F	11		ROAD	FIXED	NO	38	151313	151314
1502F	12	ST. JOHNS	ROAD	FIXED	NO	205	151503	151504
1502F	13	FREEMONT	ROAD	FIXED	NO	163	151506	151507
1502F	14	BROADWAY	ROAD	BASCULE	NO	90	151506	151507
1502F	15		ROAD	LIFT	NO	161	151507	151508
1502F	16	BURNSIDE	ROAD	BASCULE	NO	64	151508	151509
1502F	17	MORRISON	ROAD	LIFT	NO	50	151509	151510
1502F	18	HAWTHORNE	ROAD	LIFT	NO	159	151509	151510
1502F	19	MARQUAM	ROAD	FIXED	NO	102	151510	151511
1502F	20	ROSS ISLAND	ROAD	FIXED	NO	90	151511	151512
1502F	21	INTERSTATE	ROAD	FIXED	YES	35	151604	151605
1502F	22		RAIL	SWING	YES	16	151815	151816
1902C	1	TAYLORPT/EST PSSGE	ROAD	FIXED	YES	194	190105	190106
1902C	2	JAMESTOWN NORTH	ROAD	FIXED	YES	134	190203	190204

CHARACTERISTICS OF BRIDGES BY SUBZONE

SUBZONE	CODE	NAME	SURFACE	TYPE	ONLY ROUTE	HEIGHT	START NODE	END NODE
1902C	3	UNDER CONSTRUCTION	ROAD	N/A	N/A	134	190203	190204
1902C	4	MOUNT HOPE	ROAD	FIXED	YES	135	190401	190402
1902C	5	BRAYTON POINT	ROAD	FIXED	NO	135	190405	190406
2003F	1	CAPE FEAR MEMORIAL	ROAD	LIFT	YES	135	200123	200124
2003F	2	US HW#421	ROAD	FIXED	YES	65	200303	200304
2003F	3	CAPE FEAR RIVER	ROAD	FIXED	NO	55	200401	200402
2003F	4	SEABOARD SYSTEM RR	ROAD	BASCULE	NO	6	200411	200412
2102E	1	MATHEWS	ROAD	FIXED	NO	86	210129	210130
2102E	2	HART	ROAD	FIXED	NO	135	210131	210132
2102E	3	MAIN STREET	ROAD	LIFT	NO	135	210134	210135
2102E	4	ACOSTA	ROAD	LIFT	NO	164	210135	210136
2102E	5	FLORIDA EAST COAST	RAIL	BASCULE	YES	5	210135	210136
2102E	6	SHELL ISLAND/FUNNING	ROAD	BASCULE	NO	24	210312	210313
2202C	1	GREEN	ROAD	FIXED	NO	41	220410	220411
2202C	2	SSRR	RAIL	SWING	YES	50	220411	220412
2302E	1	CSX TRN	RAIL	SWING	YES	7	230904	230905
2302E	2	INTERSTATE #90	ROAD	BASCULE	YES	31	230905	230906
2302E	3	ROUTE #613	ROAD	SWING	YES	9	230927	230928
2302E	4	ROUTE #63	ROAD	FIXED	NO	73	230933	230934
2302E	5	MERR	ROAD	SWING	NO	5	230934	230935
2303C	6	ROUTE #193	ROAD	FIXED	YES	83	230507	230508
2304E	7	INTERSTATE #65	ROAD	BASCULE	YES	11	230201	230202
2305F	8	SEABOARD SYSTEM RR	RAIL	SWING	YES	10	230300	230301
2305F	9	SSRR	RAIL	SWING	YES	4	230128	230129
2305F	10	SOUTHERN RAILWAY	ROAD	SWING	YES	10	230301	230302

APPENDIX 6-O
WORKSHEETS FOR DEVELOPMENT OF LNG AND LPG CONSEQUENCES OF CASUALTIES

HUMAN LOSSES ON LNG TANKER INVOLVED IN COLLISION OR RAMMING AND ON LAND IN PROXIMITY OF TANKER

SUBZONE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES
0101	27	0	3
0102	27	0	3
0103	76	6	3
0104	3700	430	1
0105	3500	420	1
0501	27	0	3
0503	32	1	3
0801	27	0	3
0802	50	0	3
CHES BAY BRDG-TUNNEL	27	23	3
0803	27	0	3
0901	27	0	3

HUMAN LOSSES ON SECOND VESSEL
INVOLVED IN COLLISION WITH
LNG TANKER

VESSEL TYPE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES
LARGE TANKER	11	5	8
MEDIUM TANKER	9	5	7
SMALL TANKER	8	4	6
LARGE BULK CARRIER	11	5	8
MEDIUM BULK CARRIER	9	5	7
SMALL BULK CARRIER	8	4	6
LARGE TANK BARGE	0	0	0
SMALL TANK BARGE	0	0	0
LARGE DRY BARGE	0	0	0
SMALL DRY BARGE	0	0	0
LARGE PASSENGER	603	302	335
SMALL PASSENGER	27	13	15
FISHING VESSEL	9	5	7
TOW BOATS	2	1	2
OTHER VESSEL	5	2	3

HUMAN LOSSES ON LNG TANKER
INVOLVED IN A GROUNDING
AND ON LAND IN PROXIMITY
OF TANKER

SUBZONE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES
0101	0.1	0.12	29.84
0102	0.1	0.24	29.6
0103	1.2	1.8	28.2
0104	275.0	280	14
0105	320.0	320	12
0501	0.1	0.12	29.8
0503	0.1	0.13	29.8
0801	0.1	0.12	29.8
0802	0.1	0.12	29.8
CHES BAY BRDG-TUNNEL	1.6	2.2	28.2
0803	0.2	0.4	29.5
0901	0.1	0.24	29.64

HUMAN LOSSES ON SECOND VESSEL
IGNITION SOURCE IN AN
LNG TANKER GROUNDING
SUBZONES 0101, 0501, 0801 (P=.01)

VESSEL TYPE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES	CREW SIZE
LARGE TANKER	0.0	0.1	0.1	24
MEDIUM TANKER	0.0	0.1	0.1	20
SMALL TANKER	0.0	0.1	0.1	17
LARGE BULK CARRIER	0.0	0.1	0.1	24
MEDIUM BULK CARRIER	0.0	0.1	0.1	20
SMALL BULK CARRIER	0.0	0.1	0.1	17
LARGE TANK BARGE	0.0	0.0	0.0	0
SMALL TANK BARGE	0.0	0.0	0.0	0
LARGE DRY BARGE	0.0	0.0	0.0	0
SMALL DRY BARGE	0.0	0.0	0.0	0
LARGE PASSENGER	2.7	5.4	5.4	1340
SMALL PASSENGER	0.1	0.2	0.2	59
FISHING VESSEL	0.0	0.1	0.1	20
TOW BOATS	0.0	0.0	0.0	5
OTHER VESSEL	0.0	0.0	0.0	10

SUBZONES 0102, 0103, 0803, 0901
(P=.02)

VESSEL TYPE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES	CREW SIZE
LARGE TANKER	0.1	0.2	0.2	24
MEDIUM TANKER	0.1	0.2	0.2	20
SMALL TANKER	0.1	0.1	0.1	17
LARGE BULK CARRIER	0.1	0.2	0.2	24
MEDIUM BULK CARRIER	0.1	0.2	0.2	20
SMALL BULK CARRIER	0.1	0.1	0.1	17
LARGE TANK BARGE	0.0	0.0	0.0	0
SMALL TANK BARGE	0.0	0.0	0.0	0
LARGE DRY BARGE	0.0	0.0	0.0	0
SMALL DRY BARGE	0.0	0.0	0.0	0
LARGE PASSENGER	5.4	10.7	10.7	1340
SMALL PASSENGER	0.2	0.5	0.5	59
FISHING VESSEL	0.1	0.2	0.2	20
TOW BOATS	0.0	0.0	0.0	5
OTHER VESSEL	0.0	0.1	0.1	10

HUMAN LOSSES ON LPG TANKER
INVOLVED IN A COLLISION OR RAMMING
AND ON LAND IN PROXIMITY TO TANKER

SUBZONE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES
A. OPEN APPROACH	22.5	0.0	2.5
B. CONVERGENCE	22.5	0.0	2.5
C. OPEN HARBOR OR BAY	25.0	1.0	2.5
D. ENCLOSED HARBOR	390.0	42.0	1.8
E. CONSTRICTED WATERWAY	200.0	21.0	2.1
F. RIVER	200.0	21.0	2.1

HUMAN LOSSES ON SECOND VESSEL
INVOLVED IN COLLISION WITH
AN LPG TANKER

VESSEL TYPE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES
LARGE TANKER	8.6	2.2	13.2
MEDIUM TANKER	7.2	1.8	11.0
SMALL TANKER	6.1	1.5	9.4
LARGE BULK CARRIER	8.6	2.2	13.2
MEDIUM BULK CARRIER	7.2	1.8	11.0
SMALL BULK CARRIER	6.1	1.5	9.4
LARGE TANK BARGE	0.0	0.0	0.0
SMALL TANK BARGE	0.0	0.0	0.0
LARGE DRY BARGE	0.0	0.0	0.0
SMALL DRY BARGE	0.0	0.0	0.0
LARGE PASSENGER	482.4	120.6	737.0
SMALL PASSENGER	21.2	5.4	32.5
FISHING VESSEL	7.2	1.8	11.0
TOW BOATS	1.8	0.5	2.8
OTHER VESSEL	3.6	0.9	5.5

HUMAN LOSSES ON LPG TANKER INVOLVED IN A GROUNDING AND ON LAND IN PROXIMITY TO TANKER

SUBZONE	NUMBER OF FATALITIES	NUMBER OF BURNS	NUMBER OF INJURIES
A. OPEN APPROACH	0.1	0.0	22.9
B. CONVERGENCE	0.2	0.1	22.7
C. OPEN HARBOR OR BAY	0.5	0.1	22.6
D. ENCLOSED HARBOR	21.0	17.0	17.5
E. CONSTRICTED WATERWAY	10.0	8.0	20.0
F. RIVER	10.0	8.0	20.0

HUMAN LOSSES ON SECOND VESSEL
IGNITION SOURCE IN AN
LPG TANKER GROUNDING

VESSEL TYPE	NUMBER OF FATALITIES (A SUBZONES)	NUMBER OF BURNS (A SUBZONES)	NUMBER OF INJURIES (A SUBZONES)
LARGE TANKER	0.1	0.0	0.1
MEDIUM TANKER	0.1	0.0	0.1
SMALL TANKER	0.1	0.0	0.1
LARGE BULK CARRIER	0.1	0.0	0.1
MEDIUM BULK CARRIER	0.1	0.0	0.1
SMALL BULK CARRIER	0.1	0.0	0.1
LARGE TANK BARGE	0.0	0.0	0.0
SMALL TANK BARGE	0.0	0.0	0.0
LARGE DRY BARGE	0.0	0.0	0.0
SMALL DRY BARGE	0.0	0.0	0.0
LARGE PASSENGER	6.7	1.3	5.4
SMALL PASSENGER	0.3	0.1	0.3
FISHING VESSEL	0.1	0.0	0.1
TOW BOATS	0.0	0.0	0.0
OTHER VESSEL	0.1	0.0	0.0

SECTION 7.

DEVELOP ESTIMATES OF COSTS ASSOCIATED WITH OIL AND HAZARDOUS CHEMICAL SPILLS AND COSTS OF IDLE RESOURCES DURING VESSEL REPAIRS

Prepared For:

The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Prepared By:

Eastern Research Group, Inc.
6 Whittemore Street
Arlington, MA 02174
November 1990

DEVELOP ESTIMATES OF COSTS ASSOCIATED WITH OIL AND HAZARDOUS CHEMICAL SPILLS AND COSTS OF IDLE RESOURCES DURING VESSEL REPAIRS

NOTE: This section documents the Eastern Research Group effort performed in support of Section 6 of the Port Needs Study (Volume I), under Purchase Order #90-P-81428.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

FINAL REPORT

SECTION ONE

EXECUTIVE SUMMARY

ERG prepared a data base on oil spill cleanup efforts for the Department of Transportation, Transportation Systems Center (TSC) in Cambridge, MA. The data base was designed to provide information about the costs of oil spill cleanup efforts and about the determinants of those costs. ERG also prepared estimates of certain logistical and economic factors that help determine the social costs of vessel casualties, such as the length of time vessels are unavailable for productive use during repair work and the revenues loss per day from the interruption in productive services. All of the materials prepared by ERG were intended to support the TSC in its project to estimate the costs and benefits of investments in vessel traffic safety (VTS) systems for major U.S. ports. This report summarizes the results of ERG's research.

ERG compiled a data base covering 653 oil and chemical spills. The data was assembled through searches of original Coast Guard files, from literature on oil spill costs, from information provided by the Transportation Systems Center, and from data obtained from the Coast Guard Marine Pollution Incident Report System. In searches of original Coast Guard files, ERG attempted to assemble all data that could be relevant to the costs of oil spill cleanup efforts, including whether a spill reached shore, the type of oil that was spilled, weather conditions, and other factors. This additional descriptive information about the characteristics and circumstances of cleanup efforts was only occasionally available. In data obtained from other sources, such information was generally not available.

After compilation of the data base, ERG performed regression analysis across the explanatory variables in order to develop the best possible model of oil spill cleanup costs. ERG considered several forms of the regression equation and the use of a variety of explanatory variables that are believed to influence the cost of cleanup operations. A good "fit" of the data was found with a simple equation in which the logarithm of cleanup costs was presumed to be determined by the logarithm of the quantity of material spilled. The proportion of variance of the dependent variable that is explained by this specification of the equation (the R^2 statistics) was over 70%. Other variables, such as the product spilled (heavy or light petroleum) and whether the spill reached shore, were found to have a minor impact on the explanatory power of the regressions.

ERG estimated various cost elements that determine the direct and indirect costs of vessel casualties, such as could be prevented by improved vessel traffic safety systems. ERG first derived estimates of the time needed for vessel repairs of differing severity, such as could be necessitated from collisions or groundings. For most commercial ships, repair work is performed with great haste in order to return the vessel to productive service. For dry cargo carriers and tankers, shipyards can accomplish $1 million of repairs or more within a two-week period. In the case of passenger vessels, the pressure to complete repairs within a short time period is even more acute, and millions of dollars in repairs will be accomplished within a two-week period.

The loss of productive services from the vessel represents the idling of a useful resource. One method of estimating the value of lost resources is to consider the costs of vessel operations. These costs are a lower bound estimate on the value of vessel services since, in normal markets, vessel revenues are adequate to cover the costs of these operations. ERG estimated the combined operating and capital costs of three common categories of vessels at $10,000 to over $17,000 per day. ERG also prepared estimates of the costs of other types of vessel expenses related to casualties such as the costs of dispersing the crew and costs for lightering of oil tankers. ERG also examined the costs of delays in cargo deliveries.

SECTION TWO

INTRODUCTION AND TECHNICAL APPROACH TO DEFINITION OF COSTS ASSOCIATED WITH OIL SPILLS

Under research sponsored by the Transportation Systems Center (TSC), Department of Transportation, ERG performed a study examining the costs of cleaning up oil spills. The research was intended to provide information needed for an ongoing TSC study of the potential costs and benefits of a vessel traffic safety (VTS) system for selected U.S. ports. ERG's work is intended to support that of TSC in the analysis of the potential benefits of a VTS system from the avoidance of oil spills in U.S. waters.

ERG has examined available data sources on the costs of oil spill clean-up efforts and on the clean-up technologies employed. This section describes the sources reviewed, the methodologies employed, and limitations or caveats relating to the information developed. Section Three presents the data base as it currently stands. Section Four summarizes the results of the regression analysis to define the possible predictive models of oil spill cleanup costs.

2.1 Basic Approach to Collection of Useful Information on Oil Spill Clean-up Efforts

ERG examined all available sources on oil spill occurrences. ERG sought to obtain as much data as possible that:

- Provided accurate data on the costs of oil spill clean-ups, and
- Provided descriptive information about the characteristics of spill events and the clean-up efforts taken to reduce environmental damages or liabilities.

ERG reviewed data from a number of sources, although the extent to which the sources satisfied these criteria was quite variable. Table 2-1 on the following page provides a list of variables which ERG attempted to collect for each of the spills reported in the various sources.

TABLE 2-1

Partial List of Variables Coded When Possible for Each Spill Report

■ Date of spill	■ Marine Safety Office (MSO) which monitored the cleanup
■ State	■ Major water body (Atlantic, Pacific, Gulf, Great Lakes)
■ Distance from shore	■ Water body type (bay/sound, harbor, lake, river)
■ Name of water body	■ Name of vessel(s)
■ Owner(s) of vessel(s)	■ Operator(s) of vessel(s)
■ Flag of vessel(s)	■ Cause of incident (a brief description)
■ Product spilled	■ Quantity spilled
■ Potential quantity (the amount of material at risk, e.g. the total cargo onboard a loaded tanker which has gone aground)	■ Quantity recovered during cleanup
■ Any adverse weather conditions	■ Whether or not spill reached shore
■ Miles and acres of shore-line affected	■ Cleanup methods, both offshore and offshore, that were utilized
■ Total cost of cleanup operation, excluding Coast Guard and other agency costs	

The best sources were those that provided data on a spill-by-spill basis on both costs and clean-up efforts taken. If information was given only about the clean-up efforts, it could not be incorporated into the modeling without clean-up cost data as well. All of the sources eventually used provided at least information about the costs of cleanup efforts, the quantity of oil used, and the type of oil used. In a substantial subset of the total data base, information was also available on whether the oil spill reached shore, one of the key determinants of cleanup costs because of the high expense of shore cleanup activities.

2.2 Analysis of Data Accuracy and Reliability

Because ERG derived oil spill cost data from a number of sources, it was necessary to consider any potential biases, inaccuracies, or inconsistencies in the data. Several issues are described below. The descriptions refer to data collected from several sources, but particularly from a variety of Coast Guard data bases. For a description of the background relevant to use of these source materials, refer to Section Three.

- ERG has pulled much information from Coast Guard On-Scene-Coordinator reports on oil spills and cleanup costs. The Coast Guard files do not provide a systematic format for reporting of the cleanup methods used, and therefore, some files appear not to have provided full details on this item. Further, ERG staff may have inadvertently omitted some details of the cleanup operation during the file searches.

- There may be variation in the definition of cleanup costs among the sources reporting. ERG attempted to exclude the costs of damages to environmental resources or costs for vessel salvage. Some of the sources reviewed, however, do not fully describe their cost assumptions and there may be unintended variation on this point.

- In the Coast Guard cases, cost information is generated when cases are "federalized," wherein the Coast Guard takes over full responsibility for execution of the cleanup. In such cases, however, potential or actual responsible parties may have expended some cleanup efforts before acknowledging or acceding to the Coast Guard role. There is no record in the Coast Guard files of the amount of spending by a responsible party on spill cleanup efforts. Thus, the cost figures may occasionally underestimate the actual expenditures on the cleanup.

- The additional Coast Guard data obtained from the Marine Pollution Incident Report System may include incomplete reports of costs if private companies as well as the Coast Guard participated in the cleanup efforts. It is also possible that, despite efforts to identify and eliminate duplicates, that some of the cases in the MPIR data covers the same spill as the data collected by ERG from individual Coast Guard offices. Such duplicates could occur in the years covered by the MPIR data, 1986 through 1988.

SECTION THREE
DESCRIPTION OF THE DATA COLLECTED

Section 3.1 reviews the data sources examined by ERG to date and presents a description of additional data sources which will also be examined during the course of this work. Section 3.2 explains the role of the U.S. Coast Guard in oil spill cleanups in the United States, while Section 3.3 presents a summary and brief analysis of each of the data sets. Section 3.4 describes the final data base. The data base itself, however, is presented in Appendix A.

3.1 Review of Data Sources

ERG assembled data from the following sources:

1. U.S. Coast Guard files on major spill events held at the Marine Environmental Response office (MER) in Washington, D.C.

2. Files covering all spills occurring within the First Coast Guard District in which the Coast Guard was directly involved in cleanup. These files are maintained at the MER in Boston.

3. Data files on spills that were held in the Eighth Coast Guard District MER in New Orleans on spills in which the Coast Guard in that region has been involved.

4. Data on 5 spill cleanup efforts, obtained during a meeting with the Boston MSO, on spill cleanup efforts that office had supervised. Of these, only two appear to be included in the data set reviewed at the First Coast Guard District MER. The other three incidents were added to the data base.

5. Spills reported in three years of data from the Marine Pollution Incident Report system (MPIR) which includes information on all spills overseen by the Coast Guard. For federalized spills, the total costs of the cleanup are also included in this data base.

6. Data on 15 spills which occurred in Canadian waters between 1979 and 1987. This information was provided by Canadian consultants working under contract to the Transportation Systems Center on another phase of the VTS study.

7. Data on 26 spills which resulted in compensation being paid for cleanup actions through the International Tanker Owners Pollution Federation Limited (ITOPFL). The ITOPFL has published an analysis of these spills and provided ERG with data on spill quantities, cleanup methods, and costs. A majority of the spills occurred in Europe.

8. Data provided by the International Oil Pollution Compensation (IOPC) Fund, an organization which handles compensation claims for oil pollution damage above and beyond that which is covered by a ship owner's liability. This source provided most of the foreign spill reports that are included in the data base.

9. Information on approximately a dozen spills collected from various sources and compiled by TSC. ERG also attempted to complete the cost data for a number of other spills for which TSC had compiled partial data. ERG's contacts to the firms involved were, however, generally unsuccessful in soliciting additional data.

10. Information presented in a draft report from the Minerals Management Service prepared by Kearney/Centaur.

The spill information from these diverse sources can also be grouped into two broad categories. The first category represents data from all sources except number 5 above. From these sources, ERG compiled information from original or secondary sources on a case-by-case basis. For source number 5 above, the Coast Guard Marine Pollution Incident Report System, ERG received a data file en masse of several hundred spill incidents. This MPIR data provided more than one-half of the observations in the overall data base and is therefore quite important to the study results. Nevertheless, ERG generally had more complete information about spills other than those from the MPIR as the result of searches of other source materials. In the sections below, the major data sources are reviewed in greater detail.

3.2 Background on U.S. Coast Guard Involvement in Marine Pollution Cleanup

The Coast Guard does not generally become involved in the direct cleanup of marine oil spills. Normally, where a responsible party (i.e. the person or company that owns the oil) is known and comes forward, the Coast Guard plays only a supervisory role, monitoring the cleanup and attending to issues of public safety related to the spill. Under the provisions of the Clean Water Act, however, the Coast Guard is charged with the responsibility of responding directly to certain marine pollution incidents. These include those where:

- the responsible party is unknown or cannot be located;
- the responsible party refuses to assume responsibility for the spill;
- the responsible party is financially unfit to assume responsibility for the spill cleanup; or
- the responsible party's performance in cleaning up the spill is judged to be inadequate or otherwise unsatisfactory.

In these cases, the Coast Guard on-scene coordinator (OSC) is authorized to "federalize", that is, take over the cleanup operation[1]. Depending on the sequence of events, particular cleanups may be either fully or partially federalized. In the case of a "mystery spill", where no responsible party can be found, the Coast Guard assumes responsibility for the cleanup from the beginning. In other instances, the Coast Guard may initially federalize a case, only to have a responsible party come forward and take over. Alternatively, the Coast Guard may have to intercede part way through a private cleanup if the operation is not being conducted in a timely and satisfactory manner.

The majority of the 12,000 spills which occur each year are cleaned up by the responsible party. A provision of the Clean Water Act authorizes the Coast Guard to pursue repayment for spill cleanup expenses from responsible parties. In addition to the direct costs of the cleanup, the Coast Guard may also assess the costs for any administrative and other expenses incurred by the Coast Guard and other state and federal government agencies and departments involved in the spill response. The threat of these additional charges has been found to be an effective inducement to force responsible parties into action.

---

[1] It should be noted that the Coast Guard itself is not the one who performs the cleanup. Environmental response personnel at the various Marine Safety Offices (MSOs) maintain basic ordering agreements (BAOs) with one or more private cleanup contractors in the area. These contractors carry out the majority of the cleanup work supervised by the local Coast Guard offices. The Coast Guard may undertake some initial response action (e.g. deploying booms) and will normally expend resources monitoring and supervising a cleanup.

For spills which are federalized, the Clean Water Act authorizes a fund (the 311k fund) to which the local Coast Guard office can apply for reimbursement of its contractor and administrative costs. In a federalized cleanup, the on-scene coordinator makes an initial estimate of the amount of federal funds which need to be committed to the cleanup. Throughout the cleanup, records of the costs expended and estimated final costs are to be maintained. The files on federalized spill cleanups therefore contain fairly complete accounts of the costs of these cleanups. For the regression analysis, ERG attempted to identify the cleanup costs only, as opposed to additional costs expended by the Coast Guard for monitoring the cleanup effort.. In some cases, however, only a total cost figure was available (i.e., one which provided both the cleanup costs and possibly some Coast Guard costs). Appendix B provides a listing of the spill data base and separate totals on the cleanup and Coast Guard costs of spills.

A subset of the federalized spills also provide detailed information concerning, among other things, the cleanup techniques utilized. These include either major spills or spills in which innovative cleanup technologies or spill management techniques were employed which have relevance for national planning purposes. This report, prepared by the on-scene coordinator, covers such things as the cause of the spill, an evaluation of the cleanup, and any recommendations which arise.

3.3 Descriptions of the Major Data Sources Used

3.3.1 Data on Major Spills and Other Spills Held at Coast Guard Marine Environmental Response (MER) Offices in Washington, Boston, and New Orleans

The Marine Environmental Response offices receive and maintain files on all major spills[2] and any other spills which require a full report from the on-scene coordinator. The largest collection of files are maintained at the Coast Guard offices in Washington, and the regional offices in Boston and New Orleans. These files constitute a good source of

---

[2] "Major" spills are defined by the Coast Guard as spills of 100,000 gallons or more if they occur in coastal waters and 1,000 gallons or more in inland waters.

information on both the costs of spill cleanups and the cleanup methods and procedures used. A chronological report of the cleanup progress, including the cleanup methods utilized, is often included in these reports.

ERG personnel reviewed information on several hundred spills dating back to 1976 in Coast Guard offices. These files constitute the most complete set of information concerning major spills in which the U.S. Coast Guard has had direct involvement. During the reviews, however, it was found that a substantial number of the reports could not be used for the purposes of this analysis. These spills fall into one of four categories;

- The spill was not federalized. Information on the costs of spill cleanups for non-federalized spills was not generally available.
- The spill was only partially federalized. The Coast Guard assumed responsibility for only a portion of the cleanup, hence the complete costs of the cleanup are not documented.
- No oil or other material was actually spilled. In many cases preventative action must be taken where only the threat of a spill arises. Information from these cases was recorded by ERG, but is not utilized in the analysis contained in this report.
- Information on the costs of the spill cleanup was not provided. In some cases, even though the spill was federalized, the total costs of the spill cleanup could not be found in the file.

As a result of the reviews, ERG was able to record relatively complete information on the costs and cleanup of only a portion of the files reviewed. Partial information was recorded for an additional selection of spills, although, as will be shown, data without cost or quantity data on the spill was not used.

ERG also reviewed files on federalized spills which are held at the MER offices in Boston, Massachusetts and in New Orleans, Louisiana. In general, these files contain less information concerning the spill cleanup effort than those on file in Washington. They do, however, contain most of the relevant cost data.

3.3.2 Review of Data Obtained from the Coast Guard Marine Pollution Data Base

The Transportation System Center received a set of files from the Coast Guard MPIR covering the years 1986, 1987 and 1988. TSC staff reviewed and interpreted the complex structure of the MPIR data and then provided the files and a data record to ERG for use on this project.

The MPIR data is based on reporting of pollution incidents provided by Coast Guard offices to the Coast Guard headquarters in Washington, D.C. The data represent final reporting of spill incidents and therefore constitute a useful source of information on spill incidents. The data describe the source, type and amount of materials spilled and whether a cleanup action was taken. Of most interest for this study, the MPIR data also provide information on the cleanup costs incurred in the spill was "federalized," that is if the Coast Guard took over responsibility for the cleanup actions. ERG was aware of the potential for duplication of spill incidents in the MPIR, with the data collected directly from the Coast Guard MER offices. As is discussed below, ERG took several measures to eliminate apparent duplicates in the data entries.

3.3.3 Data on Spills Monitored by the International Tanker Owners Pollution Federation Limited (ITOPFL)

The International Tanker Owners Pollution Federation Limited is a London-based organization which assists tanker owners in handling oil pollution cleanups and damage claims. ITOPFL staff have monitored oil spill cleanup, and published an analysis of 26 of these spills[3]. The analysis attempted to account for variation in the costs of oil spill cleanups, and examined such factors as: quantity and type of material spilled, location of spill, and cleanup methods used.

[3] "Comparative Costs of Oil Spill Cleanups," T.H.Moller, H.D. Parker, and J.A. Nichols, in Proceedings of the American Petroleum Association's 1987 Oil Spill Cleanup Conference.

The published information on the 26 spills included in the ITOPFL analysis included sufficient detail to allow for integration into the data base being developed by ERG. The data set includes primarily larger spills of 1,000 barrels or more. In all cases, it is assumed that at least some of the spilled material reached shore, as information on onshore cleanup techniques used was provided. Over half of the spills resulted in costs of $1 million or more, with the costliest spill cleanup totalling $23.8 million.

This and other sources could introduce biases into the data base if their are differences in oil spill cleanup techniques or philosophies between countries. Foreign nations may have higher or lower standards for oil spill cleanups. Also, some of the international mechanisms for compensating vessels of oil spill cleanup efforts may encourage more or less complete cleanup efforts through economic incentives or disincentives implicit in the payment mechanisms. Section Four investigates the difference in cleanup costs between U.S. and other nations.

3.3.4 Data on Spills Examined by International Oil Pollution Compensation Fund

The International Oil Pollution Compensation (IOPC) Fund is an organization that pays compensation for oil pollution damage under certain sets of conditions having to do with ship owner liability under international maritime conventions. For the purposes of this study, ERG was able to utilize IOPC Fund data on the circumstances and costs of cleanup for a variety of international oil spills. This data helped to supplement the reports obtained from the ITOPFL and from other sources on foreign spills.

3.3.5 Data Obtained from Other Sources

ERG also obtained from a variety of other sources. Some information was provided to ERG by the TSC project monitor, Judy Schwenk, based on her reviews of literature, including the Golob Oil Pollution Bulletin. ERG also endeavored to complete the information on a number of spills identified by TSC by contacting the companies (the shipping company, the cargo charterer or the cleanup contractor). These efforts were generally unsuccessful, however.

ERG also obtained a copy of a draft reported prepared for the Minerals Management Service by Kearney/Centaur. That study included information on the spill quantities and costs for approximately 100 cases. ERG entered this information into the data base as well.

3.4 Summary of the Spill Data Base

A summary of the spills for which relatively complete information was collected is provided in Appendix A. The spills are ranked in terms of the quantity of material spilled. All cost data show the total direct cost of the cleanup actions. These costs exclude any administrative or other costs incurred by the Coast Guard or other agencies for initial response and monitoring of the cleanup.

As the Appendix A table indicates, a number of spills cost more than $1 million in cleanup expenses. The most expensive spill in this set of data resulted from the grounding of the Exxon Valdez in Prince William Sound off Alaska. That spill of 10.8 million gallons of crude oil is estimated to have cost over $2 billion in cleanup expenses.

The final data base reflects ERG's efforts to eliminate any duplicate entries from the diverse sources and to correct any errors or inconsistencies in other data entered. Numerous entries from the Kearney/Centaur data, for example, duplicated entries from other sources such as the IOPC Fund. The identification of duplicates was complicated because of inconsistencies in the reporting of spills from various sources. For example, some sources gave only the year of a spill, whereas other gave the exact date. In some cases, ERG staff had to make judgments about the validity of separate entries with similar characteristics. In endeavoring to eliminate all duplicates, it is possible that ERG incorrectly eliminated a spill that was otherwise correctly described in one of the data bases.

SECTION FOUR

REGRESSION ANALYSIS ON MARINE SPILL DATA

4.1 Introduction

ERG combined information on marine spills from the numerous sources listed earlier and performed regression analysis on the combined data set. The purpose of the analysis is to estimate statistical equations that could be used to predict the costs of cleanup associated with future spills of oil and other materials.

The oil spill data was first examined for consistency. Then, alternative forms of the regression equations were explored. Finally, the regression results were evaluated in terms of their meaning and explanatory potential. Sections 4.2 through 4.4 discuss these three steps.

4.2 Data Verification and Transformation

A number of steps were taken to produce a single, consistent set of data for use in estimating statistical relationships. These are describe below:

- Conversion of spill quantity to consistent base unit - All spill quantities were converted into a single base unit, gallons. Various sources report spill quantity in terms of barrels spilled, or tons spilled. ERG used conversion factors of 1 barrel = 42 U.S. gallons and 1 ton = 215.9 gallons. The conversion factor for tons is based on an average density (0.85) of a range of petroleum products;

- Conversion of all data given in foreign currencies to U.S. dollar amounts - Several of the sources used provided information on cleanup costs in terms of foreign currencies, particularly the Japanese yen, but several other currencies as well. ERG used the dollar/foreign currency exchange rates at the end of the year for the foreign spills, as reported in publications from the International Oil Pollution Compensation Fund.

- Adjustment of spill cleanup costs to constant dollar amounts - All spill cleanup costs were converted from their base year amount to a constant dollar amount. Cleanup costs were inflated to 1990 dollars using the Census Bureau's Producer Price Index (PPI). This index is published monthly in the Monthly Labor Review. A time series of this data can be found in the annual Economic Report of the President and in other sources. The PPI tracks changes in costs of goods and services used in the production of other goods and services. ERG judged that the PPI is an appropriate index for adjusting the prices of industrial goods and services such as oil spill cleanup services.

- Elimination of spills with zero spill quantity or cleanup cost - Those observations where either spill quantity or spill cleanup costs were zero (or unknown) were dropped from the data set. These include incidents where no spill occurred, where the spill quantity or cleanup cost was unknown, or where a spill took place but no cleanup action was taken;

- Elimination of duplicate spills from data base - Because several sources were used to obtain information on spill cleanups, there was a possibility that more than one source had provided information on the same spill. The data set was sorted on variables such as vessel name and spill location. Where duplicate records were found, the information from each source was combined to create a single record;

- Coding of type of material spilled - The type of material involved in each spill was coded, where possible, as either: (1) heavy petroleum product, (2) light petroleum product, (3) chemical, (4) other, or (5) unknown. In many cases, the response to spills involving light petroleum products such as gasoline, kerosene, or diesel fuel are limited to monitoring and observing the spill. This is because spills of these materials dissipate rapidly through evaporation. Actual cleanup of such spills is generally viewed as both difficult and unnecessary, assuming the threat to the environment or public safety is minimal;

- Coding of whether spill hit shoreline - Where available, information concerning whether the spill affected shorelines or not was coded. Much of the cost of cleaning up such spills occurs onshore. For spills that do not reach shore, response may often include only monitoring actions.

Once all of these variables were coded and adjusted, a set of 662 observations was obtained.

4.3 Data Regressions

The purpose of the regression analysis is to explore any statistical relationships between spill size and spill cleanup cost. We began with the a priori assumption that spill cleanup cost is some positive function of spill size, i.e., the larger the spill, the larger the cleanup cost. Spill size is the independent variable, and cleanup cost the dependent variable. The first step in the analysis explored the possible functional forms of this relationship. In Table 4-1, several possible functional forms are considered.

In Table 4-1, Equations 1 to 3 specify cleanup cost as a function, respectively, of:

(1) Spill size, i.e., a linear functional relationship. This implies a constant slope. The estimated cleanup costs will decrease or increase at a constant rate with respect to changes in spill size;

(2) Spill size and the square of spill size, i.e., a quadratic relationship. In this case, the change in cleanup costs with respect to a given change in spill size will increase or decrease along the curve;

(3) The natural log of spill size, i.e. a non-linear relationship. In such a curve, the coefficient on the log of spill size represents the change in cleanup cost associated with a given percentage change in spill size.

As seen in the results, Equations 1 - 3, with spill size as the dependent variable, have very little explanatory power. R^2 values for these equations are 0.04, 0.11, and 0.05, respectively. This means that very little of the variation of spill cleanup cost is explained by linear, quadratic, or non-linear variations in spill size.

Equations 4 - 6 use cost per gallon spilled as the dependent variable, and regress it against the three forms of spill size. As seen in the results, the explanatory power of these equation forms is very weak. With cleanup cost per gallon expressed as a linear function of spill size, R^2 is equal to 0.0001. R^2's of 0.0002 and 0.015 were obtained using cost per gallon as a quadratic and non-linear function of spill size, respectively.

In Equations 7 - 9, the natural log of cleanup cost is regressed against the linear, quadratic, and non-linear forms of spill size. R^2 values for the first of these two are 0.04 and 0.09. When regressed against the natural log of spill size, however, the R^2 rises to 0.74. This means that about three-quarters of the variation in the dependent variable is explained by the variation in the independent variable. This is a reasonably good result for data of this sort. The coefficient of the dependent variable is 0.76, which indicates economies of scale in cleanup cost. The interpretation of this coefficient for an equation of this form is as follows: at any point on the curve, a 10 percent increase in spill size is associated with a 7.6 percent increase in cleanup costs. The standard error of this coefficient indicates that the value of 0.76 is statistically significant. A plot of the regression line and actual spill data is shown in Figure 4-1.

A final set of regressions (Equations 10 - 12) were estimated using the natural log of the cost per gallon as the dependent variable. When regressed against the linear, quadratic, and non-linear forms of the independent variable, these resulted in R^2's of 0.02, 0.02 and 0.22, respectively. All of these provided results that were inferior to those obtained using Equation 9, which is non-linear in both the dependant and independent variables. It should be noted, however, that the log-linear specification of the cost per gallon regression shown in Equation 12 is consistent with Equation 9 and that the estimated coefficients for Equation 9 may be obtained by solving the estimate of Equation 12 for the log of cleanup costs.

Based on the results discussed above, ERG focused on the log-linear functional form represented in Equation 9. This form had the highest R^2 value (0.74), and describes a plausible relationship between spill cleanup cost and spill size.

Effects of Type of Material Spilled

In Equations 13-15 we examined the effects of several additional explanatory variables. Equation 14 includes two dummy variables that represent the type of material spilled. The first dummy takes a value of 1 if the material is a heavy petroleum product and 0 otherwise. Presumably, spills of heavy petroleum products are more difficult to clean up than other types. Indeed, often little effort is made to clean up offshore spills of gasoline, kerosene or other light products. Such materials are quite volatile and either evaporate or are quickly dispersed by wave action. The other dummy takes a value of 1 if the spill involved chemicals or other non-petroleum products[1].

The inclusion of the dummy variables for type of material spilled raises the R^2 value slightly, from 0.7376 to 0.7399. The coefficient value for spill size falls slightly, and both coefficients for the dummy variables are significant and positive. This suggests that spills of heavy petroleum or chemicals may be somewhat more costly to clean up than spills of a similar size involving light petroleum products. The relatively small effect on R^2 shows that while the variables may be significant they add little explanatory power to the overall model.

A separate regression for spills of chemicals and other non-petroleum products is shown in Equation 14. A total of 70 spills are included, although only five of these are definitely identified as chemicals (see footnote 1). For these spills as a group, the R^2 value is low (0.16) suggesting that chemical spill cleanup costs cannot be predicted accurately using the data available.

---

[1] Only 5 spills were in the MPIR data base were positively identified as involving chemicals, however an additional 65 that were coded with asterisks were assumed to involve chemicals for purposes of the regressions. According to Coast Guard personnel, the asterisks appear when the person reporting the spill provides the type of material himself, rather than inputting a code for the type of material spilled. Thus, spills where the type of material appears as asterisks involve materials that are not commonly spilled.

Figure 4-2 shows total spill cost and cost per gallon spilled for the five spills identified as chemicals, while Figure 4-3 shows a scatter diagram for all chemical and other non-petroleum spills.

Effect of Proximity to Shore

Equation 15 investigates the effects of proximity to shore on spill cleanup cost. Evidence exists to suggest that spills that remain at sea cause less damage and are also less likely to be cleaned up. Some caution is required when examining these results, as ERG was able to determine whether the spill came ashore in only 101 of the 653 spills[2]. In 92 of the cases it was determined that the spill did reach the shoreline, while only 9 cases were found where the spill remained at sea. In this model, the coefficient on spill size remains about the same, while the dummy variable is significant but negative. This would imply that spills that do not reach shore are more costly to clean up than spills of the same size that do come ashore. This result is somewhat counterintuitive; however, it may be due to the fact that the spills identified as remaining at sea are smaller, on average, than those that reached shore. Also, it is possible that more spills that reach shore can be cleaned up using land-based cleanup equipment, such as vacuum trucks, which are relatively inexpensive to deploy. Finally, the effect on the estimated coefficient of the incomplete information on whether the spill reached shore is unknown.

Equation 16 includes the dummy variable from Equation 13 for heavy oil as well as that from Equation 15 indicating whether or not the spill reached shore. Only 88 spills contained information on both of these variables. The regression results are similar to those already seen: regression coefficient of 0.78, dummy for heavy oil positive and significant, dummy for reaching shore negative and somewhat significant.

In Equations 17 and 18, we performed separate regressions of the general model (Equation 9) for these subsets of the data, namely for spills of heavy petroleum products only (Equation 17) and for spills that reach shore (Equation 18). Recall that the fit in Equation 9 was $R^2 = 0.74$ with a coefficient of 0.76 for spill size. In Equation 17, the fit is somewhat better ($R^2 = 0.81$) while

[2] The MPIR data base, which was the source of 450 of the 653 spills analyzed, provides no means for identifying whether the spill reached shore or not.

the coefficient for spill size is similar at 0.78. In Equation 18, both the R^2 and the coefficient are similar.

Differences Between Large and Small Spills

Additional investigations of the log-linear form of the model are shown in Equations 19 and 20. Here, an attempt was made to find out whether there are any differences in the model parameters for small and large spills. Of the 653 spills in the data base, 492 (or 75 percent) are very small, 1,000 gallons or less in size. The average size of the 161 spills over 1,000 gallons, on the other hand, is 2.0 million gallons.

Separate regressions were run for each group of spills. Plots of cleanup cost against spill size are shown in Figures 4-4 and 4-5. For small spills (Equation 19), the constant term (or intercept) is 5.34 and is higher than that for larger spills (Equation 20). The slope coefficient, which indicates the economies of scale, is 0.51. For larger spills, however, the slope coefficient is 0.74, suggesting that economies of scale are smaller for these spills.

Note that the R^2 values for both regressions are smaller than the R^2 obtained by regressing the entire data set. This is due to the fact that the independent variable in the regression on the total data set explains some of the variance between the means of the cleanup costs for each of the two size classes of spills. The separate size class regressions explain only the variance around the mean costs for each spill. Despite lower R^2 values, the combined sums of the squared residuals for the two size class regressions is about 5% less than the sum of the squared residuals obtained from Equation 9 for the entire data set.

Differences Between Spills in U.S. Waters and Foreign Spills

The location of the spill, i.e., whether the spill occurred in U.S. or foreign waters, was the final variable investigated . It has been suggested that spill cleanup costs may differ for spills occurring in various geographic locations because countries have different standards for cleaning up such spills. The question "How clean is clean?" may be answered differently around the globe. Or, for a given cleanup effort, spill cleanup costs may differ among locations for reasons such as weather or prevailing sea conditions, availability of cleanup requirement, and local economic conditions.

Equation 21 tests whether spills occurring in U.S. waters result in higher cleanup costs than similar cleanups occurring elsewhere. For purposes of these regressions, spills occurring in waters off the continental United States (i.e., including Hawaii and Alaska and excluding Puerto Rico, U.S.V.I., Guam, etc.) were flagged with a dummy variable taking the value of 1, while for all other spills the variable took a 0. A total of 542 spills, representing 83 percent of the total, occurred in U.S. waters.

The regression results are interesting, as they show the dummy variable to be significant yet negative. Thus, spills outside the U.S. may cost more to cleanup than spills within U.S. waters. Compared to Equation 9, the base model, this regression has a similar intercept, coefficient for spill size, and R^2. Thus, while the dummy variable is significant it adds little in the way of explanatory power to the model.

4.4 Conclusion

The results presented above indicate that the log-linear form of the equation provides a reasonable fit to the data when regressing spill cleanup cost against the quantity of material spilled. The scatter diagram shown in Figure 4-1 indicates the reasonably high level of correlation between these two variables over the entire range of spill sizes investigated.

The R^2 value of 0.74 obtained by regressing the log of cleanup cost against the log of spill size has not been greatly improved through the addition of numerous other possible explanatory variables. While some of these additional variables appear to be significant, they fail to increase the overall explanatory power of the model. From this standpoint, Equation 9 stands out as the best model specification.

The slope coefficient of 0.74 indicates that there are economies of scale with respect to cleanup cost. As explained, a coefficient of less than one is interpreted as meaning that a given percentage increase in spill size is associated with a less than equal percentage increase in spill costs. As shown in Equations 19 and 20, the economies may be smaller for larger spills than for smaller ones, although the significance of the differences between the two coefficients has not been tested.

TABLE 4-1
Summary of Regression Results on Oil Spill Data Base

Equation 1

Dependent	Y	Cleanup cost ($1990)
Independent(s)	X	Spill size (gallons)

Regression Output:

Constant		2,543,712
Std Err of Y Est		42,181,025
R Squared		0.0424
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	1.1291	
Std Err of Coef.	0.2104	
t-statistic	5.3664	
t-probability	0.0000	

Equation 2

Dependent	Y	Cleanup cost ($1990)
Independent(s)	X	Spill size (gallons)
	X^2	Square of spill size

Regression Output:

Constant		2,356,441
Std Err of Y Est		76,088,039
R Squared		0.1125
No. of Observations		662
Degrees of Freedom		659
X Coefficient(s)	11.8188	(0.0000)
Std Err of Coef.	1.2992	0.0000
t-statistic	9.0973	(8.6228)
t-probability	0.0000	0.0000

Equation 3

Dependent	Y	Cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size

Regression Output:

Constant		(14,053,770)
Std Err of Y Est		41,980,375
R Squared		0.0515
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	2,970,075	
Std Err of Coef.	499,808	
t-statistic	5.9424	
t-probability	0.0000	

TABLE 4-1 (Cont.)
Summary of Regression Results on Oil Spill Data Base

Equation 4

Dependent	Y/X	Cleanup cost/gal ($1990)
Independent(s)	X	Spill size (gallons)

Regression Output:

Constant		106.3773
Std Err of Y Est		629.9938
R Squared		0.0001
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	(0.0000)	
Std Err of Coef.	0.0000	
t-statistic	(0.2671)	
t-probability	0.3948	

Equation 5

Dependent	Y/X	Cleanup cost/gal ($1990)
Independent(s)	X	Spill size (gallons)
	X^2	Square of spill size

Regression Output:

Constant		106.7830
Std Err of Y Est		630.4500
R Squared		0.0002
No. of Observations		653
Degrees of Freedom		650
X Coefficient(s)	(0.0000)	0.0000
Std Err of Coef.	0.0000	0.0000
t-statistic	(0.3031)	0.2414
t-probability	0.3809	0.4047

Equation 6

Dependent	Y/X	Cleanup cost/gal ($1990)
Independent(s)	ln(X)	Log of spill size

Regression Output:

Constant		241.1486
Std Err of Y Est		625.3125
R Squared		0.0149
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	(23.3724)	
Std Err of Coef.	7.4448	
t-statistic	(3.1394)	
t-probability	0.0009	

TABLE 4-1 (Cont.)
Summary of Regression Results on Oil Spill Data Base

Equation 7

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	X	Spill size (gallons)

Regression Output:

Constant		8.7114
Std Err of Y Est		2.8575
R Squared		0.0400
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	0.0000	
Std Err of Coef.	0.0000	
t-statistic	5.2098	
t-probability	0.0000	

Equation 8

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	X	Spill size (gallons)
	X^2	Square of spill size

Regression Output:

Constant		8.6667
Std Err of Y Est		2.7829
R Squared		0.0909
No. of Observations		653
Degrees of Freedom		650
X Coefficient(s)	0.0000	(0.0000)
Std Err of Coef.	0.0000	0.0000
t-statistic	7.2247	(6.0293)
t-probability	0.0000	0.0000

Equation 9

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size

Regression Output:

Constant		4.3484
Std Err of Y Est		1.4940
R Squared		0.7376
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	0.7609	
Std Err of Coef.	0.0178	
t-statistic	42.7759	
t-probability	0.0000	

TABLE 4-1 (Cont.)
Summary of Regression Results on Oil Spill Data Base

Equation 10

Dependent	ln(Y/X)	Log of cleanup cost/gal ($1990)
Independent(s)	X	Spill size (gallons)

Regression Output:

Constant		2.9795
Std Err of Y Est		1.6742
R Squared		0.0171
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	(0.0000)	
Std Err of Coef.	0.0000	
t-statistic	(3.3696)	
t-probability	0.0004	

Equation 11

Dependent	ln(Y/X)	Log of cleanup cost/gal ($1990)
Independent(s)	X	Spill size (gallons)
	X^2	Square of spill size

Regression Output:

Constant		2.9809
Std Err of Y Est		1.6753
R Squared		0.0173
No. of Observations		653
Degrees of Freedom		650
X Coefficient(s)	(0.0000)	0.0000
Std Err of Coef.	0.0000	0.0000
t-statistic	(1.1898)	0.3146
t-probability	0.1173	0.3766

Equation 12

Dependent	ln(Y/X)	Log of cleanup cost/gal ($1990)
Independent(s)	ln(X)	Log of spill size

Regression Output:

Constant		4.3484
Std Err of Y Est		1.4940
R Squared		0.2173
No. of Observations		653
Degrees of Freedom		651
X Coefficient(s)	(0.2391)	
Std Err of Coef.	0.0178	
t-statistic	(13.4445)	
t-probability	0.0000	

TABLE 4-1 (Cont.)
Summary of Regression Results on Oil Spill Data Base

Equation 13

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
	X2	Product (1 if heavy oil; else 0)
	X3	Product (1 if chem/other; else 0)

Regression Output:			
Constant		4.1429	
Std Err of Y Est		1.4898	
R Squared		0.7399	
No. of Observations		653	
Degrees of Freedom		649	
X Coefficient(s)	0.7547	0.3125	0.3530
Std Err of Coef.	0.0180	0.1405	0.1822
t-statistic	41.9898	2.2239	1.9377
t-probability	0.0000	0.0133	0.0265

Equation 14

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
		chemical spills only

Regression Output:		
Constant		6.1484
Std Err of Y Est		1.6208
R Squared		0.1657
No. of Observations		70
Degrees of Freedom		68
X Coefficient(s)	0.3826	
Std Err of Coef.	0.1041	
t-statistic	3.6753	
t-probability	0.0002	

Equation 15

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
	X3	Shore (1 if spill hit shore; else 0)

Regression Output:		
Constant		5.6625
Std Err of Y Est		1.6936
R Squared		0.7486
No. of Observations		101
Degrees of Freedom		98
X Coefficient(s)	0.7686	(1.0706)
Std Err of Coef.	0.0461	0.6231
t-statistic	16.6741	(1.7182)
t-probability	0.0000	0.0445

TABLE 4-1 (Cont.)
Summary of Regression Results on Oil Spill Data Base

Equation 16

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
	X2	Product (1 if heavy oil; else 0)
	X3	Shore (1 if spill hit shore; else 0)

Regression Output:			
Constant		5.4304	
Std Err of Y Est		1.6615	
R Squared		0.7605	
No. of Observations		101	
Degrees of Freedom		97	
X Coefficient(s)	0.7414	0.7643	(1.0641)
Std Err of Coef.	0.0469	0.3478	0.6113
t-statistic	15.8156	2.1977	(1.7407)
t-probability	0.0000	0.0152	0.0425

Equation 17

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
		spills of heavy oil only

Regression Output:		
Constant		4.3137
Std Err of Y Est		1.3231
R Squared		0.8095
No. of Observations		371
Degrees of Freedom		369
X Coefficient(s)	0.7788	
Std Err of Coef.	0.0197	
t-statistic	39.6044	
t-probability	0.0000	

Equation 18

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
		spills coming ashore only

Regression Output:		
Constant		4.5710
Std Err of Y Est		1.7106
R Squared		0.7467
No. of Observations		92
Degrees of Freedom		90
X Coefficient(s)	0.7712	0.0000
Std Err of Coef.	0.0473	0.0000
t-statistic	16.2892	0.3146
t-probability	0.0000	0.3769

TABLE 4-1 (Cont.)
Summary of Regression Results on Oil Spill Data Base

Equation 19

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
		spills <= 1,000 gallons

Regression Output:

Constant		5.3404
Std Err of Y Est		1.3451
R Squared		0.2153
No. of Observations		492
Degrees of Freedom		490
X Coefficient(s)	0.5100	
Std Err of Coef.	0.0440	
t-statistic	11.5947	
t-probability	0.0000	

Equation 20

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
		spills > 1,000 gallons

Regression Output:

Constant		3.7633
Std Err of Y Est		1.7690
R Squared		0.5539
No. of Observations		161
Degrees of Freedom		159
X Coefficient(s)	0.8306	
Std Err of Coef.	0.0591	
t-statistic	14.0516	
t-probability	0.0000	

Equation 21

Dependent	ln(Y)	Log of cleanup cost ($1990)
Independent(s)	ln(X)	Log of spill size
	X2	U.S. (1 if spill in U.S.; 0 otherwise)

Regression Output:

Constant		4.9480
Std Err of Y Est		1.4841
R Squared		0.7414
No. of Observations		653
Degrees of Freedom		650
X Coefficient(s)	0.7299	(0.5231)
Std Err of Coef.	0.0203	0.1678
t-statistic	36.0151	(3.1176)
t-probability	0.0000	0.0010

Figure 4-1

Plot of Spill Size Against Cleanup Cost

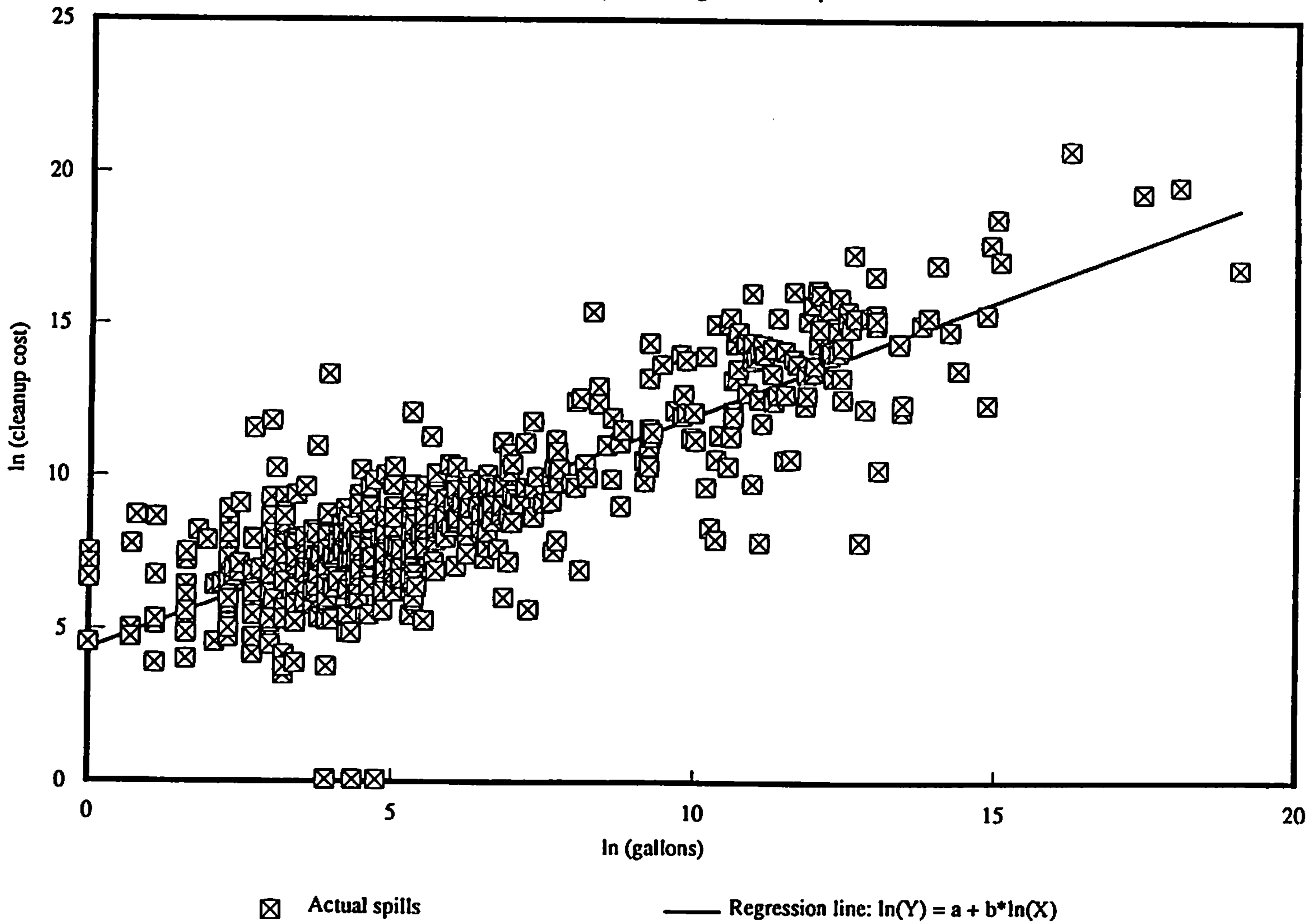


Figure 4-2

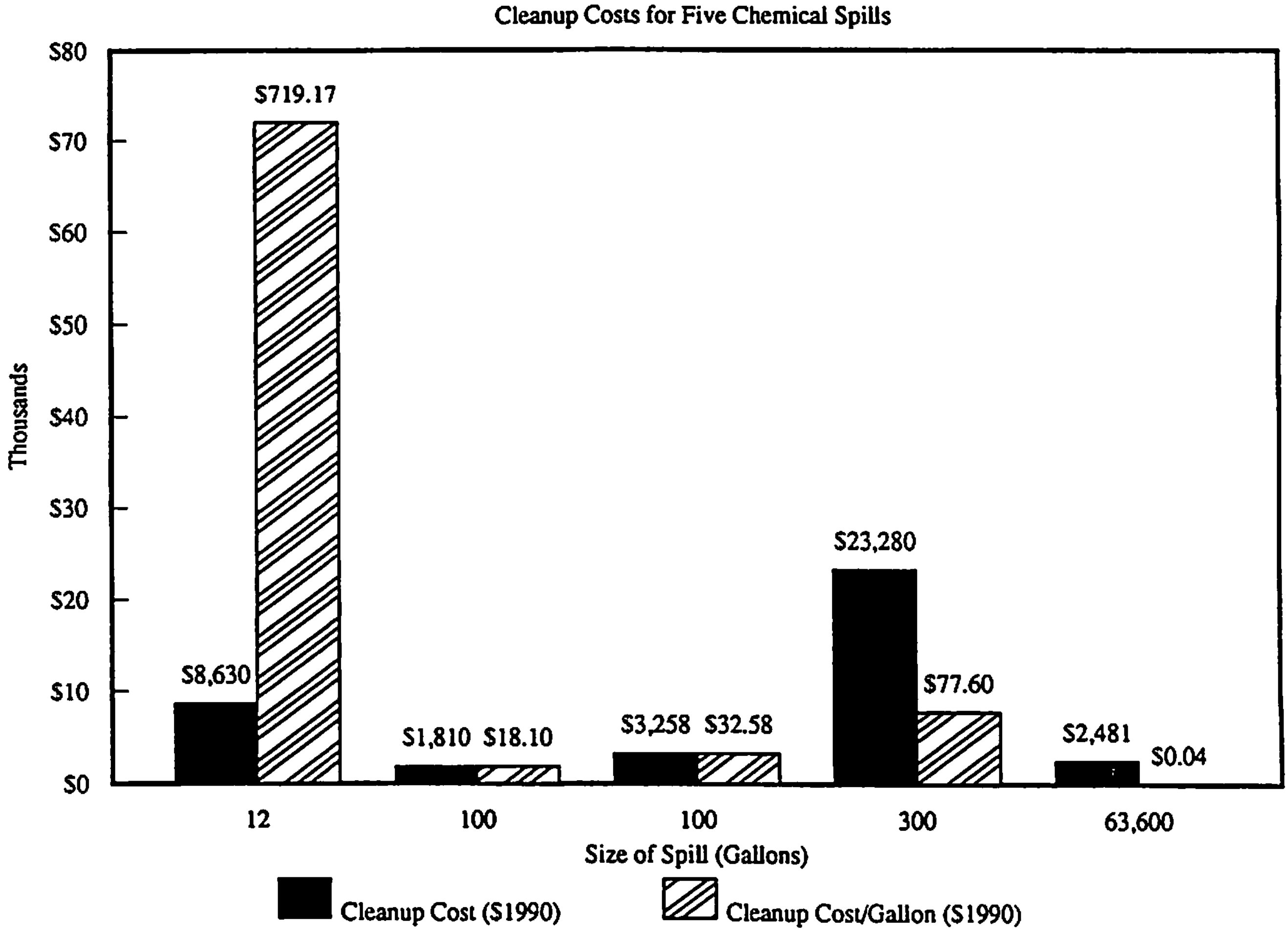

Cleanup Costs for Five Chemical Spills
$80
$70
$60
$50
$40
$30
$20
$10
$0
Thousands
$719.17
$8,630
$1,810 $18.10
$3,258 $32.58
$23,280
$77.60
$2,481
$0.04
12
100
100
300
63,600
Size of Spill (Gallons)
Cleanup Cost ($1990)
Cleanup Cost/Gallon ($1990)

Figure 4-3

Plot of Chemical and Other Spill Types

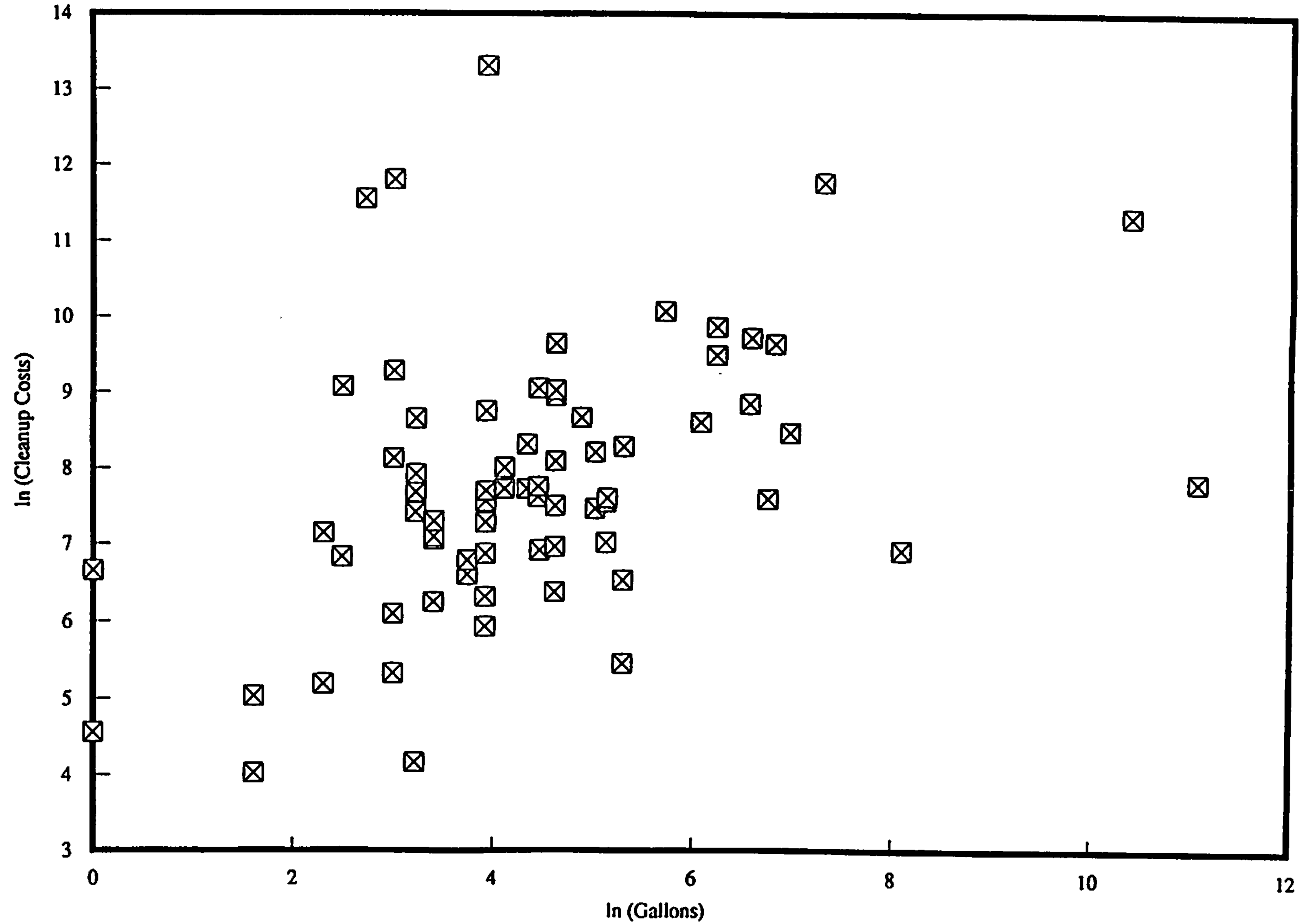


Figure 4-4

Plot of Spill Size Against Cleanup Cost, Spills 1,000 gallons and under

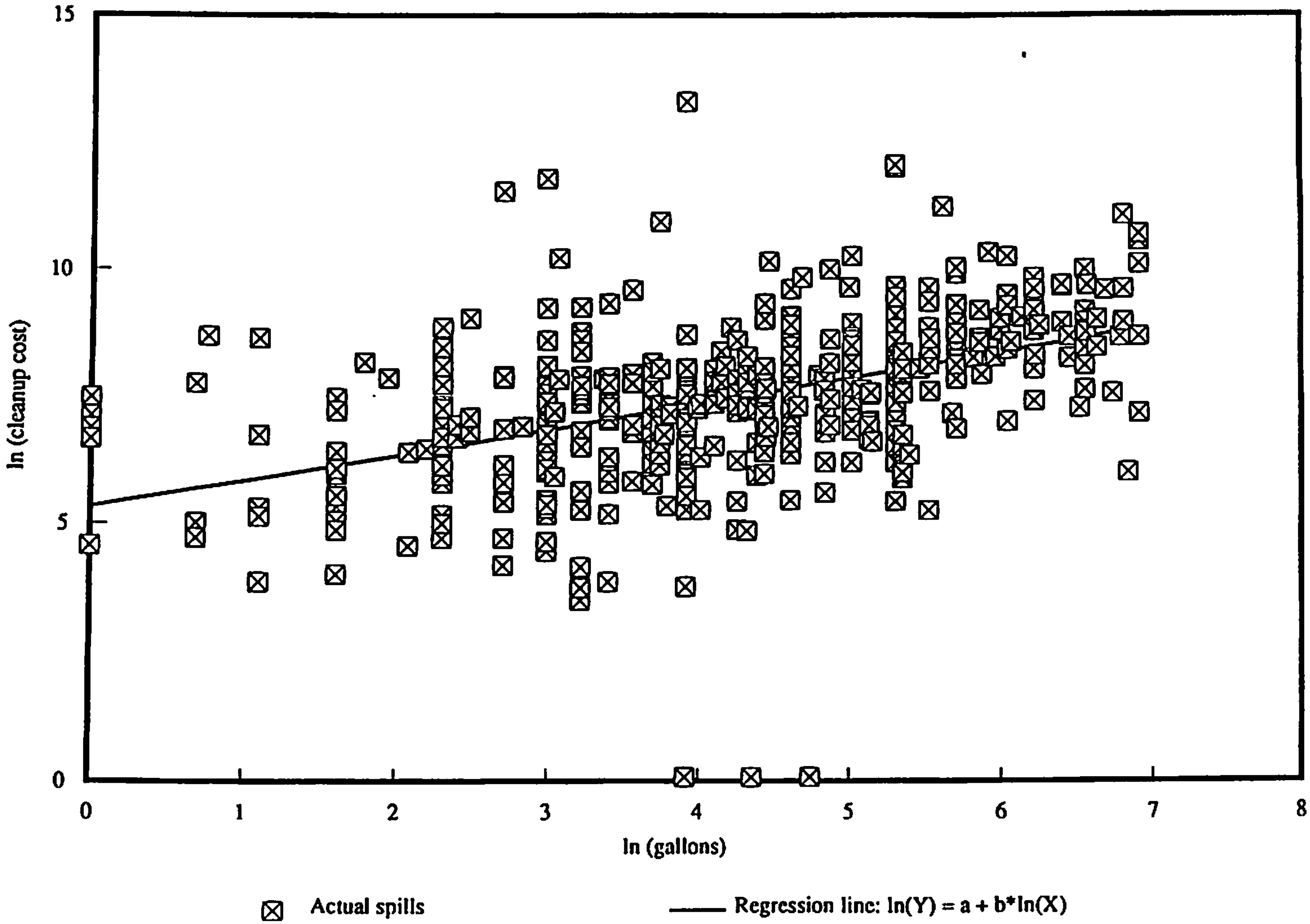
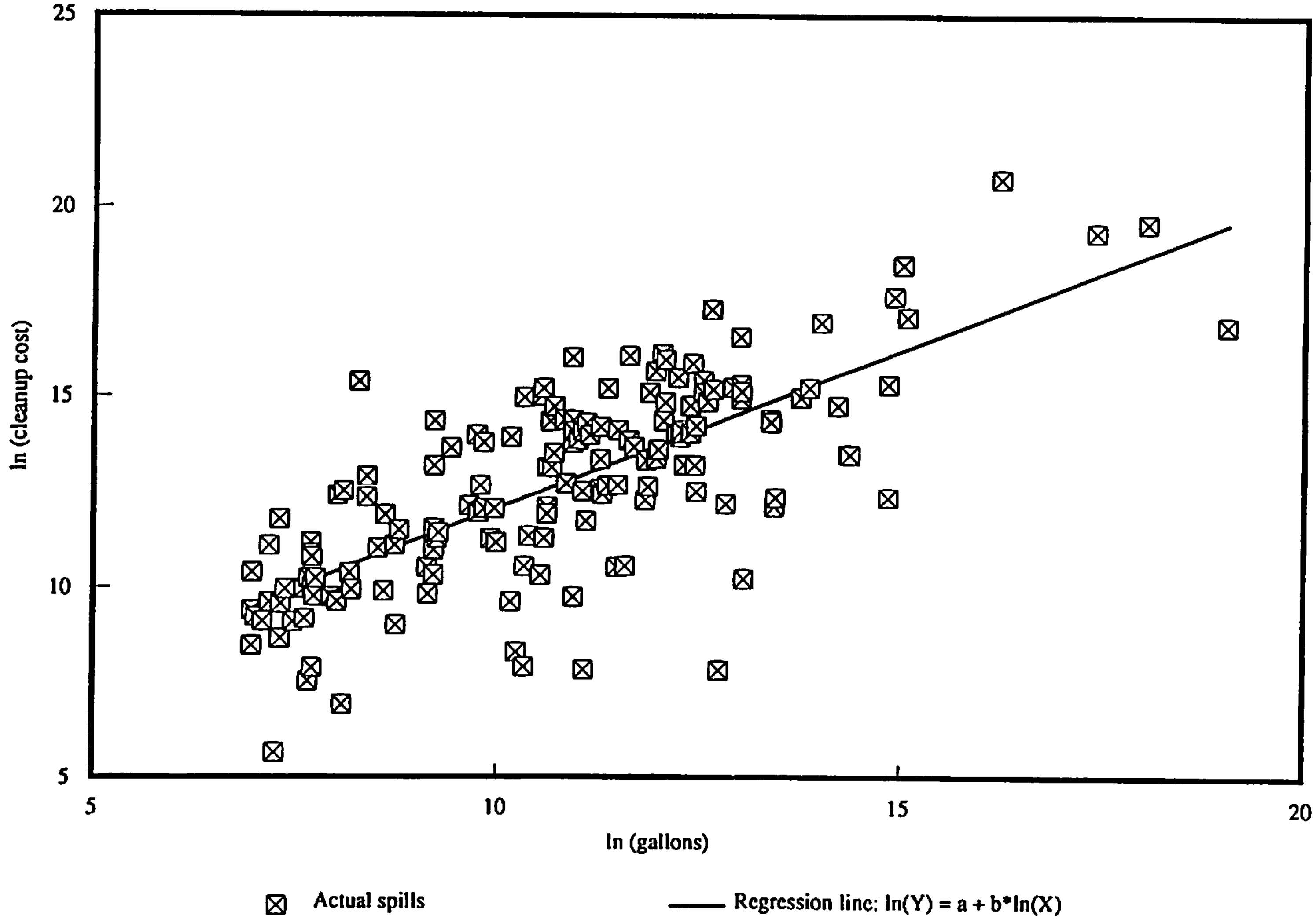


Figure 4-5

Plot of Spill Size Against Cleanup Cost, Spills over 1,000 gallons



SECTION FIVE

DEVELOPMENT OF FACTORS FOR USE IN ESTIMATING DIRECT AND INDIRECT COSTS

ERG assembled data on common or representative elements of maritime economics that were judged to be potentially useful by the Transportation Systems Center in the development of estimates associated with the direct and indirect costs of vessel casualties. These estimates are needed as part of the benefit/cost model being developed by TSC for the Coast Guard.

ERG prepared estimates of a set of variables that represent part of the cost (or that help determine the costs) of vessel casualties. The items include the typical duration of dock time for vessel repairs, vessel operating costs and capital costs per day of dock time, the relationship of vessel cargo-capacities to vessel drafts (for use in relating measures of maritime economics to measures used in the design of port traffic safety systems), foregone operating revenues, and miscellaneous other items that affect vessel casualties. Each set of estimates is presented in a table below, along with a description of the sources of each estimate.

5.1 Derivation of Estimates of the Duration of Vessel Dock Time

ERG compiled estimates of the amount of time necessary to accomplish major vessel repair jobs that may have resulted due to collisions or groundings. In order to develop the necessary estimates, ERG contacted personnel in various U.S. shipyards and requested general estimates of repair times for jobs of various monetary values. Table 5-1 presents the estimates. The data in Table 5-1 and in this section are based primarily on telephone discussions with personnel of the Norfolk, Jacksonville, and Newport News shipyards. All of the persons contacted stated that their estimates consisted of only very rough approximations of the possibly complicated repair circumstances.

Table 5-1
REPRESENTATIVE DURATIONS FOR
VESSEL REPAIRS OF SPECIFIED SEVERITY
(days)

VESSEL CATEGORIES (% of Repair for Struct. Damage)	Cost of Repair ($'000)								
	$5	$10	$25-75	$100	$250	$500	$1,000	$5,000	Comment
Dry cargo (75%)	NA	NA	NA	2	5-12	7-14	14-35	60-90	Requirements for cleaning of cargo holds can affect repair time (also true for tankers).
Tanker (75%)	NA	NA	NA	2	5-12	7-14	14-35	60-90	Tanker repairs are lengthy, more costly for given collision due to complications of design, cargo, tank cleaning.
Passenger or Ferry (50%)	NA	NA	NA	NA	2-3	5	10	14	Passenger ferries have greatly compressed schedules; Ship owner may bring in hundreds of workers to repair passenger areas.
Barges (100%)	NA	NA	NA	2	5-12	7-14	14-35	NA	Length of barge repairs similar to other cargo vessels. Repair jobs over $2 million are rare.
Fishing (100%)	3-7	14-21	28-35	30-50	60-90	NA	NA	NA	Duration of repairs often varies dramatically with the availability of parts.

NA= Not commonly applicable for the vessel class, not estimated.

(a) Based on repair costs for U.S. ship yards. For repairs in foreign ship yards, the costs of repairs should be reduced by 15-25%

Source: ERG estimates based on conversations with estimating and sales personnel at Jacksonville, Norfolk and Newport News shipyards. Estimates are subject to considerable uncertainty due to variability of repair circumstances. Estimates for duration of smaller repairs for fishing vessels (those under $100,000) were based on conversations with Robert Kershaw, President of Robert N. Kershaw, Inc., Braintree, MA.

The repair time estimates are intended to reflect approximate central tendencies for the distribution of the time needed for dock repairs for general classes of vessels. In most cases, repair work will be undertaken with considerable urgency because the cost of repair is often less important than the foregone revenue of the vessel's dock time. While docked for repairs necessitated by a vessel casualty (such as damage to the bow resulting from a collision), the ship owner will attempt to complete any other repairs that can be accomplished simultaneously that won't delay the vessel's return to productive service.

In order to solicit the estimates of repair time, ERG defined its question to shipyard managers in terms of the total costs of repair. In most cases, however, a portion of the repairs being performed on a vessel will include both structural work, and other repairs to various "topside" equipment, including boilers, steering systems, and other items. In the case of passenger vessels, a repair period may be used to refurbish some passenger areas. The portion of the repair costs attributable to topside equipment is not related in most cases to vessel casualties such as rammings or groundings. It is useful, therefore, to consider that various portions of the repair costs should be discounted if the repair durations shown in Table 5-1 are to be related to vessel casualty damage estimates such as those that are reported in the Coast Guard data base, CASMAIN. ERG estimated the percentage of the repair totals that are likely to be generated by structural (i.e., hull) repairs as opposed to other types of repairs. In the case of barges, where there may be little topside equipment, all of the repair was categorized as structural repair. In the case of passenger vessels, however, only 50% of the repairs are credited to structural damage such as would be caused by a ramming or grounding. In subsequent calculations, the repair costs for the different vessel categories are corrected by the percentage amounts shown in Table 5-1 to eliminate from consideration repairs that are not related to casualties.

As the table shows, only repair jobs of $5 million or more for bulk carriers and tankers consume as much as two months of time. In the case of passenger ships, the scheduling of work is even more urgent, and the quantity of repair work performed in a given period of dock time will be even greater.

The categories for the monetary value of repair work apply equally to repairs due to collisions, rammings or groundings. At the lower end of scale, repair work would cover relatively minor damages, modest holes in the steel plates of the hull (such as due to a low speed collision), or damage to a propeller (such as due to a grounding). At the other end of the scale, a repair job costing $5 million would cover extensive repairs to numerous steel plates on the bow of the ship or a lengthy gash in the hull due to a major grounding incident.

Most repair jobs are considered so urgent that ship owners of all types are likely to require that the repair contract include a clause that penalizes the shipyard for any delays in the completion of work. In the case of passenger ships, these clauses could call for damages of over $200,000 per day or more. Even Navy ships generally include penalties for delays in work completion.

The most extreme example of tight repair scheduling is the case of passenger ship companies that will hire hundreds of additional shipyard workers at their own expense to assist the regular shipyard personnel to complete a repair turnaround. Most of the additional workers, however, perform repair work on the passenger areas and do not participate in the type of structural repairs.

The length of repair jobs for several classes of vessels are similar. Regardless of the type of vessel, the nature of the repair work to correct structural damage would be similar. All of the major vessel classes are constructed with steel hulls, and the nature of repair activities are, therefore, essentially the same.

Nevertheless, the pattern of repair work among vessels includes some variation. Repair jobs due to casualties for tankers tend to be more expensive than for other vessels because of the greater curvature in the hull and the additional expense of repairing the shaped steel plates. Repair work for barges tends to be less expensive because of the lack of moving parts on most barges, which are unpowered vessels. Also, repair work on barges would very rarely total $5 million. One shipyard estimator suggested that $1.5 to $2 million is approximately as high as barge repairs are likely to run. As noted, the repair work for passenger vessels is generally much more costly because of the large amounts of work performed on passenger areas.

The high value to even short-term repair jobs is also indicated by the data available from the U.S. Shipbuilders Council of America, 1989. That source shows that, for the major shipyards they represent, all repair work performed in 1987 on commercial vessels totalled just over $18 million. According to shipyard personnel, it is reasonable to estimate that this value was generated by not many more than 18 repair jobs, i.e., the average repair job cost $1 million.

The estimates cover only U.S. shipyards, and repair costs for foreign shipyards are substantially lower. The duration of repairs in foreign shipyards can be estimated by lowering the dollar value of repairs shown in Table 5-1 by a percentage that represents the foreign cost advantage. Repair costs were estimated to be approximately 25% lower in foreign shipyards other than Europe and 15% lower in Europe.

By law, U.S. flagged ships must be repaired in the U.S. Vessels of other flags may also use U.S. shipyards if their location or capability for repair is most suitable to their needs. Cruise ships running voyages in the Caribbean may use the Jacksonville, Florida shipyard, for example, to save the passage time needed to reach the shipyards located in the Far East. Tramp cargo ships, however, which traverse the globe, are much more likely to use the lower cost Far Eastern shipyards whenever possible.

ERG also considered whether the vessel repair durations are increased by waiting periods before work begins within shipyards. That is, should the estimates of interruptions in vessel sailings include a period for delays before repair work is begun on vessels. Discussions with shipyard personnel indicate that U.S. shipyards would generally go to considerable lengths to accommodate a vessel owner's demand for an immediate start to repair work. If shipyards are already busy with repair work, the shipyards would still attempt to accommodate the new repair work by hiring additional workers and through extensive overtime work among the existing workers. The persons contacted stated that 16- and 18-hour workdays were a common response to busy periods.

The general responsiveness of shipyards to shipowner's needs suggests that it is not necessary to add a shipyard delay to the estimates of the repair periods. Therefore, the repair periods shown in Table 5-1 are recommended for use in selecting values for TSC's cost and benefit model.

5.2 Vessel Operating Costs

ERG assembled data on operating costs from several sources. Lloyd's Shipping Economist (August, 1990) provided information on operating costs and on current market prices for vessels. ERG contacted several industry sources in collecting information on the appropriate assumptions for use in estimating the capital costs of vessel operations.

Table 5-2 presents data on the operating costs estimated by Lloyd's for three common vessel types: a 100,000 deadweight tanker, a panamax cargo carrier (average deadweight calculated at 61,000 tons), and a 20,000-30,000 deadweight containership. Breakdowns are provided for crew costs, vessel supplies, and operating repairs and maintenance. These elements correspond to the operating costs (net of capital) that would be accrued during dock time. Fuel costs can be ignored; the heavy fuel consumption level would apply only until the vessel reaches port. While in port, and until the crew is discharged (if it is to be discharged), some small costs for diesel fuel only would also be incurred. Diesel oil requirements are approximately 2 tons per day (at current market rates of $140 per ton) (Note 1).

ERG also estimated the capital costs of the vessels represented in the table, using the closest corresponding vessel prices as reported in Lloyd's Shipping Economist (August 1990). ERG assumed that vessels are financed over a ten-year period at an 8% interest rate based on financing data available in Lloyd's. This interest rate estimate was derived from capital financing information provided in Lloyd's. The estimate of financing over a ten-year period was judged by ERG to be representative of industry practices. ERG selected the following vessel values:

Tanker - The capital cost was extrapolated from the value given in Lloyd's for a secondhand tanker at 80,000 deadweight built in 1981. That price was given as $30 million. ERG extrapolated the value of a 100,000 deadweight ton tanker to be $34.5 million. (ERG extrapolated using the average market value for the incremental tonnage by noting the difference in values for a 32,000 deadweight ton tanker and the 80,000 ton tanker.)

Panamax Bulk Carrier - Lloyd's lists the value of a five-year old bulk carrier of 70,000 deadweight ton tanker at $21 million dollars. (A panamax carrier is built to the maximum

Table 5-2

OPERATING COSTS OF
SELECTED COMMON VESSEL TYPES
(1st Qtr. 1990, $000/mo.)

Cost Category	Vessel A 10-12 yr. old, 100,000 dwt tanker	Vessel B 10-yr. old, panamax bulk carrier	Vessel C 5-10 yr. old, 20,000-30,000 dwt. containership
Crew	$50.8	$46.4	$46.4
Stores, supplies, running repairs & maint.	$33.8	$20.0	$22.5
Management & insurance	$32.0	$25.0	$19.5
Total operating costs per month, net of capital costs	$116.6	$91.4	$88.4
Total operating cost per day, net of capital costs	$3.9	$3.0	$2.9
Est. market value of vessel ($ million)	$34.5	$18.0	$23.0
Monthly capital charge (amortized over 10-yr. financing period)	$418.6	$218.4	$279.1
Capital charge per day	$14.0	$7.3	$9.3
Total operating and capital cost per day	$17.8	$10.3	$12.2

Source: Data on operating costs are derived from Lloyd's Shipping Economist, August 1990. Capital costs are based on estimated market values for the specified vessels based on prices for aged vessels, in secondhand market. Crew costs assume Indian officers and Korean hands, i.e., relatively low-priced labor costs. Fuel costs are not included.

dimensions of a carrier that can pass through the Panama Canal.) An average Panamax carrier is 61,000 deadweight tons. ERG assumed that the greater age of the vessel described in Table 5-2 and its slightly smaller size would reduce the market value to approximately $18 million.

Containership - Lloyd's list the value of a five-year old containership of approximately 20,000 to 30,000 deadweight capacity (1,600 twenty-foot equivalent units) at $23 million. ERG used this value in the capital calculations.

Table 5-2 shows that daily capital costs substantially exceed the daily operating costs based on the assumptions used. The daily capital costs are estimated at $14,000, $7,300 and $9,300 for the three vessel categories. Total daily operating costs (including capital) for the vessel classes exceed $10,000 per day for each class of vessel. The highest daily expense is estimated for the tanker at $17,800. Some of the individuals contacted by ERG estimated that daily operating costs actually exceed $15,000 per day for any ship as large or larger than a handy-sized (20,000-30,000 deadweight ton vessel) (Note 2). In these estimates only the tanker exceeds $15,000 per day. These higher estimates of the ship owner's daily cost may be based on estimates of financing costs for newer vessels or financing based on poorer loan terms.

5.3 Foregone Revenues Due to Vessel Casualties

An alternative means of measuring the burden of vessel casualties is to consider the foregone revenues, or opportunity costs, to the ship owner of the unexpected loss of ship services. Foregone revenues exceed the social costs of the vessel casualty by the amount of any "excess" profits or returns going to the ship owner. Nevertheless, the use of foregone revenues is a reasonable approximation to the opportunity cost of the vessel casualty.

ERG used the Lloyd's Shipping Economist for data on current charter market rates. The rates are published periodically in Lloyd's in the Ship Fixture Report, based on recent sailings. Table 5-3 summarizes a selection of charter rates for different classes of vessels. As seen from the data, the definition of typical charter rates can be specified only given a specific cargo and route.

Table 5-3

SAMPLE OF CHARTER RATES,
July, 1990

Entry	Shipment Quantity (metric tons)	Cargo	Load Area	Discharge Area	Rate/ton (a)	
	Dry Single Voyage Fixtures - Departed North America					
1	100,000	Coal	Roberts Bank, N.A.	Brazil	$8.00	
2	9,150	Flour	Vancouver	Haiphong	$56.50	
3	50,000	Barly, General	North Pac.	Saudi Arabia	$16.50	
4	80,000	Iron ores	Seven Islands	Philadelphia	$2.75	
5	10,800	Flour	Halifax	Alexandria	$35.00	
	Dry Single Voyage Fixtures - Departed US Gulf					
1	30,000	Ammon. Phosphate	US Gulf	India	$37.00	
2	16,500	Potassium Nitrate	US Gulf	India	$37.00	
3	35,000	Phosphorus, bulk	Tampa	India	$30.00	
4	50,000	Coal	US Gulf	Taiwan	$14.80	
5	50,000	Coal	US Gulf	Taiwan	$14.50	
	Trip/Time Charters - 10,000-79,999 DWT Dry Bulk Carriers				Rate (b)	
1	27,684	Not specified	Great Lakes	Singapore	$10,200	
2	19,089	Not specified	U.S. Atl. Coast	Brazil	$5,500	(c)
3	39,715	Not specified	Cape Town	Singapore	$10,000	
4	69,568	Not specified	US Gulf	Far East	$9,000	
5	66,423	Not specified	North Pacific	S. Korea	$7,000	(c)
6	60,484	Not specified	Rotterdam	Far East	$8,250	
	Tanker Spot Fixtures - Departed Arabian Gulf				Rate (d)	
1	345,000	Petr., Dirty	Arabian Gulf	UK/Continent	45	
2	250,000	Petr., Dirty	Arabian Gulf	S. Korea	45	
3	127,000	Petr., Dirty	Arabian Gulf	Mediterranean	88	
4	25,000	Clean Petr.	Arabian Gulf	Botany Bay	225	
5	245,000	Petr., Dirty	Arabian Gulf	Singapore	58	

(a) Rate is quoted in terms the total charge per ton for the voyage.
(b) Rate is quoted in terms of the charge per day during the voyage.
(c) The charterer of the vessel is also providing the fuel needed for the voyage to the ship owner.
(d) The rate is quoted in terms of the cost in terms of the Worldscale currency, i.e., in terms of an index based on world currencies.

Source: "Lloyd's Maritime Ship Fixtures," Lloyd's Shipping Economist, July 1990.

Distinct charter rates also exist, for a given product or cargo, for different-sized vessels. Smaller tankers, for example, cost more to operate per ton of cargo, but can enter more ports, so that delivery can be made more convenient.

For this study, ERG has not attempted to define consistent estimates of the current charter rates for various classes of vessels because of the additional complications of specifying typical market rates. The charter rates are also extremely sensitive to market conditions and fluctuate widely. Over time, therefore, the charter market rates are an erratic indicator of the social costs created by the temporary loss of vessel services. The daily operating costs of the vessel appear to provide much more consistent estimates of the loss of vessel services that occur due to vessel casualties.

5.4 Estimates Relating Vessel Deadweight Capacity to Vessel Drafts

ERG also examined the relationship of vessel cargo-carrying capacity to vessel drafts. The relationship is of interest so that economic data can be related used in conjunction with analyses of port traffic control lanes.

ERG reviewed ship dimension data in the Lloyd's Register of Ships to correlate vessel drafts and cargo capacity. Table 5-4 summarizes the relationships defined. The categorization must be considered approximate because of the variety of vessel designs and other inconsistencies evident in the distribution of data characteristics.

The categories for vessel drafts were provided by the Transportation Systems Center. The estimates of gross tonnage, deadweight tonnage and vessel length were developed by ERG. In some cases, TSC provided only small and large categories, and ERG attempted only to develop some plausible vessel designs that could be associated with those categories. Only vessels of over 65 feet in length were considered.

In the passenger and ferry boat category, many large cruise ships, such as those associated with Caribbean cruise routes, would be found in the medium draft category (19 to 30 feet). The

Table 5-4

CORRELATION OF VESSEL DRAFTS
WITH COMMON DEADWEIGHT TONNAGE LEVELS,
BY TYPE OF VESSEL

Vessel Type/ Draft Category	Gross Tonnage	Deadweight Tonnage	Length (meters)	Length (feet)	Vessels Included in Category
Passenger/Ferry					
< 19 ft.	<8,000	<10,000	<140	450	Commuter boats, smaller ferries, Islander (out of Woods Hole, MA)
19–30 ft.	8,000–11,000	10,000–18,000	140–275	450–900	Most cruise ships, Bermuda Star, Song of Norway
>30 ft.	12,000+	16,000+	275+	900+	Largest cruise ships, QE 2, Caribbean Princess
Dry Cargo					
< 19 ft.	<2,300	<5,000	<90	<300	Small general cargo, coastal carriers, small refrigerator vessels
19–30 ft.	2,300–10,000	5,000–15,000	90–150	300–500	General cargo, medium-bulk carriers, vehicle carriers, containerships
>30 ft.	10,000+	15,000+	150+	500+	Largest bulk carriers, largest containerships

Table 5-4

CORRELATION OF VESSEL DRAFTS
WITH COMMON DEADWEIGHT TONNAGE LEVELS,
BY TYPE OF VESSEL (cont.)

Vessel Type/ Draft Category	Gross Tonnage	Deadweight Tonnage	Length (meters)	Length (feet)	Vessels Included in Category
Tanker					
< 19 ft.	<2,500	<4,000	<90	<300	Smallest LPG, chemical tankers
19–30 ft.	2,500–11,000	4,000–20,000	90–170	300–550	Parcel tankers, (carriers of oil, chemicals, molasses), smaller oil tankers
>30 ft.	11,000+	20,000+	170+	550+	Largest oil tankers, Exxon Valdez
Barge – Dry Cargo					
Small	NE	NE	20–50	65–300	No pattern identified
Large	NE	NE	50+	300–600	No pattern identified
Barge – Tanker					
Small	NE	NE	20–75	65–300	30,000–50,000 bbl tankers
Large	NE	NE	75+	300–600	Over 50,000 bbl tankers

Table 5-4

CORRELATION OF VESSEL DRAFTS
WITH COMMON DEADWEIGHT TONNAGE LEVELS,
BY TYPE OF VESSEL (cont.)

Vessel Type/ Draft Category	Gross Tonnage	Deadweight Tonnage	Length (meters)	Length (feet)	Vessels Included in Category
Fishing					
Small	NE	NE	20-50	65-165	Most fishing vessels
Large	NE	NE	50+	165+	Factory fish processsing vessels
All Other					
Small	NE	NE	NE	NE	
Large	NE	NE	NE	NE	

Source: ERG estimates, based on reviews of vessel characteristics as reported in Lloyd's Register of Ships, 1990.

smaller category would capture commuter ferry boats, and some fairly large-capacity ferries, such as the Islander which operates out of Woods Hole, MA and Martha's Vineyard, MA.

Most types of cargo vessels can be found in almost any of the vessel categories, although there are some patterns that can be identified. Small general cargo carriers and refrigerated vessels have drafts of less than 19 feet. Most other general cargo carriers, vehicle carriers and containerships have drafts of between 19 and 30 feet. Most bulk carriers and the largest versions of the other cargo carriers (including general cargo vessels and refrigerated ships) have the deepest drafts.

In the tanker category, the most shallow drafts are found among the fleets of small LPG carriers and chemical tankers. Parcel tankers (in which oil, chemicals, molasses, and other products may be carried) and smaller oil tankers constitute the medium category. Large oil tankers have vessel drafts of 30 to over 60 feet. The other vessel categories are also summarized in the table.

5.5 Additional Elements of the Exceptional Costs Associated with Vessel Casualties

Ship owners could face a variety of additional costs, beyond vessel repair costs, when their ship is involved in a casualty. This section describes some of the elements of these costs.

Discharge of Crew Members - If a vessel is involved in a major casualty, the ship owner is likely to dismiss his crew as soon as it is evident that the ship cannot be returned to productive use in the near future. U.S.-flagged vessels, which must employ U.S. crews are likely to be given a severance-type payment for their services. European crews are also likely to receive some benefits that would cushion the financial impact of their discharge.

Seamen from other foreign nations, and particularly third world countries have little bargaining power with owners and are more likely to be treated poorly in the event their ship is disabled. Owners running under a "flag of convenience" have considerable leeway concerning the discharge of their crews and, in numerous cases, have more-or-less abandoned their crews. Poor working conditions and disputes over unpaid wages have occurred particularly in years while cargo-carrying prices were depressed (Machalaba, 1987). In other cases, however, ship owners under a flag of convenience may send crews to their homes

To estimate the cost of discharging the crew, ERG judged that the purchase of airline flights home for crew members represented an approximate medium level of crew benefits among the wide variation in arrangements. ERG also assumed that a third world crew was employed in order to be consistent with the assumptions used in Table 5-2. ERG calculated the cost of sending an average of 25 crew members home (to Korea or Bombay) at approximately $800 per person or a total of $20,000.

Costs of Cargo Charterers of Delays in Shipping - ERG contacted several industry ship brokers, charterers and ships agents about the possible costs of vessel delays to parties shipping or receiving cargo. In general, the cost of vessel delays to cargo chartering concerns could not be quantified. In the discussion below, ERG considers first the impact of short delays of no more than one to two weeks, as well as the impacts of longer delays.

Companies shipping cargo by sea can usually accommodate delays of two or more weeks before scheduling becomes a concern. Various persons stated that it is not usual for ship owners or their agents to hear complaints from cargo shippers over relatively short delays. For example, a delay in a shipment of new cars is typically of much less concern to the shipper than the assurance that the cars arrive undamaged.

The need for some flexibility in cargo shipping schedules is also indicated by the fact that some cargo shippers may encounter a delay of several days in getting cargo placed onto an appropriate ship. While the shipper usually has arranged a schedule for loading and departure of his cargo, the schedule may go awry before the cargo has left port. He may have to locate another cargo ship and reschedule the departure of his cargo - a process that usually would result in several days of delay.

Most sea-going cargo is insured against damage or loss at sea. It is quite unusual, however, for cargo to be insured with regard to its delivery date. If the cargo delivery is so sensitive, it is more likely to be sent by air, if at all possible. Of course, some delays could cause problems for shippers of fruits and vegetables. Even for these products, however, short delays are generally accepted.

One exception to the general lack of concern over cargo deliver delays could occur in the case of oil shipments. Oil shipments are often sold and resold among traders once or several times while the tanker is in transit. A ship captain, for example, may have only a general course and heading (e.g., head for the North Atlantic coast) and will be telexed final instructions on where the oil is to be delivered only upon nearing shore. During these transactions, some oil traders may suffer paper or actual losses due to market price shifts, and such losses could be aggravated if the oil delivery is delayed. In such cases, the oil trader may complain bitterly about any delays in delivery. Such losses, however, represent only a redistribution of income among oil traders and do not represent social costs, i.e., do not reflect any use of society's resources. These potential costs have been ignored in the analysis.

A second exception to the acceptance of cargo delays can occur prior to or during the holiday season. One industry executive noted that some Christmas items could decline in value if they do not reach their destination during the prime holiday shopping period (Thorjussen, 1990). This type of cargo, however, represents an extremely small portion of aggregate shipping.

If delays exceed a few weeks, or if the cargo is lost, it is possible for there to be greater dislocations among the receiving party. Theoretically, the loss of the cargo could diminish supply of the particular product enough for prices to rise. Prices rises in such cases could occur because of actual product shortages, or because of speculative changes in prices on spot markets, as has occurred after some oil spills. Such an occurrence, however, must be quite rare. Individual shipments of commodities do not represent a substantial percentage of market supply in the great majority of cases. Market dislocations would also be temporary, i.e., they may last only until a replacement order of the cargo is delivered.

In general, none of the persons contacted could provide useful generalizations about the economic impacts of cargo losses. Instances of dislocations to product markets tend to be unique to specific markets and circumstances and ERG could not develop a meaningful model of these costs.

Costs for additional unloading and loading of cargo if a vessel is damaged - ERG examined the additional costs that a ship owner could incur if the cargo-carrying vessel is damaged and cargo must be transferred to another vessel. Instances in which cargo is transferred into a replacement vessel are fairly rare, but such cases can occur and should be considered.

In general, ERG found that the use of replacement vessels to complete voyages is not common. If a ship is disabled, it will usually be brought into port by some means, i.e, after the completion of emergency repairs or under tow. (Some of the most relevant costs of vessel casualties, therefore, are the exceptional towing and tug charges that would be incurred.) A cargo transfer will occur at sea, generally, only under particular circumstances, such as (1) when a vessel is sinking anyway and there is an opportunity to rescue some of the cargo, or (2) the vessel is in danger of sinking and removing cargo may help, or (3) the vessel is leaking (oil), and removing the cargo minimizes the environmental damage or explosion threat.

A transfer of cargo that is necessitated by a casualty could also occur in port, of course, and more normal cargo-handling arrangements would be used. In such cases, the ship owner or the cargo charterer must pay several exceptional charges including extra pilotage charges, towing and tug charges while in the port, dock charges, extra charges for storage of the product at the dock, additional custom charges if international shipments are involved, and the loading and reloading costs.

One common form of cargo transferring, however, is quite common and involves the "lightering" of oil tankers in which part or all of a tanker's shipment is transferred into lightering vessels or into other product tankers. The larger tanker vessels are not able to enter certain ports and must lighter their cargoes in order to provide for delivery. Lightering is a routine practice near many ports.

For this study, of course, lightering is of most interest when it may be needed after a vessel collision or grounding. Lightering after a collision, however, is still only possible near or in ports where calm seas and weather are more likely to prevail. Seas as high as only 3 or 4 feet can prevent lightering of a damaged tanker. Lightering vessels, such as could be needed when an oil tanker is damaged, may be chartered at rates varying from $5,000 to $25,000 per day.

The following scenario describes the additional costs that may be incurred in the event of a collision or damage to an oil tanker. In this scenario it is assumed that the tanker is damaged while it is leaving a port. The estimates were prepared by ERG staff based on conversations with industry personnel in the port of Boston. The sequence of additional costs and management requirements are:

> A tanker is damaged in a collision or grounding. It is desirable to return the vessel to the dock but an actual or potential leak of the oil cargo could prevent the return or movement of the vessel at the current time. A decision is made to lighter the vessel. The actual lightering from a handy-sized tanker may require two days, but the decision to lighter, the time needed to locate ships to lighter the vessel, and the need for calm seas could mean that the entire lightering operation takes 5 days. Lightering requires the placement of oil pollution booms, appropriate lightering equipment and personnel involvement. The requisite capability can be provided by lightering companies at rates in the vicinity of $200 per hour or approximately $5,000 per day. For large-capacity lightering equipment, costs could rise to as much as $25,000 per day. During the delays caused by the lightering operation, the ship owner is also losing the normal charter rate revenue stream which in this case could be approximately $18,000 to $20,000 per day.
>
> In a revised scenario, it is assumed that the vessel is successfully towed back into the dock, specifically, to an oil terminal. Charges for tug boats with deep sea capability would total approximately $4,000 for the length of time needed to tow the tanker back into dock (10 hours each for 2 tugs). The vessel must also pay $2,500 in pilotage (based on approximate figures for Boston harbor), $1,000 in fees to tie up at (and eventually be untied from) the dock, $3,000 in additional oil terminal charges, $18,000-20,000 for the foregone revenue of the vessel's normal charter rate. Using the midpoint of the vessel's charter rate ($19,000) and assuming all of this can occur in one day, the vessel incurs $29,500 in additional costs related to the casualty. Each additional day generates another days loss of the vessel's normal charter revenue. Assuming a second tanker is summoned to scene, it's daily charter

rate ($18,000 to $20,000) until it reaches the scene and can be loaded with the oil would also represent additional charges related to the casualty.

ERG also examined the costs of transferring cargo if the damaged vessel is a dry cargo carrier. Again, however, cargo handling costs are extremely variable by commodity and across the range of port and terminal facilities. One rough estimate of cargo handling costs was given at $10-15 per ton (Thorjussen, 1990).

5.6 Selection of Final Estimates of Total Social Costs of Vessel Casualties

ERG assembled the materials from the estimates previously given and developed estimates of total social costs for representative vessel casualties. The estimates in all cases must only be considered judgments of representative costs and cannot be described as statistical averages.

Table 5-5 provides the totals derived for the vessel categories and for hypothetical categories of damage severity (minor, medium and severe). The largest totals are generated by the larger passenger vessel categories reflecting the foregone revenues from repair delays. Numerous other categories of vessels, however, would also face losses in the millions of dollars for medium or severe damages.

The origin of the estimates summarized in Table 5-5 are presented in Tables 5-5a through 5-5c. Each of the cost categories is developed and estimated for each vessel category and for each hypothetical damage category. The cost categories covered include vessel repair costs, crew dismissal costs, losses due to temporary interruption of vessel services, and exceptional port charges such as for piloting, dockage, and tug services for towing of disabled vessels.

The vessel repair costs are selected from values presented in Table 5-1 for each of the vessel types. The repair estimates are not intended to define a range of repair costs but to describe relatively commonplace repair circumstances within the categories of minor, medium and severe repair needs.

Table 5-5

SUMMARY OF ESTIMATES FOR TOTAL
SOCIAL COSTS OF VESSEL CASUALTIES
($'000)

Damage Categories	Vessel Drafts <19ft.	Vessel Drafts 19-30 ft.	Vessel Drafts >30 ft.	Vessel Drafts Small	Vessel Drafts Large
		Passenger		Barges	
Minor	$276	$431	$633	$109	$113
Medium	$1,251	$2,006	$3,008	$538	$560
Severe	$3,551	$4,606	$6,008	$1,083	$1,135
		Dry Cargo		Fishing	
Minor	$294	$325	$367	$201	$411
Medium	$992	$1,071	$1,176	$301	$581
Severe	$4,442	$4,671	$4,976	$626	$1,151
		Tanker			
Minor	$364	$405	$447		
Medium	$1,167	$1,271	$1,376		
Severe	$4,967	$5,271	$5,576		

Source: ERG estimates. Estimates are derived from Tables 5-5a through 5-5c.

Crew dismissal costs refer to the expenditures for sending a crew home when the voyage is interrupted. As was noted previously, however, crews may be retained for repair periods that are less than two weeks. In such cases, therefore, there are no crew dismissal costs. The costs of crew services during the repair period are included in the vessel operating costs.

Daily vessel operating costs are used as a proxy for the daily social benefit of the vessel services. The more exact measure of the social value of vessel operations would include a normal profit return to the shipowner for the entrepreneurial risk of providing vessel services. Data on vessel profit levels are generally not available, however, and fluctuate widely over time with market conditions. ERG used the more accessible and stable data series on vessel operating costs. ERG also made use of the Table provided in Table 5-2 above describing the operating costs of three vessel types. ERG noted, however, that the crew assumptions made for the estimates in Table 5-2 describe a below-average crew cost. The figures from Table 5-2 were therefore increased in order to capture overall averages that are more reflective of the world fleet.

Disabled vessels will incur exceptional costs for reentering harbors, tug service, and dockage. The costs of such services could vary widely. ERG has developed estimates assuming that the disabled ship does not encounter extreme difficulties in returning to a harbor or in being brought to a shipyard area. Some charges are noted, however, for each category of possible expense. ERG has, however, not included costs for cargo offloading and reloading onto replacement vessels. It is rare for cargo to be transferred between vessels; those expecting the cargo are likely to tolerate some delays in delivery, such as would be required to allow emergency repairs. If offloading must be included, the costs of cargo handling are extremely variable. For oil cargoes, however, the use of lightering vessels at an expense of $20,000 per day for several days could be added to the costs for the tanker category.

5.7 Forecasts of Tanker and Dry Cargo Shipping Markets during the 1990's

ERG found the most recent available forecasts of shipping markets to be those prepared by the London City University Business School, as reported in Lloyd's Shipping Economist (LSE), December 1988. The general content of the forecasts for tanker charter rates was also confirmed in conversations with industry personnel and more recent articles in LSE. It should be noted, however, that the Iraqi invasion of Kuwait on August 2, 1990 is an important exogenous shock to shipping markets, and particularly tanker shipping markets, and could have important implications for shipping markets.

London City University economists prepared a set of shipping market forecasts that were based on assumptions of competitive shipbuilding markets, rational expectations by investors, and exogenous freight demand (i.e., the demand for shipping is not affected by changes in freight rates). In general, the London City University economists forecast steady improvements in tanker and dry cargo shipping rates during the 1990s. The increases in charter rates are expected to be greatest in the tanker market due (prior to the Iraqi invasion) due to steady increases in the quantity of oil imports by Western developed nations. The City University Business School timecharter index (which represents the $/dwt/month timecharter rate for a 100,000 deadweight ton tanker) was forecast to increase from 5.8 at the end of 1989 to 7.5 by the end of 1995 to 8.5 at the end of 2000. Contributing to tightness in the tanker market is the aging of the tanker fleet which will cause many older tankers (those 15 years old or more) to be scrapped during the 1990s. U.S. oil imports have also been forecast to grow steadily, although even a zero growth scenario for oil imports is expected to see increasing timecharter rates.

The City University Business School forecast for dry cargo markets is more tentative because of the greater market fluctuations and uncertainties. Nevertheless, during the 1990s, dry cargo timecharter rates are forecast to increase at a rate slightly above world inflation (inflation was estimated at 3.0 percent per annum). This index is forecast to grow from 176 in 1987 to 226 by the end of 1995 and 235 by the end of the year 2000.

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

	Passenger/Ferry		
	Drafts		
Social Cost Category/ Assumptions	19 ft.	19-30ft.	Over 30 ft.
Struct. Repair Costs ($)	$125,000	$125,000	$125,000
Repair Duration (days)	2	2	2

Assumptions

The amount and duration of repairs are based on data in Table 5-1, assuming a minor casualty.

	19 ft.	19-30ft.	Over 30 ft.
No. of Crew	15	400	800
Crew Dismissal Costs ($/member)	$0	$0	$0
Total Crew Dismissal Costs	$0	$0	$0

Assumptions

The crew is not dismissed for the short repair duration.

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Vessel Operating Costs ($/day)	$75,000	$150,000	$250,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$150,000	$300,000	$500,000

Assumptions

Based on estimates of penalties included in shipyard contracts for repair work for any delays in returning vessel to productive service.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$1,000	$6,000	$8,000

Assumptions

Piloting charges estimated at $0, $1,000 and $1,500, with smallest vessel not requiring pilot services in vicinity of port where vessel operates. Vessels require 5, 20 and 25 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $0, $1,000 and $1,500 for offloading before towing to repair yard.

Total Social Costs for Representative Vessel Casualty - Passenger ($)	$276,000	$431,000	$633,000

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Social Cost Category/ Assumptions	Dry Cargo Vessel Drafts < 19 ft.	Dry Cargo Vessel Drafts 19-30ft.	Dry Cargo Vessel Drafts Over 30 ft.
Struct. Repair Costs ($)	$200,000	$200,000	$200,000
Repair Duration (days)	10	10	10
Assumptions			
The amount and duration of repair is selected based on values in Table 5-1.			
No. of Crew	17	20	24
Crew Dismissal Costs ($/member)	0	0	0
Total Crew Dismissal Costs	$0	$0	$0
Assumptions			
The crew is not dismissed for the minor repair job.			

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$9,000	$12,000	$16,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$90,000	$120,000	$160,000

Assumptions

Vessel operating costs for medium category are based on values for a panamax carrier but increased by 20% to indicate the below average operating costs of that estimate. Larger vessel is assumed to be newer and thus to have greater capital costs. Smaller vessel is assumed to have operating expenses equal to 75% of the medium category.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,750	$5,000	$7,000

Assumptions

Piloting charges estimated at $1,000, $1,000 and $1,500. Vessels require 10, 15 and 20 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $750, $1,000 and $1,500. No estimate is made for the increased cargo handling costs if cargo is offloaded. Extra cargo handling is rare.

Total Social Costs for Representative Vessel Casualty - Dry Cargo($)	$293,750	$325,000	$367,000

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Social Cost Category/ Assumptions	Tanker Drafts < 19 ft.	19-30ft.	Over 30 ft.
Struct. Repair Costs ($)	$200,000	$200,000	$200,000
Repair Duration (days)	10	10	10
Assumptions			
Based on values in Table 5-1.			
No. of Crew	17	20	24
Crew Dismissal Costs ($/member)	0	0	0
Total Crew Dismissal Costs	$0	$0	$0
Assumptions			
The crew is not dismissed for the minor repair job.			

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$16,000	$20,000	$24,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$160,000	$200,000	$240,000

Assumptions

Operating costs are extrapolated from values shown in Table 5-2, but have been increased to reflect the below average operating costs for the estimate in the Table. Operating costs are higher for tankers than for dry cargo carriers partly because market demand has driven vessel values, and thus capital costs to new purchasers, upwards.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,750	$5,000	$7,000

Assumptions

Piloting charges estimated at $1,000, $1,000 and $1,500. Vessels require 10, 15 and 20 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $750, $1,000 and $1,500. No lightering costs were assumed. If lightering is added, a lightering vessel's ervices at $20,000 per day for two days is representative of emergency procedures. This estimate assumes the lightering vessel is reasonably available.

Total Social Costs for Representative Vessel Casualty - Tanker($)	$363,750	$405,000	$447,000

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Social Cost Category/ Assumptions	Barges - Dry Cargo and Tankers	
	Drafts	
	Small	Large
Struct. Repair Costs ($)	$100,000	$100,000
Repair Duration (days)	2	2
Assumptions		

Based on values given in Table 5-1.

No. of Crew	4	6
Crew Dismissal Costs ($/member)	$0	$0
Total Crew Dismissal Costs	$0	$0
Assumptions		

Crew is assumed to be U.S. seamen who receive a week's wage for the interrupted voyage.

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	3000	5000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$6,000	$10,000

Assumptions

Barge operating costs were estimated at 25% and 35% the costs of the panamax carrier in Table 5-2.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,000	$3,000

Assumptions

The barges are estimated to incur piloting costs of $1,000 and docking costs of $1,000. Additionally, deep sea barges are needed for 5 hours at a rate of $200/hr.

Total Social Costs for Representative Vessel Casualty – Barges ($)	$109,000	$113,000

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Social Cost Category/ Assumptions	Fishing Vessels	
	Small	Large
Struct. Repair Costs ($)	$50,000	$50,000
Repair Duration (days)	30	30
Assumptions		
Based on values for vessel repairs shown in Table 5-1.		
No. of Crew	15	40
Crew Dismissal Costs ($/member)	$0	$0
Total Crew Dismissal Costs	$0	$0
Assumptions		
Crew are assumed to be local fishermen. Contracts are assumed not to include severance costs. Many fishermen are employed as independent contractors and would not receive any such payments.		

Table 5-5a

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MINOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$5,000	$12,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$150,000	$360,000
Assumptions		
Vessels were assumed to generate revenues at a rate of $300 per day per fishermen. This total includes all overhead expenses for the vessel. The rate of revenue generation is based on an assumed average salary of $30,000 per fishermen divided by 200 fishing days per year.		
Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$800	$1,200
Assumptions		
Vessels are assumed to require service of deep sea tugs for 4 and 6 hours respectively. No other charges, such as those for pilotage and docking, were assumed to apply.		
Total Social Costs for Representative Vessel Casualty – Fishing ($)	$200,800	$411,200

Source: ERG estimates. Specific sources given as described above.

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

	Passenger/Ferry		
	Drafts		
Social Cost Category/ Assumptions	19 ft.	19-30ft.	Over 30 ft.
Struct. Repair Costs ($)	$500,000	$500,000	$500,000
Repair Duration (days)	10	10	10

Assumptions

The amount and duration of repairs are based on data in Table 5-1, assuming a casualty of moderate severity.

No. of Crew	15	400	800
Crew Dismissal Costs ($/member)	$0	$0	$0
Total Crew Dismissal Costs	$0	$0	$0

Assumptions

The crew is assumed not to be dismissed for the moderate duration repair work. Alternatively, crew may be discharged temporarily with no interim compensation.

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Vessel Operating Costs ($/day)	$75,000	$150,000	$250,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$750,000	$1,500,000	$2,500,000

Assumptions

Based on estimates of penalties included in shipyard contracts for repair work for any delays in returning vessel to productive service.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$1,000	$6,000	$8,000

Assumptions

Piloting charges estimated at $0, $1,000 and $1,500, with smallest vessel not requiring pilot services in vicinity of port where vessel operates. Vessels require 5, 20 and 25 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $0, $1,000 and $1,500 for offloading before towing to repair yard.

Total Social Costs for Representative Vessel Casualty - Passenger ($)	$1,251,000	$2,006,000	$3,008,000

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

	Dry Cargo Vessel		
	Drafts		
Social Cost Category/ Assumptions	< 19 ft.	19-30ft.	Over 30 ft.
Struct. Repair Costs ($)	$750,000	$750,000	$750,000
Repair Duration (days)	25	25	25
Assumptions			
The amount and duration of repair is selected based on values in Table 5-1.			
No. of Crew	17	20	24
Crew Dismissal Costs ($/member)	$800	$800	$800
Total Crew Dismissal Costs	$13,600	$16,000	$19,200
Assumptions			
The crew are assumed to be from a Pacific rim country and receive airfare home.			

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$9,000	$12,000	$16,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$225,000	$300,000	$400,000

Assumptions

Vessel operating costs for medium category are based on values for a panamax carrier but increased by 20% to indicate the below average operating costs of that estimate. Larger vessel is assumed to be newer and thus to have greater capital costs. Smaller vessel is assumed to have operating expenses equal to 75% of the medium category.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,750	$5,000	$7,000

Assumptions

Piloting charges estimated at $1,000, $1,000 and $1,500. Vessels require 10, 15 and 20 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $750, $1,000 and $1,500. No estimate is made for the increased cargo handling costs if cargo is offloaded. Extra cargo handling is rare.

Total Social Costs for Representative Vessel Casualty - Dry Cargo($)	$992,350	$1,071,000	$1,176,200

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Social Cost Category/ Assumptions	Tanker Drafts < 19 ft.	Tanker Drafts 19-30ft.	Tanker Drafts Over 30 ft.
Struct. Repair Costs ($)	$750,000	$750,000	$750,000
Repair Duration (days)	25	25	25
Assumptions			
Based on values in Table 5-1.			
No. of Crew	17	20	24
Crew Dismissal Costs ($/member)	$800	$800	$800
Total Crew Dismissal Costs	$13,600	$16,000	$19,200
Assumptions			
The crew is assumed to be from a Pacific rim country and receives airfare home.			

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$16,000	$20,000	$24,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$400,000	$500,000	$600,000

Assumptions

Operating costs are extrapolated from values shown in Table 5-2, but have been increased to reflect the below average operating costs for the estimate in the Table. Operating costs are higher for tankers than for dry cargo carriers partly because market demand has driven vessel values, and thus capital costs to new purchasers, upwards.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,750	$5,000	$7,000

Assumptions

Piloting charges estimated at $1,000, $1,000 and $1,500. Vessels require 10, 15 and 20 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $750, $1,000 and $1,500. No lightering costs were assumed. If lightering is added, a lightering vessel's ervices at $20,000 per day for two days is representative of emergency procedures. This estimate assumes the lightering vessel is reasonably available.

Total Social Costs for Representative Vessel Casualty - Tanker($)	$1,167,350	$1,271,000	$1,376,200

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Social Cost Category/ Assumptions	Barges - Dry Cargo and Tankers	
	Drafts	
	Small	Large
Struct. Repair Costs ($)	$500,000	$500,000
Repair Duration (days)	10	10

Assumptions

Based on values given in Table 5-1.

No. of Crew	4	6
Crew Dismissal Costs ($/member)	$1,200	$1,200
Total Crew Dismissal Costs	$4,800	$7,200

Assumptions

Crew is assumed to be U.S. seamen who receive 2 weeks' wages for the interrupted voyage.

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	3000	5000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$30,000	$50,000

Assumptions

Barge operating costs were estimated at 25% and 35% the costs of the panamax carrier in Table 5-2.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,000	$3,000

Assumptions

The barges are estimated to incur piloting costs of $1,000 and docking costs of $1,000. Additionally, deep sea barges are needed for 5 hours at a rate of $200/hr.

Total Social Costs for Representative Vessel Casualty – Barges ($)	$537,800	$560,200

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Social Cost Category/ Assumptions	Fishing Vessels Small	Fishing Vessels Large
Struct. Repair Costs ($)	$100,000	$100,000
Repair Duration (days)	40	40

Assumptions

Based on values for vessel repairs shown in Table 5-1.

	Small	Large
No. of Crew	15	40
Crew Dismissal Costs ($/member)	$0	$0
Total Crew Dismissal Costs	$0	$0

Assumptions

Crew are assumed to be local fishermen. Contracts are assumed not to include severance costs. Many fishermen are employed as independent contractors and would not receive any such payments.

Table 5-5b

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MEDIUM REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$5,000	$12,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$200,000	$480,000
Assumptions		
Vessels were assumed to generate revenues at a rate of $300 per day per fishermen. This total includes all overhead expenses for the vessel. The rate of revenue generation is based on an assumed average salary of $30,000 per fishermen divided by 200 fishing days per year.		
Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$800	$1,200
Assumptions		
Vessels are assumed to require service of deep sea tugs for 4 and 6 hours respectively. No other charges, such as those for pilotage and docking, were assumed to apply.		
Total Social Costs for Representative Vessel Casualty - Fishing ($)	$300,800	$581,200

Source: ERG estimates. Specific sources given as described above.

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Social Cost Category/ Assumptions	Passenger/Ferry Drafts 19 ft.	19-30ft.	Over 30 ft.
Struct. Repair Costs ($)	$2,500,000	$2,500,000	$2,500,000
Repair Duration (days)	14	14	14

Assumptions

The amount and duration of repairs are based on data in Table 5-1, assuming a casualty of moderate severity.

No. of Crew	15	400	800
Crew Dismissal Costs ($/member)	$0	$0	$0
Total Crew Dismissal Costs	$0	$0	$0

Assumptions

The crew is assumed not to be dismissed for the duration of the repair work. Alternatively, crew may be discharged temporarily with no interim compensation.

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Vessel Operating Costs ($/day)	$75,000	$150,000	$250,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$1,050,000	$2,100,000	$3,500,000

Assumptions

Based on estimates of penalties included in shipyard contracts for repair work for any delays in returning vessel to productive service.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$1,000	$6,000	$8,000

Assumptions

Piloting charges estimated at $0, $1,000 and $1,500, with smallest vessel not requiring pilot services in vicinity of port where vessel operates. Vessels require 5, 20 and 25 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $0, $1,000 and $1,500 for offloading before towing to repair yard.

Total Social Costs for Representative Vessel Casualty - Passenger ($)	$3,551,000	$4,606,000	$6,008,000

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Social Cost Category/ Assumptions	Dry Cargo Vessel Drafts < 19 ft.	Dry Cargo Vessel Drafts 19-30ft.	Dry Cargo Vessel Drafts Over 30 ft.
Struct. Repair Costs ($)	$3,750,000	$3,750,000	$3,750,000
Repair Duration (days)	75	75	75
Assumptions			
The amount and duration of repair is selected based on values in Table 5-1.			
No. of Crew	17	20	24
Crew Dismissal Costs ($/member)	$800	$800	$800
Total Crew Dismissal Costs	$13,600	$16,000	$19,200
Assumptions			
The crew are assumed to be from a Pacific rim country and receive airfare home.			

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$9,000	$12,000	$16,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$675,000	$900,000	$1,200,000

Assumptions

Vessel operating costs for medium category are based on values for a panamax carrier but increased by 20% to indicate the below average operating costs of that estimate. Larger vessel is assumed to be newer and thus to have greater capital costs. Smaller vessel is assumed to have operating expenses equal to 75% of the medium category.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,750	$5,000	$7,000

Assumptions

Piloting charges estimated at $1,000, $1,000 and $1,500. Vessels require 10, 15 and 20 hours of deep sea tug service at $200/hr. Extra dockage.charges are estimated at $750, $1,000 and $1,500. No estimate is made for the increased cargo handling costs if cargo is offloaded. Extra cargo handling is rare.

Total Social Costs for Representative Vessel Casualty - Dry Cargo($)	$4,442,350	$4,671,000	$4,976,200

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Social Cost Category/ Assumptions	Tanker Drafts < 19 ft.	19-30ft.	Over 30 ft.
Struct. Repair Costs ($)	$3,750,000	$3,750,000	$3,750,000
Repair Duration (days)	75	75	75

Assumptions

Based on values in Table 5-1.

No. of Crew	17	20	24
Crew Dismissal Costs ($/member)	$800	$800	$800
Total Crew Dismissal Costs	$13,600	$16,000	$19,200

Assumptions

The crew is assumed to be from a Pacific rim country and receives airfare home.

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$16,000	$20,000	$24,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$1,200,000	$1,500,000	$1,800,000

Assumptions

Operating costs are extrapolated from values shown in Table 5-2, but have been increased to reflect the below average operating costs for the estimate in the Table. Operating costs are higher for tankers than for dry cargo carriers partly because market demand has driven vessel values, and thus capital costs to new purchasers, upwards.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,750	$5,000	$7,000

Assumptions

Piloting charges estimated at $1,000, $1,000 and $1,500. Vessels require 10, 15 and 20 hours of deep sea tug service at $200/hr. Extra dockage charges are estimated at $750, $1,000 and $1,500. No lightering costs were assumed. If lightering is added, a lightering vessel's ervices at $20,000 per day for two days is representative of emergency procedures. This estimate assumes the lightering vessel is reasonably available.

Total Social Costs for Representative Vessel Casualty - Tanker($)	$4,967,350	$5,271,000	$5,576,200

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Social Cost Category/ Assumptions	Barges - Dry Cargo and Tankers	
	Drafts	
	Small	Large
Struct. Repair Costs ($)	$1,000,000	$1,000,000
Repair Duration (days)	25	25

Assumptions

Based on values given in Table 5-1.

	Small	Large
No. of Crew	4	6
Crew Dismissal Costs ($/member)	$1,200	$1,200
Total Crew Dismissal Costs	$4,800	$7,200

Assumptions

Crew is assumed to be U.S. seamen who receive 2 weeks' wages for the interrupted voyage.

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	3000	5000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$75,000	$125,000

Assumptions

Barge operating costs were estimated at 25% and 35% the costs of the panamax carrier in Table 5-2.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$3,000	$3,000

Assumptions

The barges are estimated to incur piloting costs of $1,000 and docking costs of $1,000. Additionally, deep sea barges are needed for 5 hours at a rate of $200/hr.

Total Social Costs for Representative Vessel Casualty - Barges ($)	$1,082,800	$1,135,200

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Social Cost Category/ Assumptions	Fishing Vessels	
	Small	Large
Struct. Repair Costs ($)	$250,000	$250,000
Repair Duration (days)	75	75
Assumptions		
Based on values for vessel repairs shown in Table 5-1.		
No. of Crew	15	40
Crew Dismissal Costs ($/member)	$0	$0
Total Crew Dismissal Costs	$0	$0
Assumptions		
Crew are assumed to be local fishermen. Contracts are assumed not to include severance costs. Many fishermen are employed as independent contractors and would not receive any such payments.		

Table 5-5c

SELECTION OF FINAL ESTIMATES
OF SOCIAL COSTS FROM VESSEL CASUALTIES (cont.)
- MAJOR REPAIRS -

Vessel Operating Costs, incl. capital costs ($/day)	$5,000	$12,000
Total Foregone Value of Vessel Revenues During Repairs Daily Costs X Days for Repair)	$375,000	$900,000

Assumptions

Vessels were assumed to generate revenues at a rate of $300 per day per fishermen. This total includes all overhead expenses for the vessel. The rate of revenue generation is based on an assumed average salary of $30,000 per fishermen divided by 200 fishing days per year.

Exceptional Port Charges for Return to Port, Piloting, Docking ($)	$800	$1,200

Assumptions

Vessels are assumed to require service of deep sea tugs for 4 and 6 hours respectively. No other charges, such as those for pilotage and docking, were assumed to apply.

Total Social Costs for Representative Vessel Casualty - Fishing ($)	$625,800	$1,151,200

Source: ERG estimates. Specific sources given as described above.

NOTES TO SECTION FIVE

1. Estimated by ERG based on a telephone communication between John Eyraud of ERG and Colin Kennery, of LQM Associates. The estimate is also confirmed by the Lloyd's Shipping Economist, August 1990, Ship Fixture Report. The Ship Fixture Report includes data on the charter rates for major vessel categories, including arrangements for payment of fuel oil.

2. For example, ERG contacted Mr. Ted Thorjussen of the West Gulf Maritime Association. Mr. Thorjussen had examined the costs to vessel owners of shipping delays that had occurred in the Houston Ship Channel and had judged that daily vessel operating costs were at least $15,000 per day per vessel in most cases. ERG could not determine what the differences were in the operating assumptions between the estimates presented here and those used by others, such as that of Mr. Thorjussen. If newer vessels are considered, however, daily ship owner costs could easily exceed $15,000 per day.

REFERENCES TO SECTION FIVE

Lloyd's of London Press Ltd. 1990. Register of Ships, 1990-1991. London, U.K.

Lloyd's of London Press Ltd. 1990. Lloyd's Shipping Economist. 1990. Articles and features referenced include "Rates and Prices Data," "Supply and Demand Data," "Costs/Finance," "Gulf Crisis, Uncertainty and Instability Return," all from September, 1990 issue. Also "Cubs' Optimistic View of Rates/Prices in the 1990s, December, 1988. London, U.K.

Machalaba, Daniel. 1987. Sea of Trouble: Conditions Deteriorate on Freighters as Owners Battle Recession, Try to Keep Costs Down. Wall Street Journal, October 14, 1987.

Shipbuilders Council of America. 1989. Ship Repair Report. Washington, D.C.

Thorjussen, Ted. 1990. Telephone communication between John Eyraud of ERG and Ted Thorjussen, West Gulf Maritime Association. October 25, 1990.

APPENDIX A

DATA ON MARINE OIL

AND CHEMICAL SPILLS

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
1	80	ARABIAN GULF	NA	HASBAH 6	185,220,000	9	1	21,368,531	0.12
2	78	BRITTANY COAST	NA	AMOCO CADIZ	67,729,200	1	1	321,865,387	4.75
3	67	UNITED KINGDOM	NA	TORREY CANYON	36,000,006	9	1	251,355,234	6.98
4	89	PRINCE WILLIAM SOUND	AK	VALDEZ	10,800,006	1	1	1,016,057,092	94.08
5	85	N EUROPE	NA	NA	3,412,500	9	1	26,115,279	7.65
6	69	C.CALIFORNIA	CA	SANTA BARBARA	3,234,000	9	1	104,796,846	32.40
7	80	FRANCE	NA	TANIO	2,914,380	1	2	45,364,311	15.57
8	84	GALVESTON	LA	ALVENUS M/V	2,751,000	1	1	228,334	0.08
9	85	N AMERICA	NA	NA	2,730,000	9	1	4,417,502	1.62
10	87	CHILE, ABRA CANAL	NA	CABO PILAR	1,717,128	1	1	708,064	0.41
11	85	N EUROPE	NA	NA	1,680,000	9	1	716,108	0.43
12	84	SAN FRANCISCO	CA	PUERTO RICAN	1,470,000	1	1	2,535,776	1.73
13	79	USSR	NA	ANTONIO GRAMSCI	1,187,340	9	1	22,847,019	19.24
14	83	P.R. CHINA	NA	NA	1,028,244	9	9	4,031,266	3.92
15	85	FAR EAST	NA	NA	924,000	9	1	3,134,193	3.39
16	79	P.R. CHINA	NA	NA	677,292	9	9	228,608	0.34
17	85	S AMERICA	NA	NA	672,000	9	1	179,645	0.27
18	83	SOUTH KOREA	NA	NA	640,332	9	9	1,662,411	2.60
19	85	FAR EAST	NA	NA	630,000	9	1	1,776,069	2.82
20	88	BRITTANY COAST	NA	AMAZZONE	461,790	1	1	27,023	0.06
21	85	N AMERICA	NA	NA	441,000	9	1	3,652,383	8.28
22	85	N EUROPE	NA	NA	436,800	9	1	3,026,373	6.93
23	85	PHILADELPHIA	PA	GRAND EAGLE	435,540	1	1	4,387,37[illegible]	10.07
24	88	SAN FRANCISCO BAY	CA	MARTINEZ MFG COMPLEX	432,000	1	1	15,594,218	36.10
25	89	HUNTINGTON BEACH	CA	AMERICAN TRADER	395,010	9	9	4,064,228	10.29
26	88	SF BAY PORT	CA	NA	365,400	1	1	194,486	0.53
27	89	GALVESTON	TX	NA	340,620	1	9	2,462	0.01
28	81	DALARO	SWED	JOSE MARTI	307,860	9	9	3,879,100	12.60
29	76	ST. LAWRENCE RIVER	QUE	NEPCO 140	300,000	1	1	31,998,484	106.66
30	89	PROVIDENCE	RI	WORLD PRODIGY	288,666	1	2	2,797,326	9.69

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized In Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
31	85	N EUROPE	NA	NA	273,000	9	1	4,897,609	17.94
32	79	NECHES RIVER	TX	ESSO BAYWAY	273,000	9	9	3,530,852	12.93
33	89	HOUSTON	TX	RACHEL B M/V/T/B 2514	252,000	1	1	266,555	1.06
34	76	CHESAPEAKE BAY	VA	STC-101	250,000	1	1	1,505,811	6.02
35	86	SOUTH KOREA	NA	NA	246,288	9	9	536,414	2.18
36	85	PUGET SOUND	WA	ARCO ANCHORAGE	238,980	1	1	7,677,906	32.13
37	84	P.R. CHINA	NA	NA	233,982	9	9	1,246,061	5.33
38	90	ENGLAND	NA	ROSEBAY	231,855	1	1	2,535,000	10.93
39	87	UNITED ARAB EMIRATES	NA	AKARI	215,880	1	1	539,931	2.50
40	85	FAR EAST	NA	NA	210,000	9	1	1,331,999	6.34
41	87	NA	NA	GLACIER BAY	207,564	9	1	1,240,764	5.98
42	87	ANCHORAGE	AK	SS GLACIER BAY	205,800	1	1	1,113,769	5.41
43	79	ALASKA	AK	LEE WAN ZIN	200,004	9	2	5,268,030	26.34
44	79	JAPAN	NA	NA	197,022	9	9	1,224,779	6.22
45	71	OAKLAND ESTUARY	CA	PORT PETROLEUM CO.	171,000	9	9	8,475,814	49.57
46	84	PORTLAND	OR	MOBILE OIL	170,604	1	1	2,756,278	16.16
47	85	N AMERICA	NA	NA	168,000	9	1	1,691,476	10.07
48	85	N AMERICA	NA	NA	163,800	9	1	9,874,100	60.28
49	77	PORT ARTHUR	TX	MISS CAROLYN/DIXIE VENGANCE	157,920	1	9	805,578	5.10
50	86	SOUTH KOREA	NA	NA	153,930	9	9	645,153	4.19
51	85	ITALY	NA	PATMOS/CASTILLO DE MONTEARAG	151,116	1	1	6,183,923	40.92
52	87	FINLAND	NA	ANTONIO GRAMSCI	140,322	1	1	3,552,509	25.32
53	83	JAPAN	NA	NA	138,558	9	9	303,575	2.19
54	85	FAR EAST	NA	NA	136,500	9	1	602,185	4.41
55	83	GALVESTON	TX	NA	134,400	1	9	214,098	1.59
56	79	JAPAN	NA	MIYA MARU #8	116,575	9	9	862,131	7.40
57	85	N EUROPE	NA	NA	109,200	9	1	1,020,770	9.35
58	85	N EUROPE	NA	NA	109,200	9	1	9,344,297	85.57
59	86	NEW YORK	NY	AMAZON VENTURE	105,706	9	1	38,340	0.36
60	85	N EUROPE	NA	NA	95,550	9	1	314,637	3.29

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
61	80	JAPAN	NA	NA	95,424	9	9	1,334,568	13.99
62	81	CLEVELAND	WI	NA	94,438	1	2	37,218	0.39
63	85	N EUROPE	NA	NA	84,000	9	1	3,963,130	47.18
64	78	MOBILE	AL	ROLLNES	84,000	1	2	312,012	3.71
65	83	PORTLAND	OR	BLUE MAGPIE	78,900	9	1	247,410	3.14
66	83	JAPAN	NA	EIKO MARU # 1/CAVALRY	77,069	9	1	286,977	3.72
67	89	HAMILTON	ONT	NANCY ORR GAUCHER	76,986	9	9	626,215	8.13
68	87	JAPAN	NA	NA	76,986	9	9	1,463,906	19.02
69	88	ANACORTES	WA	M-C-N OIL BARGE NO. 5	67,357	9	2	1,178,460	17.50
70	85	DENMARK	NA	JAN	64,764	1	1	1,612,206	24.89
71	85	SWEDEN	NA	SOTKA	64,764	1	1	122,140	1.89
72	84	GALVESTON	TX	NA	63,600	9	3	2,481	0.04
73	84	SOUTH KOREA	NA	NA	61,572	9	9	1,315,478	21.36
74	86	SOUTH KOREA	NA	NA	61,572	9	9	266,483	4.33
75	80	JAPAN	NA	HOSEI MARU/KINREI MARU	58,288	9	1	1,042,675	17.89
76	82	PORT AUXEAS	NA	IMPERIALACAD	55,697	9	2	17,085	0.31
77	85	N EUROPE	NA	NA	54,600	9	1	1,717,112	31.45
78	85	FAR EAST	NA	NA	54,600	9	1	1,304,801	23.90
79	85	N EUROPE	NA	NA	54,600	9	1	952,738	17.45
80	82	GERMANY	NA	ONDINA	53,970	1	1	8,956,253	165.95
81	86	SAN JUAN	PR	ST THOMAS	50,400	1	1	328,606	6.52
82	87	SOUTH KOREA	NA	NA	49,266	9	9	1,743,521	35.39
83	86	GERMANY	NA	BRADY MARIA/WAYLINE	43,176	1	1	2,458,124	56.93
84	80	SWEDEN	NA	FURENAS/KARMAN	43,176	1	9	733,167	16.98
85	85	S EUROPE	NA	NA	42,000	9	1	503,712	11.99
86	86	CHAROLETTE AMALIE	VI	ST.THOMAS	41,392	9	1	1,670,632	40.36
87	87	P.R. CHINA	NA	NA	40,026	9	9	177,016	4.42
88	80	SOUTH KOREA	NA	NA	40,026	9	9	148,400	3.71
89	87	ANCHORAGE	AK	ALL ALASKAN	40,000	9	2	506,788	12.67
90	80	JAPAN	NA	NA	38,472	9	9	78,704	2.05

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
91	86	SWEDEN	NA	THUNTANK 5	37,779	1	1	3,978,802	105.32
92	85	N EUROPE	NA	NA	36,960	9	1	30,049	0.81
93	78	JAPAN	NA	NA	36,960	9	9	3,245,446	87.81
94	88	BALTIMORE	MD	NA	32,000	9	4	82,778	2.59
95	89	MOBILE	AL	CHRIS CARTER T/B	30,450	9	1	2,692	0.09
96	80	JAPAN	NA	UNSEI MARU/SUN EDELWEISS	30,223	9	1	37,807	1.25
97	90	NORWAY	NA	AZALEA	29,988	9	9	3,131,400	104.42
98	87	SOUTH KOREA	NA	NA	27,720	9	9	4,005	0.14
99	86	NA	NA	APEX HOUSTON	25,872	9	1	15,103	0.58
100	76	HAMPTON ROADS	VA	ATC-133	25,600	9	1	1,112,674	43.46
101	79	JAPAN	NA	SHOWA MARU	21,588	9	9	70,241	3.25
102	85	N EUROPE	NA	NA	21,000	9	1	170,898	8.14
103	85	PORT ARTHUR	TX	ZENIT AURORA	20,000	1	1	76,779	3.84
104	87	SOUTH KOREA	NA	NA	18,480	9	9	171,032	9.26
105	82	JAPAN	NA	FUKUTOKU MARU #8/KOSHU MARU	18,350	1	1	959,915	52.31
106	85	S EUROPE	NA	NA	17,640	9	1	312,273	17.70
107	85	JAPAN	NA	KOSHUN MARU # 1/RYOZAN MARU	17,270	9	1	153,461	8.89
108	90	HAWAII	HI	TEXACO CONNECTICUT	16,800	0	2	1,176,471	70.03
109	87	SOUTH KOREA	NA	NA	15,414	9	9	182,680	11.85
110	87	SOUTH KOREA	NA	NA	12,306	9	9	839,097	68.19
111	83	JAPAN	NA	KOEI MARU # 3/ALBIERTO	10,578	9	1	89,757	8.49
112	81	CORPUS CHRISTI	TX	NA	10,374	1	9	77,885	7.51
113	86	SAN FRANCISCO	CA	BEAVER STATE	10,000	9	1	84,680	8.47
114	77	BALTIMORE	MD	NA	10,000	1	9	30,133	3.01
115	89	LANAI/MOLOKAI	HI	INDEPENDENCE	10,000	1	2	101,606	10.16
116	86	LARCHMONT	NY	NA	10,000	9	1	57,294	5.73
117	88	AKUN ISAND	AK	AOYAGI MARU	10,000	9	1	526,205	52.62
118	90	VANCOUVER	B.C.	RUBIN LOTUS/Arcturus	9,996	9	9	1,710,000	171.07
119	88	NA	NA	NA	9,324	9	1	18,237	1.96
120	87	BRONX	NY	NA	9,200	9	1	36,295	3.95

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
121	84	JAPAN	NA	TSUNEHISA MARU # 8	6,476	1	1	96,750	14.94
122	90	GALVESTON	TX	NA	6,300	1	2	8,078	1.28
123	79	JAPAN	NA	NA	6,174	9	9	64,840	10.50
124	87	HOUSTON	TX	BALTIMORE	5,460	9	1	142,828	26.16
125	87	JAPAN	NA	HINODE MARU # 1	5,397	1	1	19,581	3.63
126	84	PORT ARTHUR	TX	ORTONIA SUN M/V	5,000	1	9	59,453	11.89
127	84	JAPAN	NA	KOHO MARU # 3	4,318	1	1	396,568	91.85
128	82	JAPAN	NA	SHIOTA MARU # 2	4,318	1	1	229,376	53.13
129	90	SPAIN	NA	AVAJ 2	3,886	1	1	4,719,000	1,214.41
130	86	EAST BOSTON	MA	SOUNDER	3,600	9	2	20,600	5.72
131	87	NORFOLK	VA	GOVERNOR HENDRICKS	3,500	9	1	31,904	9.12
132	87	JAPAN	NA	SOUTHERN EAGLE/GOOD FAITH	3,238	9	2	270,499	83.53
133	86	ALGERIA	NA	OVED GUETERINI	3,238	9	4	1,001	0.31
134	85	SAN JUAN	PR	A REGINA	3,000	1	2	242,264	80.75
135	87	PAGO PAGO	AS	UNKNOWN SOURCE	3,000	9	1	15,027	5.01
136	88	NEWPORT NEWS	VA	NA	2,800	9	1	17,074	6.10
137	88	SEATTLE	WA	UNKNOWN SOURCE	2,300	9	2	27,582	11.99
138	86	BOCA GRANDE	FL	STACI LYNN	2,260	9	2	17,375	7.69
139	88	GALVESTON	TX	NA	2,210	1	1	2,621	1.19
140	88	NA	NA	NA	2,206	9	1	22,162	10.05
141	86	RICHMOND	CA	NA	2,200	9	2	48,009	21.82
142	81	JAPAN	NA	SUMA MARU # 11	2,159	1	1	70,343	32.58
143	79	JAPAN	NA	MEBARUZAKI MARU #5	2,159	9	9	51,630	23.92
144	90	NEW ORLEANS	LA	NA	2,100	1	9	27,626	13.16
145	86	VENICE	LA	WGH-79	2,100	9	4	1,830	0.87
146	88	PORT CANAVERAL	FL	CAPT BOB	2,010	9	2	9,546	4.75
147	86	LEMONT	IL	NA	2,000	9	1	20,974	10.49
148	79	HALIFAX	NS	NA	1,749	9	1	8,813	5.04
149	87	NEW BEDFORD	MA	NA	1,574	9	2	20,893	13.27
150	87	NORFOLK	VA	GOVERNOR HENDRICKS	1,500	9	1	5,673	3.78

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
151	88	PORT EVERGLADES	FL	UNKNOWN SOURCE	1,500	9	2	14,256	9.50
152	86	CORPUS CHRISTI	TX	HIMALAYA	1,470	9	1	5,633	3.83
153	86	WILMINGTON	CA	NA	1,470	9	4	128,098	87.14
154	86	CHANNELVIEW	TX	NA	1,400	9	4	281	0.20
155	86	GEORGETOWN	SC	BORON	1,300	9	2	14,809	11.39
156	88	JAPAN	NA	TAIYO MARU # 13	1,295	9	1	64,264	49.61
157	86	PALM BEACH	FL	UNKNOWN SOURCE	1,200	9	2	8,877	7.40
158	88	PAGO PAGO	AS	UNKNOWN SOURCE	1,100	9	1	10,119	9.20
159	86	ST CROIX	VI	ROSAOMAIRA	1,050	9	2	31,953	30.43
160	90	CORPUS CHRISTI	TX	CHAMPION T/S	1,050	1	2	11,902	11.34
161	87	HANAUMA BAY/KOKO HEAD	HI	UNKNOWN SOURCE	1,050	9	4	4,703	4.48
162	86	PORT EVERGLADES	FL	MARLAGO I	1,000	9	1	1,323	1.32
163	90	MORGAN CITY	MS	JOYCE MARIE F/V	1,000	1	2	6,042	6.04
164	90	MOBILE	FL	MULPHA TAPAH M/V	1,000	1	2	25,000	25.00
165	86	STAMFORD	CT	NA	1,000	9	1	39,380	39.38
166	86	PORTLAND	OR	NEW YORK	1,000	9	1	45,032	45.03
167	85	ST JOHNS	NFLD	NA	933	9	2	419	0.45
168	88	EUCLID	OH	NA	900	9	1	8,044	8.94
169	87	ORANGE	TX	WINFRED W	900	9	4	15,263	16.96
170	88	BOSTON	MA	FREDERICKSBURG	900	1	1	64,900	72.11
171	87	GALVESTON	TX	NA	882	9	1	5,962	6.76
172	87	TEXAS CITY	TX	UNKNOWN SOURCE	840	9	4	1,968	2.34
173	86	PASADENA	TX	NA	798	9	1	15,012	18.81
174	86	DEER PARK	TX	NA	756	9	1	4,881	6.46
175	83	JAPAN	NA	SHINKAI MARU # 3	756	1	1	8,434	11.16
176	86	BALTIMORE	MD	UNKNOWN SOURCE	710	9	4	16,546	23.30
177	86	ISLAMORADA BEACH	FL	UNKNOWN SOURCE	705	9	1	6,549	9.29
178	87	PORT CANAVERAL	FL	NA	700	9	1	2,106	3.01
179	87	NA	NA	OCEAN CLIPPER	700	9	2	6,390	9.13
180	88	GREAT BRIDGE	VA	UNKNOWN SOURCE	700	9	2	9,937	14.20

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
181	88	DANIA,	FL	UNKNOWN SOURCE	700	9	1	8,051	11.50
182	86	NEW ROCHELLE	NY	NA	700	9	2	3,386	4.84
183	88	NORFOLK	VA	GIUSEPPE LEMBO	700	9	1	4,826	6.89
184	88	WAIMANALO	HI	UNKNOWN SOURCE	700	9	4	6,874	9.82
185	88	CAMDEN	NJ	NA	700	9	1	22,433	32.05
186	86	EVERETT	WA	NA	675	9	2	1,469	2.18
187	86	DEER PARK	TX	NA	630	9	1	5,993	9.51
188	88	PORT ARTHUR	TX	NA	630	9	1	3,933	6.24
189	86	SEATTLE	WA	UNKNOWN SOURCE	600	9	1	7,971	13.28
190	88	TACOMA	WA	ATALANTA	600	9	2	8,017	13.36
191	86	WEST FRANKLIN	IN	NA	600	9	1	16,570	27.62
192	87	PORT CANAVERAL	FL	UNKNOWN SOURCE	600	9	1	16,117	26.86
193	83	ST JOHNS	NFLD	CAVALLO	518	9	2	7,535	14.54
194	87	SABINE	TX	KEY LADY	504	9	1	4,152	8.24
195	88	PAGO PAGO	AS	UNKNOWN SOURCE	500	9	1	6,750	13.50
196	86	FLUSHING QUEENS	NY	NA	500	9	1	1,685	3.37
197	86	GLOUCESTER	MA	BABY JERRY	500	9	2	15,358	30.72
198	86	SOUTH BOSTON	MA	NA	500	9	1	10,169	20.34
199	88	GALVESTON	TX	TX61252V F/V	500	1	2	3,149	6.30
200	87	NORTH BRADDOCK	PA	NA	500	9	4	13,184	26.37
201	86	MILWAUKEE	WI	UCKA	500	9	4	19,062	38.12
202	87	WOODRIVER	IL	UNKNOWN SOURCE	500	9	1	3,181	6.36
203	86	SEATTLE	WA	PIONEER III	460	9	2	8,805	19.14
204	87	PAGO PAGO	AS	UNKNOWN SOURCE	430	9	4	5,403	12.56
205	88	LAKE CHARLES	LA	AMAZON VENTURE	420	9	1	10,979	26.14
206	88	WILMINGTON	CA	UNKNOWN SOURCE	420	9	1	28,849	68.69
207	88	NA	NA	NA	420	9	1	4,665	11.11
208	88	BAYTOWN	TX	NA	420	9	1	1,135	2.70
209	88	PHILADELPHIA	PA	NA	420	9	1	13,663	32.53
210	87	KEY WEST	FL	BLUE FIN	400	9	2	8,650	21.63

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
211	87	RODEO	CA	GOLDEN COAST	400	9	2	7,699	19.25
212	88	MOBILE	AL	NA	400	9	1	6,743	16.86
213	86	ST JOHNS	NFLD	RIAKI	389	9	2	4,044	10.41
214	86	NEW BEDFORD	MA	ALYDAR	372	9	2	31,431	84.49
215	87	MOREHEAD CITY	NC	JENS JUHL	355	9	2	2,851	8.03
216	86	FT LAUDERDALE	FL	NA	350	9	2	5,368	15.34
217	86	MIAMI	FL	UNKNOWN SOURCE	350	9	1	5,833	16.66
218	87	PITI	GU	JUDITH CAROL	350	9	2	10,118	28.91
219	88	HOUSTON	TX	MAR CORAL	336	9	1	3,987	11.86
220	87	PORTSMOUTH	VA	NA	300	9	1	4,399	14.66
221	86	PORT OF PALM BEACH	FL	LONG ISLAND EXPRESS	300	9	1	5,771	19.24
222	88	PAGP PAGO	AS	UNKNOWN SOURCE	300	9	1	3,465	11.55
223	86	BROOKLYN	NY	NA	300	9	3	23,280	77.60
224	87	NORFOLK	VA	NA	300	9	1	6,516	21.72
225	87	PROVIDENCE	MA	NA	300	1	2	20,861	69.54
226	87	BROOKLYN	NY	NA	300	9	1	980	3.27
227	89	NY	NJ	MARACIABO	300	1	1	10,805	36.02
228	86	PORT EVERGLADES	FL	NA	300	9	1	7,863	26.21
229	88	PAGO PAGO HARBOR	SA	NA	300	9	1	2,600	8.67
230	86	WHITING	IN	NA	300	9	1	3,859	12.86
231	87	PASCAGOULA	MS	NA	300	9	1	5,267	17.56
232	88	CLEVELAND	OH	NA	300	9	1	11,342	37.81
233	87	DARTMOUTH	NS	COGSWILLIAM	291	9	1	1,320	4.53
234	90	BOSTON	MA	NA	275	1	1	77,000	280.00
235	89	CORPUS CHRISTI	TX	NA	252	1	1	5,767	22.88
236	88	MOBILE	AL	NA	252	9	1	2,038	8.09
237	89	GALVESTON	TX	NA	252	1	1	4,744	18.83
238	87	SEATTLE	WA	UNKNOWN SOURCE	250	9	2	3,654	14.61
239	86	PORT SALERNO	FL	UNKNOWN SOURCE	250	9	2	7,235	28.94
240	86	SAVANNAH	GA	KRUSEVAC	250	9	1	3,461	13.84

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = "***" (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
241	87	OAKLAND	CA	UNKNOWN SOURCE	250	9	1	11,953	47.81
242	88	MIAMI	FL	JUDITE	250	9	2	194	0.78
243	87	VIRGINIA BEACH	VA	NA	250	9	1	7,173	28.69
244	88	PORT EVERGLADES	FL	RAPTURE	250	9	2	15,697	62.79
245	86	HAMPTON	VA	NA	235	9	1	3,186	13.56
246	86	FULTON	TX	UNKNOWN SOURCE	220	9	1	589	2.68
247	87	CHANNELVIEW	TX	NA	210	9	1	411	1.96
248	86	SULPHUR	LA	AMAZON VENTURE	210	9	1	3,165	15.07
249	89	PORT ARTHUR	TX	NA	210	1	2	2,627	12.51
250	89	MOBILE	AL	NA	210	1	1	4,382	20.87
251	86	LAPORTE	TX	NA	210	9	1	1,954	9.30
252	90	CORPUS CHRISTI	TX	NA	210	1	1	628	2.99
253	86	ARANSAS PASS	TX	UNKNOWN SOURCE	210	9	1	698	3.32
254	87	GALVESTON	TX	NA	210	9	1	367	1.75
255	86	FULTON	TX	UNKNOWN SOURCE	210	9	1	870	4.14
256	86	HOUSTON	TX	NA	210	9	1	2,040	9.71
257	87	PITI	GU	NA	200	9	1	2,707	13.53
258	86	STURGEON BAY	WI	JOHN M. SELVICK	200	9	1	1,147	5.73
259	86	FLOREFFE	PA	AO B 234	200	9	2	1,659	8.30
260	86	ESSEX	MD	GRAND-TRAVELER	200	9	2	3,225	16.13
261	88	PORT CANAVERAL	FL	UNKNOWN SOURCE	200	9	1	6,045	30.22
262	88	NY	NY	NA	200	1	1	165,380	826.90
263	87	JUNEAU	AK	NA	200	9	2	940	4.70
264	89	LIS	CT	NA	200	1	2	13,046	65.23
265	87	ISLE OF PALMS	SC	NA	200	9	2	6,941	34.71
266	89	PROVIDENCE	MA	OLYMPIC SUN II	200	1	1	16,105	80.53
267	86	BALTIMORE	MD	UNKNOWN SOURCE	200	9	1	3,106	15.53
268	86	PORT CHESTER	NY	NA	200	9	1	12,900	64.50
269	86	PAGO PAGO	AS	UNKNOWN SOURCE	200	9	4	693	3.47
270	86	RIVIERA BEACH	FL	MARLAGO I	200	9	1	4,776	23.88

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
271	86	STERLING HEIGHTS	MI	NA	200	9	1	6,170	30.85
272	88	CAMDEN	NJ	NA	200	9	1	3,791	18.96
273	86	SAVANNAH	GA	NA	200	9	2	782	3.91
274	88	CORPUS CHRISTI	TX	NA	200	9	4	233	1.16
275	89	PROVIDENCE	MA	NA	200	1	1	4,428	22.14
276	86	LOUISVILLE	KY	NA	200	9	1	174,542	872.71
277	86	NA	NA	UNKNOWN SOURCE	200	9	1	7,065	35.33
278	86	FT LAUDERDALE	FL	UNKNOWN SOURCE	200	9	1	5,837	29.19
279	86	WOOD RIVER	IL	UNKNOWN SOURCE	200	9	4	3,932	19.66
280	87	MCKEESPORT	PA	NA	200	9	1	5,498	27.49
281	86	VALDEZ	AK	BETTY A	200	9	2	506	2.53
282	86	FOWLER'S BEACH	DE	NA	200	9	1	9,224	46.12
283	87	STATEN ISLAND	NY	TEXACO 807	200	9	2	5,499	27.50
284	88	JACKSONVILLE	FL	UNKNOWN SOURCE	200	9	1	3,199	16.00
285	86	ESSEX	MD	KNOT TWO WORRY	200	9	2	3,225	16.13
286	88	HONOLULU	HI	UNKNOWN SOURCE	200	9	2	3,426	17.13
287	88	PAGO PAGO	AS	NA	200	9	1	2,087	10.44
288	88	SAN JUAN	PR	UNKNOWN SOURCE	200	9	1	4,290	21.45
289	87	MORRO BAY	CA	SARDA SARDA	172	9	2	761	4.43
290	87	PAGO PAGO	AS	UNKNOWN SOURCE	170	9	4	1,989	11.70
291	87	CORPUS CHRISTI	TX	NA	168	9	4	1,124	6.69
292	87	GALVESTON	TX	NA	168	9	1	1,137	6.77
293	87	GALVESTON	TX	W 110	168	9	2	798	4.75
294	86	DEER PARK	TX	LUCOR WICKLIFFE	168	9	4	1,890	11.25
295	87	SAN LEON	TX	TX6777WX	168	9	1	1,036	6.17
296	88	SKAGIT BAY	WA	SEA OTTER	160	9	2	2,116	13.23
297	88	CAPE CANAVERAL	FL	MOBY DICK	150	9	2	7,878	52.52
298	88	CHESAPEAKE	VA	STC 007	150	9	4	1,732	11.55
299	87	GALVESTON	TX	NA	150	9	1	504	3.36
300	86	WYANDOTTE	MI	NA	150	9	1	5,018	33.46

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
301	86	SEATTLE.	WA	NA	150	9	1	1,684	11.23
302	89	MOBILE	FL	LITTLE MAN F/V	150	9	2	5,984	39.89
303	87	NA	NA	HANNAH 5101	150	9	1	29,330	195.53
304	86	NEWPORT NEWS	VA	UNKNOWN SOURCE	150	9	4	3,660	24.40
305	87	FT.LAUDERDALE	FL	NA	150	9	1	2,777	18.51
306	87	PORT CANAVERAL	FL	UNKNOWN SOURCE	150	9	2	5,640	37.60
307	89	PROVIDENCE	MA	NA	150	0	1	1,177	7.85
308	88	PITI	GU	KAZUTAKA MARU NO. 8	150	9	1	949	6.33
309	88	CAPTIVA ISLAND	FL	MARY L	150	9	2	5,475	36.50
310	86	PORT EVERGLADES	FL	NA	150	9	2	2,233	14.89
311	88	KAPAA	HI	UNKNOWN SOURCE	147	9	1	15,818	107.61
312	87	PAGO PAGO	AS	UNKNOWN SOURCE	130	9	2	1,738	13.37
313	86	SAN JUAN	PR	NA	130	9	4	5,734	44.11
314	86	ROCKPORT	TX	UNKNOWN SOURCE	130	9	1	1,046	8.05
315	81	VANCOVER	BC	CANADIAN HIGH	130	9	2	3,539	27.32
316	83	DARTMOUTH	NS	SPRAGUEARCTU	130	9	1	22,492	173.64
317	86	HOUSTON	TX	NA	126	9	1	275	2.18
318	86	CAMERON PARISH	LA	NA	126	9	1	1,318	10.46
319	87	GALVESTON	TX	CONE JOHNSON	126	9	1	505	4.01
320	88	GALVESTON	TX	SADIE & LAURIE & R	126	9	1	912	7.24
321	87	GALVESTON	TX	CAPT. JESSE	126	9	1	1,068	8.48
322	87	PORT EVERGLADES	FL	DISCOVERY I	125	9	2	2,072	16.58
323	86	PORT TOWNSEND	WA	UNKNOWN SOURCE	125	9	2	2,640	21.12
324	86	PORT ISABEL	TX	GLORIA EVELYN	120	9	1	2,805	23.38
325	88	VALDEZ	AK	EUREKA	115	9	2	1	0.01
326	89	JAPAN	NA	FUKKOL MARU # 12	108	1	1	19,025	176.25
327	86	HOUSTON	TX	NA	105	9	1	1,514	14.42
328	87	NA	NA	NA	100	9	1	701	7.01
329	87	EUCLID	OH	NA	100	9	1	6,051	60.51
330	89	GALVESTON	TX	ZOIE LYNN F/V	100	1	2	4,096	40.96

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
331	86	NORFOLK	VA	UNKNOWN SOURCE	100	9	1	8,932	89.32
332	86	NEWPORT	OR	NA	100	9	2	1,225	12.25
333	86	JACKSONVILLE	FL	NA	100	9	2	747	7.47
334	88	MILWAUKEE	WI	NA	100	9	4	8,227	82.27
335	86	SEATTLE	WA	UNKNOWN SOURCE	100	9	2	1,459	14.59
336	87	JACKSONVILLE	FL	NA	100	9	1	5,488	54.88
337	88	JUNEAU	AK	UNKNOWN SOURCE	100	9	2	238	2.38
338	87	SAN RAFAEL	CA	JAMES J FULTON	100	9	2	8,549	85.49
339	88	ST PETERSBURG	FL	NA	100	9	1	4,633	46.33
340	86	ATLANTIC CITY	NJ	LITTLE BEAR	100	9	1	4,600	46.00
341	87	LIS	NY	NA	100	1	1	2,379	23.79
342	88	PAGO PAGO	AS	UNKNOWN SOURCE	100	9	4	1,066	10.66
343	90	NEW ORLEANS	LA	NA	100	1	2	6,261	62.61
344	88	VANCOUVER	WA	FILIPINAS	100	9	1	4,073	40.73
345	88	FT LAUDERDALE	FL	UNKNOWN SOURCE	100	9	3	1,810	18.10
346	87	PORTSMOUTH	VA	NA	100	9	2	1,802	18.02
347	87	MIAMI	FL	THOMAS CUNNINGHAM, SR.	100	9	1	1,795	17.95
348	86	CHINCOTEAGUE	VA	UNKNOWN SOURCE	100	9	4	595	5.95
349	88	SOUTHPORT	NC	NA	100	9	2	2,039	20.39
350	88	PHILADELPHIA	PA	NA	100	9	1	9,014	90.14
351	86	FORT LAUDERDALE	FL	UNKNOWN SOURCE	100	9	1	2,464	24.64
352	87	ORANGE	TX	HENRY CLAY	100	9	4	15,263	152.63
353	86	SUPERIOR	WI	NA	100	9	1	3,034	30.34
354	86	NA	NA	NA	100	9	2	2,009	20.09
355	89	NEW ORLEANS	LA	NA	100	1	2	1,889	18.89
356	87	BALTIMORE	MD	KEBAN	100	9	2	7,871	78.71
357	87	HONOLULU	HI	UNKNOWN SOURCE	100	9	2	2,085	20.85
358	87	PHILADELPHIA	PA	NA	100	9	1	3,276	32.76
359	87	PORT ISABEL	TX	NA	100	9	2	4,938	49.38
360	86	DETROIT	MI	NA	100	9	1	1,348	13.48

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = "**" (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
361	87	LAUDERDALE BY THE SEA	FL	NA	100	9	2	1,816	18.16
362	89	NY	NY	NA	100	1	1	2,220	22.20
363	86	NORFOLK	VA	UNKNOWN SOURCE	100	9	3	3,258	32.58
364	86	CLEVELAND	OH	NA	100	9	4	7,639	76.39
365	85	HALIFAX	NS	CAVALLO	86	9	2	26,324	304.85
366	87	PAGO PAGO	AS	UNKNOWN SOURCE	86	9	4	1,015	11.80
367	86	BELLINGHAM	WA	LOCHINVAR	85	9	2	2,154	25.34
368	86	MENEMSHA	MA	UNKNOWN SOURCE	85	9	1	837	9.85
369	86	GALENA PARK	TX	NA	84	9	1	2,546	30.31
370	86	HOUSTON	TX	NA	84	9	4	2,330	27.74
371	86	CHANNELVIEW	TX	NA	84	9	1	1,376	16.38
372	88	NEDERLAND	TX	CREOLE PASS	84	9	1	622	7.41
373	88	GALVESTON	TX	ROSS CHOUEST	84	9	1	1,716	20.43
374	87	LOS ANGELES	CA	UNKNOWN SOURCE	84	9	4	8,426	100.31
375	86	HOUSTON	TX	NA	84	9	1	3,284	39.09
376	88	TEXAS CITY	TX	NA	84	9	1	405	4.83
377	88	MORGAN CITY	LA	NA	84	9	4	2,407	28.65
378	86	GALENA PARK	TX	NA	84	9	1	1,965	23.39
379	86	GALVESTON	TX	NA	84	9	1	617	7.34
380	87	SABINE PASS	TX	CAPT. QUOC CUONG	84	9	4	2,029	24.16
381	86	PASADENA	TX	NA	84	9	1	1,550	18.46
382	87	LONG BEACH	CA	UNKNOWN SOURCE	84	9	1	11,510	137.02
383	86	CORPUS CHRISTI	TX	NA	84	9	1	936	11.14
384	86	DEER PARK	TX	NA	84	9	1	1,282	15.26
385	87	HOUSTON	TX	NA	84	9	1	2,106	25.07
386	86	CORPUS CHRISTI	TX	NA	84	9	1	757	9.01
387	86	PAGO PAGO	AS	UNKNOWN SOURCE	80	9	1	2,806	35.08
388	88	PALM BEACH	FL	T.J. SHERIDAN	80	9	1	744	9.30
389	87	MIAMI	FL	PAMPERO	80	9	1	1,447	18.09
390	90	CORPUS CHRISTI	TX	NA	80	1	2	392	4.90

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
391	88	MORRO BAY	CA	ANN	78	9	2	1	0.01
392	88	TAMPA	FL	ELK RIVER	75	9	1	2,441	32.55
393	86	MIAMI	FL	UNKNOWN SOURCE	75	9	1	2,197	29.30
394	88	WEST ELIZABETH	PA	VULCAN	75	9	4	4,053	54.04
395	88	KETCHIKAN	AK	AK6396B, UNNAMED	75	9	2	131	1.74
396	86	MIAMI	FL	BAHAMA ADVENTURE	75	9	1	1,478	19.71
397	87	PORTSMOUTH	VA	NA	75	9	1	2,926	39.01
398	86	MIAMI	FL	HYBUR CLIPPER	75	9	1	1,417	18.89
399	86	BALTIMORE	MD	NA	75	9	4	2,247	29.96
400	88	MONTAUK	NY	NA	70	9	2	5,572	79.60
401	86	FULTON	TX	UNKNOWN SOURCE	70	9	1	526	7.51
402	86	MIAMI	FL	UNKNOWN SOURCE	70	9	1	233	3.32
403	90	MOBILE	AL	NA	70	1	2	1,559	22.27
404	87	MIAMI	FL	SHANGRI LA	70	9	2	1,372	19.59
405	87	JACKSONVILLE	FL	NA	70	9	1	1,952	27.89
406	88	LIS	NY	NA	70	1	2	5,572	79.60
407	88	JUNEAU	AK	TEAL	70	9	2	133	1.90
408	89	CORPUS CHRISTI	TX	SIOBHAN F/V	70	1	1	2,580	36.85
409	88	MORRO BAY	CA	SEASONS	67	9	2	7,228	107.87
410	86	WESTMOUNT	NA	NA	65	9	2	3,370	52.04
411	83	LEWISPORTE	NFLD	ASTRON	65	9	2	1,785	27.56
412	89	HOUSTON	TX	NA	63	1	9	4,457	70.75
413	89	HOUSTON	TX	NA	63	1	1	2,390	37.93
414	86	KEY WEST	FL	UNKNOWN SOURCE	60	9	1	2,104	35.07
415	88	SHARPSBURG	PA	NA	60	9	4	2,977	49.62
416	86	MEHLVILLE	MO	NA	60	9	2	2,498	41.64
417	86	PORT ISABEL	TX	NA	60	9	2	702	11.70
418	86	SAN JUAN CAPISTRANO	CA	NA	60	9	4	2,247	37.45
419	86	KEY WEST	FL	UNKNOWN SOURCE	60	9	1	3,126	52.11
420	87	PORT ISABEL	TX	UNKNOWN SOURCE	60	9	1	1,605	26.74

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
421	88	MIAMI	FL	TONALA	60	9	2	2,252	37.54
422	87	NEWPORT BEACH	CA	UTOPIA	55	9	2	1,586	28.84
423	87	ROCKPORT	TX	MEGGAN RACHELLE	55	9	1	560	10.18
424	87	MANHATTAN	NY	NA	55	9	1	198	3.60
425	87	SAN FRANCISCO	CA	MARIA Z	54	9	2	1,453	26.91
426	87	PORT ANGELES	WA	LILLIAN S	50	9	2	2,170	43.40
427	88	JUNEAU	AK	UNKNOWN SOURCE	50	9	2	626	12.53
428	87	SAN RAFAEL	CA	NA	50	9	4	6,255	125.10
429	86	BERKELEY	CA	NA	50	9	4	376	7.53
430	87	PAGO PAGO	AS	UNKNOWN SOURCE	50	9	1	550	11.00
431	90	CORPUS CHRISTI	TX	NA	50	1	2	713	14.26
432	87	PITTSBURGH	PA	NA	50	9	4	1,458	29.17
433	86	MILWAUKEE	WI	NA	50	9	2	2,070	41.41
434	88	ARANSAS PASS	TX	NA	50	9	1	609	12.18
435	87	HONOLULU	HI	UNKNOWN SOURCE	50	9	2	2,588	51.76
436	87	NORFOLK	VA	GOVERNOR HENDRICKS	50	9	1	805	16.10
437	90	PORT ARTHUR	TX	SEA DOLLAR F/V	50	1	9	1,107	22.14
438	87	MIAMI	FL	UNION EXPRESS	50	9	4	559	11.17
439	87	SEATTLE	WA	UNKNOWN SOURCE	50	9	1	1,188	23.76
440	88	TAMPA	FL	RAVEN	50	9	2	1,032	20.63
441	86	HATTERAS	NC	CHERYL ANN	50	9	2	613	12.27
442	87	DANIA	FL	NA	50	9	1	419	8.38
443	86	NA	NA	CAPT. CATO	50	9	1	819	16.38
444	87	RICHMOND	CA	SEA HUNTER	50	9	2	6,232	124.64
445	86	SABINE	TX	UNKNOWN SOURCE	50	9	1	1,217	24.33
446	86	NA	NA	NA	50	9	4	972	19.43
447	88	TEXAS CITY	TX	NA	50	9	1	260	5.19
448	88	BILOXI	MS	NAUGHTY KITTEN	50	9	2	999	19.97
449	88	HONOLULU	HI	UNKNOWN SOURCE	50	9	1	2,045	40.91
450	87	TEXAS CITY	TX	STURGEON	50	9	1	376	7.52

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
451	86	SAUSALITO	CA	UNKNOWN SOURCE	50	9	2	44	0.88
452	87	CHARLESTOWN	MA	UNKNOWN SOURCE	50	9	1	1,172	23.45
453	87	MONTEREY	CA	UNKNOWN SOURCE	50	9	2	198	3.96
454	86	OCEAN CITY	MD	UNKNOWN SOURCE	50	9	4	600,950	12,019.01
455	86	HONOLULU	HI	NA	50	9	4	1,911	38.22
456	86	CAPE CANAVERAL	FL	NA	50	9	1	1,053	21.05
457	86	ESSEX	MD	GE-GI	50	9	2	3,225	64.51
458	90	PROVIDENCE	MA	EMERALD ISLE	50	0	2	2,990	59.80
459	87	MIAMI	FL	UNKNOWN SOURCE	50	9	1	2,091	41.82
460	87	RIVERHEAD	NY	NA	50	9	1	2,379	47.58
461	87	HONOLULU	HI	UNKNOWN SOURCE	50	9	2	329	6.58
462	87	NORFOLK	VA	NA	50	9	1	2,061	41.22
463	88	VALDEZ	AK	GULF WINDS	50	9	2	1	0.02
464	86	BALTIMORE	MD	NA	50	9	4	2,195	43.90
465	88	JACKSONVILLE	FL	NA	50	9	2	1,480	29.60
466	89	PORT ARTHUR	TX	NA	50	1	2	403	8.06
467	86	STOCKTON	CA	CF 9849 CG	50	9	2	1,917	38.33
468	86	EMERYVILLE	CA	NA	50	9	1	1,539	30.78
469	88	HOBUCKEN	NC	LORRAINE CAROL	50	9	1	1,969	39.38
470	87	PAGO PAGO	AS	UNCLE LOUIE	45	9	1	1,317	29.26
471	89	MOBILE	MS	NA	45	9	1	1,504	33.42
472	88	CORPUS CHRISTI	TX	NA	44	9	2	213	4.85
473	85	ST JOHNS	NFLD	NA	43	9	1	877	20.32
474	86	HOUSTON	TX	NA	42	9	4	743	17.68
475	87	CORPUS CHRISTI	TX	NA	42	9	1	1,037	24.69
476	86	LAKE CHARLES	LA	NA	42	9	1	1,186	28.25
477	86	SAN PEDRO	CA	NA	42	9	1	3,207	76.37
478	88	NORFOLK	VA	HONEYBROOK TWO	42	9	1	590	14.04
479	88	GALVESTON	TX	UNKNOWN SOURCE	42	9	2	482	11.47
480	88	CHANNELVIEW	TX	NA	42	9	1	1,570	37.38

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
481	87	PORT ARTHUR	TX	UNKNOWN SOURCE	42	9	1	1,040	24.77
482	87	PORT NECHES	TX	OVERSEAS CHICAGO	42	9	4	893	21.26
483	89	PROVIDENCE	MA	NA	42	9	1	937	22.30
484	87	NA	NA	NA	42	9	1	57,382	1,366.23
485	88	PITI	GU	JAIWON APOLLO	40	9	2	624	15.60
486	88	BODEGA BAY	CA	UNKNOWN SOURCE	40	9	2	326	8.15
487	87	CHICAGO	IL	NA	40	9	1	3,576	89.39
488	89	CORPUS CHRISTI	TX	AQUARIS T/S	40	1	1	2,254	56.34
489	86	WILMINGTON	NC	NA	40	9	1	2,313	57.83
490	88	HONOLULU	HI	UNKNOWN SOURCE	40	9	2	921	23.03
491	87	KEY LARGO	FL	UNKNOWN SOURCE	40	9	1	1,099	27.47
492	89	NY	NY	NA	40	1	1	2,989	74.73
493	87	SAVANNAH	GA	NA	40	9	1	1,193	29.83
494	87	KEY WEST	FL	UNKNOWN SOURCE	40	9	1	894	22.35
495	88	SAUSALITO	CA	ST LEO	40	9	2	1,629	40.73
496	87	BAYWOOD	NJ	NA	40	9	2	1,819	45.48
497	89	BOSTON	MA	NA	40	0	1	497	12.42
498	89	NEW ORLEANS	LA	NA	35	1	1	1,046	29.89
499	89	PROVIDENCE	MA	GRAYLING	35	1	1	2,392	68.34
500	88	CLEVELAND	OH	NA	35	9	2	2,904	82.98
501	88	PHILADELPHIA	PA	AMBIA FAIR	35	9	1	15,002	428.63
502	86	PORT ISABEL	TX	UNKNOWN SOURCE	35	9	1	351	10.01
503	87	ROCKPORT	TX	UNKNOWN SOURCE	35	9	1	915	26.15
504	87	FORT PIERCE	FL	UNKNOWN SOURCE	30	9	4	1,168	38.94
505	87	MERRITT ISLAND	FL	FL 7496 AT	30	9	2	2,293	76.44
506	86	PONCE	PR	NA	30	9	2	1,711	57.03
507	86	SEATTLE	WA	UNKNOWN SOURCE	30	9	2	182	6.07
508	88	DEER PARK	TX	NA	30	9	1	1,489	49.62
509	88	PITI	GU	AKIRA MARU NO 8	30	9	4	520	17.34
510	86	NA	NA	VIRGINIAN	30	9	1	11,437	381.25

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
511	87	JUNEAU	AK	TEDDY-BAR	30	9	2	48	1.61
512	86	SCAPPOOSE	OR	NA	30	9	4	1,478	49.28
513	88	MIAMI	FL	UNKNOWN SOURCE	30	9	1	1,399	46.62
514	87	KEY WEST	FL	UNKNOWN SOURCE	30	9	1	540	18.00
515	86	HONOLULU	HI	UNKNOWN SOURCE	30	9	1	562	18.72
516	86	WIMINGTON	NC	UNKNOWN SOURCE	30	9	1	2,705	90.17
517	86	SCAPOOSE	OR	BETTY	30	9	2	1,460	48.68
518	87	CORPUS CHRISTI	TX	NA	30	9	1	417	13.89
519	86	NORFOLK	VA	ACONCAGUA	30	9	1	2,376	79.20
520	87	SEATTLE	WA	DISTANT WATER	30	9	4	1,202	40.07
521	86	BERKELEY	CA	UNKNOWN SOURCE	30	9	2	337	11.23
522	87	HONOLULU	HI	NA	29	9	1	2,621	90.38
523	86	DEER PARK	TX	NA	25	9	1	2,115	84.62
524	88	ALLENDALE	FL	LITTLE ROSIE G	25	9	2	4,484	179.37
525	88	TAMPA	FL	SEA QUEEN	25	9	1	1,907	76.28
526	88	NEHALEM	OR	UNKNOWN SOURCE	25	9	4	2,751	110.04
527	86	GUNTERSVILLE	AL	UNKNOWN SOURCE	25	9	1	34	1.35
528	88	CHINCOTEAGUE	VA	UNKNOWN SOURCE	25	9	1	685	27.41
529	87	JUNEAU	AK	DAISY M	25	9	1	208	8.31
530	86	CHINCOTEAGUE	VA	UNKNOWN SOURCE	25	9	4	64	2.56
531	88	SACRAMENTO	CA	NA	25	9	4	5,662	226.47
532	86	LONG BEACH	CA	NA	25	9	1	932	37.30
533	87	HONOLULU	HI	UNKNOWN SOURCE	25	9	4	1,653	66.12
534	88	PROVIDENCE	MA	CRISTEN	25	0	2	10,671	426.84
535	87	PORT CANAVERAL	FL	ANDIAMO	25	9	2	6,525	261.02
536	87	DELRAY BEACH	FL	UNKNOWN SOURCE	25	9	1	2,283	91.33
537	86	SAN JUAN	PR	NA	25	9	1	1,613	64.53
538	87	SAN FRANCISCO	CA	CHIOS FAITH	25	9	1	43	1.72
539	90	GALVESTON	TX	NA	25	1	2	287	11.48
540	87	SAN DIEGO	CA	NA	25	9	4	2,149	85.96

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
541	90	NA	NA	NA	25	1	2	198	7.92
542	81	BOTWOOD	NFLD	TUINA	22	9	1	2,595	120.22
543	86	JAPAN	NA	TAKE MARU # 6	22	9	1	27,883	1,291.60
544	86	ROCKPORT	TX	UNKNOWN SOURCE	21	9	1	382	18.19
545	89	HOUSTON	TX	NA	21	9	1	1,363	64.88
546	86	SEATTLE	WA	SLEEP ROBBER	20	9	2	872	43.59
547	88	PITI	GU	NA	20	9	1	909	45.47
548	87	KEY LARGO	FL	UNKNOWN SOURCE	20	9	1	179	8.96
549	86	BALTIMORE	MD	NA	20	9	4	132,513	6,625.64
550	87	BAYONNE	NJ	NA	20	9	1	1,650	82.49
551	86	PORT CANAVERAL	FL	UNKNOWN SOURCE	20	9	1	1,094	54.71
552	88	FLOREFFE	PA	NA	20	9	4	3,386	169.29
553	86	HONOLULU	HI	NA	20	9	1	812	40.61
554	86	MIAMI	FL	MARIE LAMERCIE	20	9	1	1,084	54.20
555	87	MOBILE	AL	NA	20	9	1	463	23.15
556	88	HONOLULU	HI	NA	20	9	1	1,952	97.60
557	89	GALVESTON	TX	NA	20	1	2	1,498	74.88
558	87	JAMES ISLAND	SC	NA	20	9	2	220	11.00
559	87	NY	NJ	FELICIA	20	0	1	10,542	527.09
560	86	PASCAGOULA	MS	FL 4139 DY	20	9	2	1,010	50.50
561	87	BOSTON	MA	JOAN & CINDY	20	0	2	2,703	135.14
562	87	SEATTLE	WA	UNKNOWN SOURCE	20	9	1	1,864	93.21
563	89	GALVESTON	TX	NA	20	1	9	1,045	52.25
564	87	NEW BALTIMORE	MI	NA	20	9	1	3,252	162.61
565	86	TOLEDO	OH	NA	20	9	4	10,587	529.35
566	89	GALVESTON	TX	NA	20	1	9	959	47.96
567	87	CHANNELVIEW	TX	NA	20	9	1	881	44.05
568	86	FORT BRAGG	CA	KATHERINE D II	20	9	2	88	4.38
569	87	EUREKA	CA	UNKNOWN SOURCE	20	9	1	648	32.39
570	86	SAN JUAN	PR	UNKNOWN SOURCE	20	9	1	521	26.06

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1
Table of Marine Spill Data
Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
571	86	HAMPTON	VA	NA	20	9	4	445	22.24
572	86	BALLARD	WA	UNKNOWN SOURCE	20	9	1	713	35.67
573	90	PORT ARTHUR	TX	NA	20	9	1	244	12.20
574	86	CLEVELAND	OH	NA	20	9	1	5,617	280.85
575	88	CORPUS CHRISTI	TX	NA	20	9	1	425	21.24
576	86	FULTON	TX	UNKNOWN SOURCE	20	9	1	470	23.48
577	86	NEWPORT BEACH	CA	UNKNOWN SOURCE	20	9	1	238	11.91
578	86	NORFOLK	VA	NA	20	9	1	416	20.78
579	86	SEATTLE	WA	UNKNOWN SOURCE	20	9	2	106	5.28
580	87	JUNEAU	AK	UNKNOWN SOURCE	20	9	4	203	10.17
581	86	HYANNIS	MA	UNKNOWN SOURCE	17	9	1	1,026	60.33
582	87	PORT ISABEL	TX	NA	15	9	2	979	65.26
583	87	NORFOLK	VA	UNKNOWN SOURCE	15	9	1	419	27.94
584	86	BALTIMORE	MD	NA	15	9	4	103,252	6,883.50
585	87	HOUSTON	TX	NA	15	9	1	66	4.40
586	87	PROVINCETOWN	MA	PORPOISE	15	9	1	478	31.90
587	86	KEY WEST	FL	UNKNOWN SOURCE	15	9	1	112	7.49
588	87	PORT ARUTHUR	TX	NA	15	9	1	341	22.73
589	89	PORT ARTHUR	TX	NA	15	9	2	2,788	185.87
590	88	HONOLULU	HI	UNKNOWN SOURCE	15	9	1	2,706	180.40
591	86	CORPUS CHRISTI	TX	ANNIE K	15	9	1	231	15.43
592	88	PROVIDENCE	MA	ANNA GRACE	15	9	2	2,647	176.46
593	86	ASHTABULA	OH	NA	12	9	3	8,630	719.17
594	89	CORPUS CHRISTI	TX	NA	12	9	1	1,224	102.03
595	86	HOUSTON	TX	NA	12	9	4	936	77.98
596	88	PORT ISABEL	TX	UNKNOWN SOURCE	11	9	1	820	74.59
597	87	PORT ISABEL	TX	UNKNOWN SOURCE	11	9	1	1,058	96.19
598	88	SEATTLE	WA	OCEAN CHAMPION	10	9	1	835	83.55
599	87	PASS CHRISTIAN	MS	NA	10	9	1	616	61.59
600	87	MONTEREY	CA	UNNAMED	10	9	2	152	15.18

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
601	87	SEATTLE	WA	UNKNOWN SOURCE	10	9	1	360	35.97
602	90	BOSTON	MA	WILCOX II	10	0	2	4,803	480.27
603	86	GALVESTON	TX	UNKNOWN SOURCE	10	9	2	3,317	331.74
604	90	GALVESTON	TX	NA	10	1	4	1,267	126.70
605	87	NORTH TONAWANDA	NY	NA	10	9	1	1,540	153.98
606	87	CHANNELVIEW	TX	MISS MONIE	10	9	1	750	75.01
607	90	GALVESTON	TX	NA	10	9	1	393	39.30
608	87	MORRO BAY	CA	UNKNOWN SOURCE	10	9	1	1,232	123.18
609	87	CORPUS CHRISTI	TX	NA	10	9	4	178	17.82
610	86	JUPITER	FL	FL 80005 CH	10	9	1	112	11.23
611	87	HONOLULU	HI	UNKNOWN SOURCE	10	9	2	709	70.94
612	88	MORRO BAY	CA	OWNER'S JOY	10	9	2	7,227	722.65
613	88	BAYOU LA BATRE	AL	NA	10	9	1	720	71.97
614	87	PORT ARANSASS	TX	NA	10	9	1	339	33.88
615	86	BROWNSVILLE	TX	CORAL VOLANS	10	9	1	474	47.41
616	88	MOBILE	AL	NA	10	9	9	852	85.18
617	88	OGDENSBURG	NY	UNKNOWN SOURCE	10	9	1	2,324	232.41
618	88	PORT ISABEL	TX	UNKNOWN SOURCE	10	9	1	799	79.90
619	87	PORT ARTHUR	TX	COUNTRY GIRL	10	9	1	1,461	146.06
620	86	DEERFIELD BEACH	FL	UNKNOWN SOURCE	10	9	1	904	90.43
621	87	BEAUFORT	NC	UNKNOWN SOURCE	10	9	2	1,031	103.06
622	86	SEATTLE	WA	UNKNOWN SOURCE	10	9	1	616	61.56
623	87	GREEN BANK	WA	UNKNOWN SOURCE	9	9	1	658	73.08
624	88	JUNEAU	AK	WYOMING	8	9	1	97	12.07
625	88	BAYOU LA BATRE	AL	UNNAMED (AL7601SA)	8	9	1	617	77.09
626	86	SAN FRANCISCO	CA	RITA MARIE	7	9	2	2,630	375.70
627	89	PROVIDENCE	RI	SHARON YVONNE	6	0	1	3,578	596.30
628	87	HONOLULU	HI	UNKNOWN SOURCE	5	9	1	1,763	352.61
629	87	FORT BRAGG	CA	UNKNOWN SOURCE	5	9	1	1,376	275.18
630	86	CORPUS CHRISTI	TX	UNKNOWN SOURCE	5	9	1	210	42.02

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = "***" (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE A-1

Table of Marine Spill Data

Utilized in Regression Analysis

No.	Year	Location of Spill		Vessel(s)	Spill Size (Gallons)	[a] Did Spill Hit Shore?	[b] Product Code	Cleanup Cost $1990	Cleanup Cost/Gallon $1990
631	87	CORPUS CHRISTI	TX	NA	5	9	2	159	31.90
632	87	ROCKPORT	TX	NA	5	9	1	444	88.87
633	87	CORPUS CHRISTI	TX	NA	5	9	4	152	30.36
634	86	ROCKPORT	TX	NA	5	9	1	413	82.68
635	88	JUNEAU	AK	UNKNOWN SOURCE	5	9	4	56	11.15
636	88	CHANNELVIEW	TX	NA	5	9	1	262	52.34
637	86	CORPUS CHRISTI	TX	NA	5	9	1	617	123.35
638	86	ROCKPORT	TX	NA	5	9	1	397	79.31
639	86	CORPUS CHRISTI	TX	UNKNOWN SOURCE	5	9	1	131	26.29
640	86	SEATTLE	WA	UNNAMED	3	9	2	48	16.10
641	87	TEXAS CITY	TX	TX7210ZU	3	9	1	849	283.03
642	88	NA	NA	NA	3	9	1	5,629	1,876.17
643	87	GALVESTON	TX	NA	3	9	1	206	68.56
644	86	CORPUS CHRISTI	TX	JENNIFER	3	9	1	172	57.29
645	81	PORTWOODY	NA	ASTERION	2	9	2	5,899	2,732.36
646	86	KEY WEST	FL	MIDNIGHT PROWLER	2	9	1	112	56.17
647	86	JAMESTOWN	RI	UNNAMED	2	9	2	151	75.27
648	86	DULUTH	MN	NA	2	9	1	2,324	1,162.17
649	87	JUNEAU	AK	NA	1	9	4	96	95.69
650	86	CLIFFWOOD	NJ	NA	1	9	1	1,236	1,235.75
651	87	AMELIA CITY	FL	NA	1	9	4	779	778.70
652	86	BURIEN	WA	UNKNOWN SOURCE	1	9	1	967	967.25
653	88	PORT JEFFERSON	NY	NA	1	9	2	1,763	1,763.20

[a] 1 = spill reached shore; 2 = spill did not reach shore; 9 = NA

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

APPENDIX B

DATA ON COAST GUARD OIL SPILL RESPONSE COSTS AND CONTRACTOR CLEANUP COSTS FOR MARINE OIL AND CHEMICAL SPILLS

TABLE B-1

Distribution of Costs for Spills

With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
189	86	SEATTLE	WA	UNKNOWN SOURCE	1	600	789,111	99.0%	7,971	1.0%	797,082	100.0%
41	87	NA	NA	GLACIER BAY	1	207,564	652,902	34.5%	1,240,764	65.5%	1,893,666	100.0%
86	86	CHARLOTETTE AMALIE	VI	ST.THOMAS	1	41,392	489,764	22.7%	1,670,632	77.3%	2,160,396	100.0%
322	87	PORT EVERGLADES	FL	DISCOVERY I	2	125	261,464	99.0%	2,640	1.0%	264,104	100.0%
69	88	ANACORTES	WA	M-C-N OIL BARGE NO. 5	2	67,357	212,396	15.3%	1,178,460	84.7%	1,390,855	100.0%
432	87	PITTSBURGH	PA	NA	4	50	47,183	7.3%	600,950	92.7%	648,134	100.0%
124	87	HOUSTON	TX	BALTIMORE	1	5,460	34,864	19.6%	142,828	80.4%	177,692	100.0%
99	86	NA	NA	APEX HOUSTON	1	25,872	29,632	66.2%	15,103	33.8%	44,735	100.0%
582	87	PORT ISABEL	TX	NA	2	15	28,084	21.4%	103,252	78.6%	131,337	100.0%
94	88	BALTIMORE	MD	NA	4	32,000	19,701	19.2%	82,778	80.8%	102,479	100.0%
116	86	LARCHMONT	NY	NA	1	10,000	19,168	3.5%	526,205	96.5%	545,373	100.0%
617	88	OGDENSBURG	NY	UNKNOWN SOURCE	1	10	12,373	63.1%	7,227	36.9%	19,600	100.0%
409	88	MORRO BAY	CA	SEASONS	2	67	12,373	63.1%	7,228	36.9%	19,601	100.0%
141	86	RICHMOND	CA	NA	2	2,200	11,671	19.6%	48,009	80.4%	59,680	100.0%
119	88	NA	NA	NA	1	9,324	11,393	38.5%	18,237	61.5%	29,630	100.0%
271	86	STERLING HEIGHTS	MI	NA	1	200	11,144	6.0%	174,542	94.0%	185,686	100.0%
180	88	GREAT BRIDGE	VA	UNKNOWN SOURCE	2	700	11,001	63.3%	6,390	36.7%	17,391	100.0%
190	88	TACOMA	WA	ATALANTA	2	600	10,832	39.5%	16,570	60.5%	27,402	100.0%
146	88	PORT CANAVERAL	FL	CAPT BOB	2	2,010	10,785	53.0%	9,546	47.0%	20,331	100.0%
115	89	LANAI/MOLOKAI	HI	INDEPENDENCE	2	10,000	10,111	15.0%	57,294	85.0%	67,404	100.0%
560	86	PASCAGOULA	MS	FL 4139 DY	2	20	9,671	6.8%	132,513	93.2%	142,184	100.0%
480	88	CHANNELVIEW	TX	NA	1	42	9,517	14.2%	57,382	85.8%	66,899	100.0%
120	87	BRONX	NY	NA	1	9,200	7,569	17.3%	36,295	82.7%	43,865	100.0%
249	89	PORT ARTHUR	TX	NA	2	210	6,534	77.0%	1,954	23.0%	8,487	100.0%
285	86	ESSEX	MD	KNOT TWO WORRY	2	200	6,515	65.5%	3,426	34.5%	9,941	100.0%
59	86	NEW YORK	NY	AMAZON VENTURE	1	105,706	5,283	12.1%	38,340	87.9%	43,623	100.0%
162	86	PORT EVERGLADES	FL	MARLAGO I	1	1,000	5,173	11.6%	39,380	88.4%	44,553	100.0%
570	86	SAN JUAN	PR	UNKNOWN SOURCE	1	20	5,123	95.9%	220	4.1%	5,343	100.0%
159	86	ST CROIX	VI	ROSAOMAIRA	2	1,050	5,063	13.7%	31,953	86.3%	37,016	100.0%
152	86	CORPUS CHRISTI	TX	HIMALAYA	1	1,470	5,050	3.8%	128,098	96.2%	133,147	100.0%
457	88	ESSEX	MD	GE-GI	2	50	4,896	100.0%	1	0.0%	4,897	100.0%
114	77	BALTIMORE	MD	NA	9	10,000	4,769	5.3%	84,680	94.7%	89,449	100.0%
173	86	PASADENA	TX	NA	1	798	4,750	24.0%	15,012	76.0%	19,762	100.0%
138	86	BOCA GRANDE	FL	STACI LYNN	2	2,260	4,540	20.7%	17,375	79.3%	21,914	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
349	88	SOUTHPORT	NC	NA	2	100	4,316	22.0%	15,263	78.0%	19,577	100.0%
168	88	EUCLID	OH	NA	1	900	4,315	22.0%	15,263	78.0%	19,577	100.0%
243	87	VIRGINIA BEACH	VA	NA	1	250	3,930	95.3%	194	4.7%	4,124	100.0%
491	87	KEY LARGO	FL	UNKNOWN SOURCE	1	40	3,903	70.6%	1,629	29.4%	5,532	100.0%
605	87	MERRITT ISLAND	FL	FL 7496 AT	2	30	3,847	25.2%	11,437	74.8%	15,284	100.0%
131	87	NORFOLK	VA	GOVERNOR HENDRICKS	1	3,500	3,782	10.6%	31,904	89.4%	35,686	100.0%
317	86	HOUSTON	TX	NA	1	126	3,589	92.9%	275	7.1%	3,865	100.0%
325	88	VALDEZ	AK	EUREKA	2	115	3,532	100.0%	1	0.0%	3,533	100.0%
318	86	CAMERON PARISH	LA	NA	1	126	3,522	72.8%	1,318	27.2%	4,840	100.0%
297	88	CAPE CANAVERAL	FL	MOBY DICK	2	150	3,481	41.0%	5,018	59.0%	8,500	100.0%
488	89	CORPUS CHRISTI	TX	AQUARIS T/S	1	40	3,465	49.2%	3,576	50.8%	7,040	100.0%
289	87	MORRO BAY	CA	SARDA SARDA	2	172	3,416	81.8%	761	18.2%	4,177	100.0%
196	86	FLUSHING QUEENS	NY	NA	1	500	3,312	24.6%	10,169	75.4%	13,481	100.0%
215	87	MOREHEAD CITY	NC	JENS JUHL	2	355	3,308	53.7%	2,851	46.3%	6,159	100.0%
140	88	NA	NA	NA	1	2,206	3,294	12.9%	22,162	87.1%	25,456	100.0%
137	88	SEATTLE	WA	UNKNOWN SOURCE	2	2,300	3,273	10.6%	27,582	89.4%	30,855	100.0%
208	88	BAYTOWN	TX	NA	1	420	2,821	20.4%	10,979	79.6%	13,800	100.0%
130	86	EAST BOSTON	MA	SOUNDER	2	3,600	2,796	12.0%	20,600	88.0%	23,396	100.0%
163	90	MORGAN CITY	MS	JOYCE MARIE F/V	2	1,000	2,743	5.7%	45,032	94.3%	47,775	100.0%
155	86	GEORGETOWN	SC	BORON	2	1,300	2,642	15.1%	14,809	84.9%	17,451	100.0%
389	87	MIAMI	FL	PAMPERO	1	80	2,540	77.3%	744	22.7%	3,284	100.0%
609	87	CORPUS CHRISTI	TX	NA	4	10	2,492	70.7%	1,031	29.3%	3,523	100.0%
195	88	PAGO PAGO	AS	UNKNOWN SOURCE	1	500	2,463	13.8%	15,358	86.2%	17,821	100.0%
454	86	OCEAN CITY	MD	UNKNOWN SOURCE	4	50	2,412	53.9%	2,061	46.1%	4,473	100.0%
206	88	WILMINGTON	CA	UNKNOWN SOURCE	1	420	2,207	66.0%	1,135	34.0%	3,342	100.0%
182	86	NEW ROCHELLE	NY	NA	2	700	2,177	24.1%	6,874	75.9%	9,051	100.0%
241	87	OAKLAND	CA	UNKNOWN SOURCE	1	250	2,159	15.3%	11,953	84.7%	14,112	100.0%
267	86	BALTIMORE	MD	UNKNOWN SOURCE	1	200	2,146	80.9%	506	19.1%	2,651	100.0%
331	86	NORFOLK	VA	UNKNOWN SOURCE	1	100	2,084	31.2%	4,600	68.8%	6,684	100.0%
444	87	RICHMOND	CA	SEA HUNTER	2	50	2,066	84.6%	376	15.4%	2,442	100.0%
171	87	GALVESTON	TX	NA	1	882	1,981	24.9%	5,962	75.1%	7,943	100.0%
369	86	GALENA PARK	TX	NA	1	84	1,945	55.6%	1,550	44.4%	3,495	100.0%
205	88	LAKE CHARLES	LA	AMAZON VENTURE	1	420	1,937	6.3%	28,849	93.7%	30,786	100.0%
312	87	PAGO PAGO	AS	UNKNOWN SOURCE	2	130	1,915	25.0%	5,734	75.0%	7,649	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills

With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
183	88	NORFOLK	VA	GIUSEPPE LEMBO	1	700	1,823	7.5%	22,433	92.5%	24,256	100.0%
194	87	SABINE	TX	KEY LADY	1	504	1,788	30.1%	4,152	69.9%	5,940	100.0%
474	86	HOUSTON	TX	NA	4	42	1,776	60.0%	1,186	40.0%	2,962	100.0%
400	88	MONTAUK	NY	NA	2	70	1,756	88.3%	233	11.7%	1,988	100.0%
198	86	SOUTH BOSTON	MA	NA	1	500	1,721	8.3%	19,062	91.7%	20,783	100.0%
425	87	SAN FRANCISCO	CA	MARIA Z	2	54	1,663	53.4%	1,453	46.6%	3,116	100.0%
320	88	GALVESTON	TX	SADIE & LAURIE & R	1	126	1,539	75.3%	505	24.7%	2,044	100.0%
192	87	PORT CANAVERAL	FL	UNKNOWN SOURCE	1	600	1,478	15.6%	8,017	84.4%	9,495	100.0%
199	88	GALVESTON	TX	TX61252V F/V	2	500	1,477	31.7%	3,181	68.3%	4,658	100.0%
546	86	SEATTLE	WA	SLEEP ROBBER	2	20	1,430	56.9%	1,084	43.1%	2 514	100.0%
437	90	PORT ARTHUR	TX	SEA DOLLAR F/V	9	50	1,417	42.5%	1,917	57.5%	3,333	100.0%
248	86	SULPHUR	LA	AMAZON VENTURE	1	210	1,402	30.7%	3,165	69.3%	4,567	100.0%
151	88	PORT EVERGLADES	FL	UNKNOWN SOURCE	2	1,500	1,381	8.8%	14,256	91.2%	15,637	100.0%
308	87	PORT CANAVERAL	FL	UNKNOWN SOURCE	2	150	1,378	20.1%	5,475	79.9%	6,853	100.0%
489	86	WILMINGTON	NC	NA	1	40	1,373	43.0%	1,819	57.0%	3,192	100.0%
643	87	GALVESTON	TX	NA	1	3	1,369	61.7%	849	38.3%	2,218	100.0%
514	87	KEY WEST	FL	UNKNOWN SOURCE	1	30	1,369	76.7%	417	23.3%	1,786	100.0%
644	86	CORPUS CHRISTI	TX	JENNIFER	1	3	1,362	19.5%	5,629	80.5%	6,991	100.0%
209	88	PHILADELPHIA	PA	NA	1	420	1,362	22.6%	4,665	77.4%	6,027	100.0%
227	89	NY	NJ	MARACIABO	1	300	1,330	57.6%	980	42.4%	2,310	100.0%
244	88	PORT EVERGLADES	FL	RAPTURE	2	250	1,273	7.5%	15,697	92.5%	16,970	100.0%
272	88	CAMDEN	NJ	NA	1	200	1,236	23.9%	3,932	76.1%	5,168	100.0%
528	88	CHINCOTEAGUE	VA	UNKNOWN SOURCE	1	25	1,150	34.9%	2,149	65.1%	3,300	100.0%
564	87	NEW BALTIMORE	MI	NA	1	20	1,136	71.0%	463	29.0%	1,599	100.0%
238	87	SEATTLE	WA	UNKNOWN SOURCE	2	250	1,128	13.5%	7,235	86.5%	8,363	100.0%
274	88	CORPUS CHRISTI	TX	NA	4	200	1,120	13.9%	6,941	86.1%	8,061	100.0%
222	88	PAGP PAGO	AS	UNKNOWN SOURCE	1	300	1,102	4.5%	23,280	95.5%	24,382	100.0%
177	86	ISLAMORADA BEACH	FL	UNKNOWN SOURCE	1	705	1,100	14.4%	6,549	85.6%	7,649	100.0%
341	87	LIS	NY	NA	1	100	1,091	12.2%	7,871	87.8%	8,962	100.0%
294	86	DEER PARK	TX	LUCOR WICKLIFFE	4	168	1,072	48.5%	1,137	51.5%	2,210	100.0%
383	86	CORPUS CHRISTI	TX	NA	1	84	1,057	30.5%	2,407	69.5%	3,464	100.0%
262	88	NY	NY	NA	1	200	1,052	7.5%	12,900	92.5%	13,952	100.0%
169	87	ORANGE	TX	WINFRED W	4	900	1,017	11.2%	8,044	88.8%	9,061	100.0%
348	86	CHINCOTEAGUE	VA	UNKNOWN SOURCE	4	100	976	15.1%	5,488	84.9%	6,464	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills

With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
430	87	PAGO PAGO	AS	UNKNOWN SOURCE	1	50	962	71.9%	376	28.1%	1,338	100.0%
355	89	NEW ORLEANS	LA	NA	2	100	958	32.0%	2,039	68.0%	2,997	100.0%
283	87	STATEN ISLAND	NY	TEXACO 807	2	200	953	31.4%	2,087	68.6%	3,041	100.0%
164	90	MOBILE	FL	MULPHA TAPAH M/V	2	1,000	940	41.5%	1,323	58.5%	2,264	100.0%
350	88	PHILADELPHIA	PA	NA	1	100	937	9.9%	8,549	90.1%	9,486	100.0%
172	87	TEXAS CITY	TX	UNKNOWN SOURCE	4	840	938	32.2%	1,966	67.8%	2,904	100.0%
327	86	HOUSTON	TX	NA	1	105	929	38.0%	1,514	62.0%	2,443	100.0%
303	87	NA	NA	HANNAH 5101	1	150	916	3.0%	29,330	97.0%	30,246	100.0%
360	86	DETROIT	MI	NA	1	100	914	18.3%	4,073	81.7%	4,987	100.0%
150	87	NORFOLK	VA	GOVERNOR HENDRICKS	1	1,500	913	13.9%	5,673	86.1%	6,586	100.0%
217	86	MIAMI	FL	UNKNOWN SOURCE	1	350	911	14.5%	5,368	85.5%	6,279	100.0%
593	86	ASHTABULA	OH	NA	3	12	891	9.4%	8,630	90.6%	9,521	100.0%
626	86	SAN FRANCISCO	CA	RITA MARIE	2	7	875	25.0%	2,630	75.0%	3,505	100.0%
147	86	LEMONT	IL	NA	1	2,000	875	4.0%	20,974	96.0%	21,849	100.0%
351	86	FORT LAUDERDALE	FL	UNKNOWN SOURCE	1	100	861	14.8%	4,938	85.2%	5,800	100.0%
375	86	HOUSTON	TX	NA	1	84	850	20.6%	3,284	79.4%	4,134	100.0%
613	88	BAYOU LA BATRE	AL	NA	1	10	847	57.9%	616	42.1%	1,463	100.0%
212	88	MOBILE	AL	NA	1	400	808	10.7%	6,743	89.3%	7,550	100.0%
340	86	ATLANTIC CITY	NJ	LITTLE BEAR	1	100	804	19.7%	3,276	80.3%	4,080	100.0%
346	87	PORTSMOUTH	VA	NA	2	100	802	11.7%	6,051	88.3%	6,853	100.0%
335	86	SEATTLE	WA	UNKNOWN SOURCE	2	100	790	20.7%	3,034	79.3%	3,824	100.0%
379	86	GALVESTON	TX	NA	1	84	790	8.6%	8,426	91.4%	9,216	100.0%
424	87	MANHATTAN	NY	NA	1	55	786	33.1%	1,586	66.9%	2,372	100.0%
380	87	SABINE PASS	TX	CAPT. QUOC CUONG	4	84	785	6.4%	11,510	93.6%	12,295	100.0%
494	87	KEY WEST	FL	UNKNOWN SOURCE	1	40	785	70.7%	326	29.3%	1,111	100.0%
202	87	WOODRIVER	IL	UNKNOWN SOURCE	1	500	766	10.2%	6,750	89.8%	7,516	100.0%
188	88	PORT ARTHUR	TX	NA	1	630	763	16.2%	3,933	83.8%	4,695	100.0%
201	86	MILWAUKEE	WI	UCKA	4	500	750	19.2%	3,149	80.8%	3,899	100.0%
319	87	GALVESTON	TX	CONE JOHNSON	1	126	739	40.9%	1,068	59.1%	1,807	100.0%
418	86	SAN JUAN CAPISTRANO	CA	NA	4	60	713	22.2%	2,498	77.8%	3,212	100.0%
449	88	HONOLULU	HI	UNKNOWN SOURCE	1	50	712	10.2%	6,255	89.8%	6,967	100.0%
428	87	SAN RAFAEL	CA	NA	4	50	707	31.5%	1,539	68.5%	2,246	100.0%
323	86	PORT TOWNSEND	WA	UNKNOWN SOURCE	2	125	703	25.3%	2,072	74.7%	2,775	100.0%
324	86	PORT ISABEL	TX	GLORIA EVELYN	1	120	698	19.9%	2,805	80.1%	3,503	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills

With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
357	87	HONOLULU	HI	UNKNOWN SOURCE	2	100	678	12.8%	4,633	87.2%	5,311	100.0%
282	86	FOWLER'S BEACH	DE	NA	1	200	665	14.9%	3,791	85.1%	4,456	100.0%
612	88	MORRO BAY	CA	OWNER'S JOY	2	10	661	31.2%	1,461	68.8%	2,122	100.0%
447	88	TEXAS CITY	TX	NA	1	50	658	9.5%	6,232	90.5%	6,890	100.0%
210	87	KEY WEST	FL	BLUE FIN	2	400	656	7.0%	8,650	93.0%	9,306	100.0%
229	88	PAGO PAGO HARBOR	SA	NA	1	300	652	5.4%	11,342	94.6%	11,994	100.0%
307	89	PROVIDENCE	MA	NA	1	150	640	7.5%	7,878	92.5%	8,518	100.0%
565	86	TOLEDO	OH	NA	4	20	639	16.4%	3,252	83.6%	3,891	100.0%
278	86	FT LAUDERDALE	FL	UNKNOWN SOURCE	1	200	632	12.8%	4,290	87.2%	4,922	100.0%
586	87	PROVINCETOWN	MA	PORPOISE	1	15	626	59.9%	419	40.1%	1,045	100.0%
191	86	WEST FRANKLIN	IN	NA	1	600	625	3.7%	16,117	96.3%	16,742	100.0%
439	87	SEATTLE	WA	UNKNOWN SOURCE	1	50	613	21.8%	2,195	78.2%	2,809	100.0%
332	86	NEWPORT	OR	NA	2	100	612	7.4%	7,639	92.6%	8,251	100.0%
508	86	PONCE	PR	NA	2	30	606	64.2%	337	35.8%	943	100.0%
176	86	BALTIMORE	MD	UNKNOWN SOURCE	4	710	601	3.5%	16,546	96.5%	17,147	100.0%
153	86	WILMINGTON	CA	NA	4	1,470	590	9.5%	5,633	90.5%	6,223	100.0%
487	87	CHICAGO	IL	NA	1	40	585	34.7%	1,099	65.3%	1,684	100.0%
479	88	GALVESTON	TX	UNKNOWN SOURCE	2	42	582	39.4%	893	60.6%	1,475	100.0%
624	88	JUNEAU	AK	WYOMING	1	8	581	48.5%	617	51.5%	1,198	100.0%
461	87	HONOLULU	HI	UNKNOWN SOURCE	2	50	573	27.9%	1,480	72.1%	2,053	100.0%
404	87	MIAMI	FL	SHANGRI LA	2	70	672	9.3%	5,572	90.7%	6,143	100.0%
415	88	SHARPSBURG	PA	NA	4	60	559	19.9%	2,247	80.1%	2,808	100.0%
224	87	NORFOLK	VA	NA	1	300	550	11.1%	4,399	88.9%	4,949	100.0%
422	87	NEWPORT BEACH	CA	UTOPIA	2	55	549	73.5%	198	26.5%	747	100.0%
334	88	MILWAUKEE	WI	NA	4	100	548	18.2%	2,464	81.8%	3,012	100.0%
464	86	BALTIMORE	MD	NA	4	50	545	35.3%	999	64.7%	1,543	100.0%
354	86	NA	NA	NA	2	100	536	5.6%	9.014	94.4%	9,551	100.0%
220	87	PORTSMOUTH	VA	NA	1	300	531	8.4%	5,771	91.6%	6,302	100.0%
555	87	MOBILE	AL	NA	1	20	526	4.7%	10,587	95.3%	11,113	100.0%
551	86	PORT CANAVERAL	FL	UNKNOWN SOURCE	1	20	506	53.2%	445	46.8%	950	100.0%
436	87	NORFOLK	VA	GOVERNOR HENDRICKS	1	50	503	29.3%	1,217	70.7%	1,720	100.0%
368	86	MENEMSHA	MA	UNKNOWN SOURCE	1	85	502	37.5%	837	62.5%	1,339	100.0%
403	90	MOBILE	AL	NA	2	70	498	26.6%	1,372	73.4%	1,870	100.0%
510	86	NA	NA	VIRGINIAN	1	30	498	22.5%	1,711	77.5%	2,209	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1
Distribution of Costs for Spills
With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG		Cleanup		Total	
							Cost [c]	%	Cost [d]	%	Cost	%
426	87	PORT ANGELES	WA	LILLIAN S	2	50	495	91.8%	44	8.1%	539	100.0%
443	86	NA	NA	CAPT. CATO	1	50	495	19.1%	2,091	80.9%	2,586	100.0%
219	88	HOUSTON	TX	MAR CORAL	1	336	491	11.0%	3,987	89.0%	4,478	100.0%
293	87	GALVESTON	TX	W 110	2	168	484	37.7%	798	62.3%	1,282	100.0%
611	87	HONOLULU	HI	UNKNOWN SOURCE	2	10	484	28.2%	1,232	71.8%	1,716	100.0%
144	90	NEW ORLEANS	LA	NA	9	2,100	483	20.9%	1,830	79.1%	2,313	100.0%
370	86	HOUSTON	TX	NA	4	84	475	15.7%	2,546	84.3%	3,021	100.0%
516	86	WIMINGTON	NC	UNKNOWN SOURCE	1	30	471	46.6%	540	53.4%	1,011	100.0%
493	87	SAVANNAH	GA	NA	1	40	466	42.7%	624	57.3%	1,090	100.0%
458	90	PROVIDENCE	MA	EMERALD ISLE	2	50	464	43.3%	609	56.7%	1,074	100.0%
499	89	PROVIDENCE	MA	GRAYLING	1	35	463	33.6%	915	66.4%	1,378	100.0%
386	86	CORPUS CHRISTI	TX	NA	1	84	459	21.1%	1,716	78.9%	2,175	100.0%
451	86	SAUSALITO	CA	UNKNOWN SOURCE	2	50	458	52.2%	419	47.8%	877	100.0%
187	86	DEER PARK	TX	NA	1	630	441	6.9%	5,993	93.1%	6,435	100.0%
372	88	NEDERLAND	TX	CREOLE PASS	1	84	441	32.1%	936	67.9%	1,377	100.0%
532	86	LONG BEACH	CA	NA	1	25	441	6.3%	6,525	93.7%	6,967	100.0%
382	87	LONG BEACH	CA	UNKNOWN SOURCE	1	84	438	17.7%	2,029	82.3%	2,467	100.0%
435	87	HONOLULU	HI	UNKNOWN SOURCE	2	50	434	29.2%	1,053	70.8%	1,486	100.0%
574	88	CLEVELAND	OH	NA	1	20	432	11.3%	3,386	88.7%	3,818	100.0%
185	88	CAMDEN	NJ	NA	1	700	429	8.2%	4,826	91.8%	5,255	100.0%
247	87	CHANNELVIEW	TX	NA	1	210	427	17.3%	2,040	82.7%	2,467	100.0%
569	87	EUREKA	CA	UNKNOWN SOURCE	1	20	421	32.3%	881	67.7%	1,302	100.0%
419	86	KEY WEST	FL	UNKNOWN SOURCE	1	60	414	20.5%	1,605	79.5%	2,018	100.0%
399	86	BALTIMORE	MD	NA	4	75	406	14.3%	2,441	85.7%	2,848	100.0%
179	87	NA	NA	OCEAN CLIPPER	2	700	405	16.1%	2,106	83.9%	2,511	100.0%
433	86	MILWAUKEE	WI	NA	2	50	400	11.0%	3,225	89.0%	3,625	100.0%
266	89	PROVIDENCE	MA	OLYMPIC SUN II	1	200	400	11.0%	3,225	89.0%	3,625	100.0%
263	87	JUNEAU	AK	NA	2	200	400	11.0%	3,225	89.0%	3,625	100.0%
601	87	SEATTLE	WA	UNKNOWN SOURCE	1	10	398	10.7%	3,317	89.3%	3,715	100.0%
279	86	WOOD RIVER	IL	UNKNOWN SOURCE	4	200	394	6.1%	6,045	93.9%	6,438	100.0%
277	88	NA	NA	UNKNOWN SOURCE	1	200	387	6.6%	5,499	93.4%	5,886	100.0%
223	86	BROOKLYN	NY	NA	3	300	385	4.7%	7,863	95.3%	8,248	100.0%
342	88	PAGO PAGO	AS	UNKNOWN SOURCE	4	100	383	17.5%	1,802	82.5%	2,184	100.0%
550	87	BAYONNE	NJ	NA	1	20	374	47.4%	416	52.6%	790	100.0%

[a] from Table A-1
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown
[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.
[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources. United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1
Distribution of Costs for Spills With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
423	87	ROCKPORT	TX	MEGGAN RACHELLE	1	55	366	39.5%	560	60.6%	926	100.0%
448	88	BILOXI	MS	NAUGHTY KITTEN	2	50	364	14.4%	2.170	85.6%	2,534	100.0%
313	86	SAN JUAN	PR	NA	4	130	359	25.6%	1,046	74.4%	1,405	100.0%
225	87	PROVIDENCE	MA	NA	2	300	357	5.2%	6.516	94.8%	6,873	100.0%
453	87	MONTEREY	CA	UNKNOWN SOURCE	2	60	356	64.3%	198	35.7%	554	100.0%
623	87	GREEN BANK	WA	UNKNOWN SOURCE	1	8	355	35.1%	658	64.9%	1,013	100.0%
538	87	SAN FRANCISCO	CA	CHIOS FAITH	1	25	354	34.1%	685	65.9%	1,039	100.0%
596	88	PORT ISABEL	TX	UNKNOWN SOURCE	1	11	353	25.0%	1,058	75.0%	1,411	100.0%
299	87	GALVESTON	TX	NA	1	150	347	13.5%	2,233	86.5%	2,580	100.0%
304	86	NEWPORT NEWS	VA	UNKNOWN SOURCE	4	150	346	40.8%	504	59.2%	850	100.0%
414	86	KEY WEST	FL	UNKNOWN SOURCE	1	60	339	13.9%	2 104	86.1%	2,443	100.0%
157	86	PALM BEACH	FL	UNKNOWN SOURCE	2	1,200	337	3.7%	8,877	96.3%	9,214	100.0%
197	86	GLOUCESTER	MA	BABY JERRY	2	500	337	16.7%	1,685	83.3%	2,022	100.0%
270	86	RIVIERA BEACH	FL	MARLAGO I	1	200	337	22.7%	1,147	77.3%	1,484	100.0%
446	86	NA	NA	NA	4	50	334	12.3%	2,379	87.7%	2,713	100.0%
216	86	FT LAUDERDALE	FL	NA	2	350	334	5.4%	5,833	94.6%	6,166	100.0%
554	86	MIAMI	FL	MARIE LAMERCIE	1	20	333	79.1%	88	20.9%	420	100.0%
359	87	PORT ISABEL	TX	NA	2	100	332	15.5%	1.810	84.5%	2,143	100.0%
385	87	HOUSTON	TX	NA	1	84	330	44.9%	405	55.1%	736	100.0%
221	86	PORT OF PALM BEACH	FL	LONG ISLAND EXPRESS	1	300	328	7.8%	3,859	92.2%	4,187	100.0%
295	87	SAN LEON	TX	TX6777WX	1	168	323	23.8%	1,036	76.2%	1,359	100.0%
478	88	NORFOLK	VA	HONEYBROOK TWO	1	42	320	23.5%	1,040	76.5%	1,361	100.0%
343	90	NEW ORLEANS	LA	NA	2	100	318	14.9%	1,816	85.1%	2,134	100.0%
253	86	ARANSAS PASS	TX	UNKNOWN SOURCE	1	210	309	45.7%	367	54.3%	676	100.0%
328	87	NA	NA	NA	1	100	308	13.3%	2,009	86.7%	2,316	100.0%
384	86	DEER PARK	TX	NA	1	84	306	32.9%	622	67.1%	928	100.0%
336	87	JACKSONVILLE	FL	NA	1	100	304	8.5%	3,258	91.5%	3,562	100.0%
589	89	PORT ARTHUR	TX	NA	2	15	302	82.1%	66	17.9%	368	100.0%
276	86	LOUISVILLE	KY	NA	1	200	302	24.3%	940	75.7%	1,243	100.0%
377	88	MORGAN CITY	LA	NA	4	84	297	17.7%	1,376	82.3%	1,673	100.0%
459	87	MIAMI	FL	UNKNOWN SOURCE	1	50	296	53.3%	260	46.7%	556	100.0%
264	89	LIS	CT	NA	2	200	291	4.7%	5,837	95.3%	6,128	100.0%
338	87	SAN RAFAEL	CA	JAMES J FULTON	2	100	291	3.2%	8,932	96.8%	9,223	100.0%
178	87	PORT CANAVERAL	FL	NA	1	700	285	7.8%	3,386	92.2%	3,671	100.0%

[a] from Table A-1
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = "*** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown
[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.
[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1
Distribution of Costs for Spills
With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
476	86	LAKE CHARLES	LA	NA	1	42	283	8.1%	3,207	91.9%	3,490	100.0%
615	88	BROWNSVILLE	TX	CORAL VOLANS	1	10	280	25.9%	799	74.1%	1,079	100.0%
302	89	MOBILE	FL	LITTLE MAN F/V	2	150	278	9.1%	2,777	90.9%	3,055	100.0%
174	86	DEER PARK	TX	NA	1	756	274	5.3%	4,881	94.7%	5,155	100.0%
301	86	SEATTLE	WA	NA	1	150	269	4.6%	5,640	95.4%	5,910	100.0%
523	86	DEER PARK	TX	NA	1	25	268	11.3%	2,115	88.7%	2,384	100.0%
561	87	BOSTON	MA	JOAN & CINDY	2	20	267	27.3%	713	72.7%	981	100.0%
631	87	CORPUS CHRISTI	TX	NA	2	5	263	29.9%	617	70.1%	880	100.0%
527	86	GUNTERSVILLE	AL	UNKNOWN SOURCE	1	25	262	88.6%	34	11.4%	295	100.0%
588	87	PORT ARUTHUR	TX	NA	1	15	260	43.2%	341	56.8%	601	100.0%
534	88	PROVIDENCE	MA	CRISTEN	2	25	258	5.5%	4,484	94.5%	4,743	100.0%
259	86	FLOREFFE	PA	AO B 234	2	200	258	7.7%	3,106	92.3%	3,365	100.0%
600	87	MONTEREY	CA	UNNAMED	2	10	257	35.2%	474	64.8%	731	100.0%
614	87	PORT ARANSASS	TX	NA	1	10	253	26.0%	720	74.0%	973	100.0%
292	87	GALVESTON	TX	NA	1	168	253	18.4%	1,124	81.6%	1,377	100.0%
529	87	JUNEAU	AK	DAISY M	1	25	251	9.9%	2,283	90.1%	2,534	100.0%
431	90	CORPUS CHRISTI	TX	NA	2	50	247	11.5%	1,911	88.5%	2,158	100.0%
646	86	KEY WEST	FL	MIDNIGHT PROWLER	1	2	246	62.0%	151	38.0%	397	100.0%
416	86	MEHLVILLE	MO	NA	2	60	244	7.2%	3,126	92.8%	3,370	100.0%
371	86	CHANNELVIEW	TX	NA	1	84	242	24.2%	757	75.8%	999	100.0%
483	89	PROVIDENCE	MA	NA	1	42	240	33.3%	482	66.7%	722	100.0%
378	86	GALENA PARK	TX	NA	1	84	239	28.0%	617	72.0%	856	100.0%
481	87	PORT ARTHUR	TX	UNKNOWN SOURCE	1	42	237	13.1%	1,570	86.9%	1,807	100.0%
321	87	GALVESTON	TX	CAPT. JESSE	1	126	234	20.4%	912	79.6%	1,145	100.0%
653	88	PORT JEFFERSON	NY	NA	2	1	231	11.6%	1,763	88.4%	1,994	100.0%
539	90	GALVESTON	TX	NA	2	25	230	10.7%	1,907	89.3%	2,136	100.0%
603	86	GALVESTON	TX	UNKNOWN SOURCE	2	10	228	12.9%	1,540	87.1%	1,767	100.0%
462	87	NORFOLK	VA	NA	1	50	226	10.0%	2,045	90.0%	2,272	100.0%
434	88	ARANSAS PASS	TX	NA	1	50	225	26.8%	613	73.2%	838	100.0%
498	89	NEW ORLEANS	LA	NA	1	35	225	39.1%	351	60.9%	575	100.0%
587	88	KEY WEST	FL	UNKNOWN SOURCE	1	15	223	18.6%	979	81.4%	1,202	100.0%
628	87	HONOLULU	HI	UNKNOWN SOURCE	1	5	221	35.8%	397	64.2%	618	100.0%
417	86	PORT ISABEL	TX	NA	2	60	213	23.3%	702	76.7%	916	100.0%
393	86	MIAMI	FL	UNKNOWN SOURCE	1	75	213	12.6%	1,478	87.4%	1,692	100.0%

[a] from Table A-1
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown
[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.
[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
306	87	FT.LAUDERDALE	FL	NA	1	150	213	11.0%	1,732	89.0%	1,946	100.0%
517	86	SCAPOOSE	OR	BETTY	2	30	209	8.4%	2,293	91.6%	2,502	100.0%
566	89	GALVESTON	TX	NA	9	20	208	24.3%	648	75.7%	856	100.0%
250	89	MOBILE	AL	NA	1	210	208	19.3%	870	80.7%	1,077	100.0%
251	86	LAPORTE	TX	NA	1	210	207	22.9%	698	77.1%	904	100.0%
260	86	ESSEX	MD	GRAND-TRAVELER	2	200	202	4.1%	4,776	95.9%	4,978	100.0%
291	87	CORPUS CHRISTI	TX	NA	4	168	201	9.6%	1,890	90.4%	2,091	100.0%
373	88	GALVESTON	TX	ROSS CHOUEST	1	84	200	13.5%	1,282	86.5%	1,482	100.0%
280	87	MCKEESPORT	PA	NA	1	200	198	5.8%	3,199	94.2%	3,398	100.0%
374	87	LOS ANGELES	CA	UNKNOWN SOURCE	4	84	197	9.1%	1,965	90.9%	2,161	100.0%
240	86	SAVANNAH	GA	KRUSEVAC	1	250	196	2.7%	7,173	97.3%	7,369	100.0%
392	88	TAMPA	FL	ELK RIVER	1	75	195	12.1%	1,417	87.9%	1,612	100.0%
381	86	PASADENA	TX	NA	1	84	194	8.4%	2,106	91.6%	2,300	100.0%
518	87	CORPUS CHRISTI	TX	NA	1	30	188	13.9%	1,168	86.1%	1,356	100.0%
252	90	CORPUS CHRISTI	TX	NA	1	210	186	31.1%	411	68.9%	597	100.0%
353	86	SUPERIOR	WI	NA	1	100	184	14.8%	1,066	85.2%	1,251	100.0%
506	88	PITI	GU	AKIRA MARU NO 8	4	30	184	7.2%	2,376	92.8%	2,560	100.0%
599	87	PASS CHRISTIAN	MS	NA	1	10	183	62.0%	112	38.0%	295	100.0%
521	88	BERKELEY	CA	UNKNOWN SOURCE	2	30	181	10.9%	1,489	89.1%	1,670	100.0%
598	88	SEATTLE	WA	OCEAN CHAMPION	1	10	181	16.7%	904	83.3%	1,085	100.0%
246	86	FULTON	TX	UNKNOWN SOURCE	1	220	180	23.4%	589	76.6%	768	100.0%
642	88	NA	NA	NA	1	3	177	46.3%	206	53.7%	383	100.0%
619	87	PORT ARTHUR	TX	COUNTRY GIRL	1	10	177	17.5%	835	82.5%	1,012	100.0%
330	89	GALVESTON	TX	ZOIE LYNN F/V	2	100	173	22.5%	595	77.5%	768	100.0%
606	87	CHANNELVIEW	TX	MISS MONIE	1	10	172	18.6%	750	81.4%	922	100.0%
575	88	CORPUS CHRISTI	TX	NA	1	20	169	8.0%	1,952	92.0%	2,121	100.0%
649	87	JUNEAU	AK	NA	4	1	166	11.9%	1,236	88.1%	1,402	100.0%
500	88	CLEVELAND	OH	NA	2	35	163	5.3%	2,904	94.7%	3,067	100.0%
460	87	RIVERHEAD	NY	NA	1	50	163	13.6%	1,032	86.4%	1,195	100.0%
526	88	NEHALEM	OR	UNKNOWN SOURCE	4	25	163	9.2%	1,613	90.8%	1,776	100.0%
524	88	ALLENDALE	FL	LITTLE ROSIE G	2	25	163	14.9%	932	85.1%	1,095	100.0%
184	88	WAIMANALO	HI	UNKNOWN SOURCE	4	700	161	2.0%	8,051	98.0%	8,212	100.0%
558	87	JAMES ISLAND	SC	NA	2	20	160	25.4%	470	74.6%	629	100.0%
186	86	EVERETT	WA	NA	2	675	160	9.8%	1,469	90.2%	1,629	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = "****" (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1
Distribution of Costs for Spills
With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
544	86	ROCKPORT	TX	UNKNOWN SOURCE	1	21	157	29.2%	382	70.8%	539	100.0%
296	88	SKAGIT BAY	WA	SEA OTTER	2	160	156	6.8%	2,116	93.2%	2,272	100.0%
475	87	CORPUS CHRISTI	TX	NA	1	42	148	16.6%	743	83.4%	891	100.0%
553	86	HONOLULU	HI	NA	1	20	147	2.6%	5,617	97.4%	5,764	100.0%
673	90	PORT ARTHUR	TX	NA	1	20	145	25.4%	425	74.6%	570	100.0%
396	86	MIAMI	FL	BAHAMA ADVENTURE	1	75	143	4.7%	2,926	95.3%	3,069	100.0%
520	87	SEATTLE	WA	DISTANT WATER	4	30	139	9.1%	1,399	90.9%	1,538	100.0%
337	88	JUNEAU	AK	UNKNOWN SOURCE	2	100	136	15.4%	747	84.6%	883	100.0%
421	88	MIAMI	FL	TONALA	2	60	134	5.6%	2,252	94.4%	2,386	100.0%
388	88	PALM BEACH	FL	T.J. SHERIDAN	1	80	133	8.4%	1,447	91.6%	1,580	100.0%
477	86	SAN PEDRO	CA	NA	1	42	125	10.8%	1,037	89.2%	1,163	100.0%
533	87	HONOLULU	HI	UNKNOWN SOURCE	4	25	122	37.0%	208	63.0%	330	100.0%
402	86	MIAMI	FL	UNKNOWN SOURCE	1	70	117	5.6%	1,952	94.4%	2,069	100.0%
634	86	ROCKPORT	TX	NA	1	5	115	20.6%	444	79.4%	560	100.0%
572	86	BALLARD	WA	UNKNOWN SOURCE	1	20	115	6.5%	1,650	93.5%	1,765	100.0%
401	86	FULTON	TX	UNKNOWN SOURCE	1	70	112	17.6%	526	82.4%	638	100.0%
395	88	KETCHIKAN	AK	AK6396B, UNNAMED	2	78	111	4.7%	2,247	95.3%	2,358	100.0%
211	87	RODEO	CA	GOLDEN COAST	2	400	111	1.4%	7,699	98.6%	7,810	100.0%
427	88	JUNEAU	AK	UNKNOWN SOURCE	2	50	109	11.7%	819	88.3%	928	100.0%
376	88	TEXAS CITY	TX	NA	1	84	108	4.4%	2,330	95.6%	2,438	100.0%
639	86	CORPUS CHRISTI	TX	UNKNOWN SOURCE	1	5	106	28.9%	262	71.1%	368	100.0%
441	86	HATTERAS	NC	CHERYL ANN	2	50	106	15.9%	559	84.1%	664	100.0%
230	86	WHITING	IN	NA	1	300	104	2.9%	3,465	97.1%	3,569	100.0%
456	86	CAPE CANAVERAL	FL	NA	1	50	103	8.0%	1,188	92.0%	1,291	100.0%
549	86	BALTIMORE	MD	NA	4	20	101	29.8%	238	70.2%	339	100.0%
597	87	PORT ISABEL	TX	UNKNOWN SOURCE	1	11	101	10.9%	820	89.1%	921	100.0%
652	86	BURIEN	WA	UNKNOWN SOURCE	1	1	99	50.8%	96	49.2%	195	100.0%
284	88	JACKSONVILLE	FL	UNKNOWN SOURCE	1	200	98	29.5%	233	70.5%	330	100.0%
615	86	HONOLULU	HI	UNKNOWN SOURCE	1	30	97	7.5%	1,202	92.5%	1,299	100.0%
508	88	DEER PARK	TX	NA	1	30	94	6.0%	1,478	94.0%	1,573	100.0%
571	86	HAMPTON	VA	NA	4	20	92	4.7%	1,864	95.3%	1,957	100.0%
344	88	VANCOUVER	WA	FILIPINAS	1	100	91	4.8%	1,795	95.2%	1,886	100.0%
608	87	MORRO BAY	CA	UNKNOWN SOURCE	1	10	90	37.3%	152	62.7%	242	100.0%
339	88	ST PETERSBURG	FL	NA	1	100	90	6.8%	1,225	93.2%	1,314	100.0%

[a] from Table A-1
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown
[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.
[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
647	86	JAMESTOWN	RI	UNNAMED	2	2	90	44.4%	112	55.6%	202	100.0%
633	87	CORPUS CHRISTI	TX	NA	4	5	89	6.1%	1,376	93.9%	1,465	100.0%
583	87	NORFOLK	VA	UNKNOWN SOURCE	1	15	88	27.5%	231	72.5%	319	100.0%
605	87	NORTH TONAWANDA	NY	NA	1	10	85	20.0%	339	80.0%	423	100.0%
576	86	FULTON	TX	UNKNOWN SOURCE	1	20	82	8.2%	909	91.8%	991	100.0%
472	88	CORPUS CHRISTI	TX	NA	2	44	82	27.8%	213	72.4%	295	100.0%
452	87	CHARLESTOWN	MA	UNKNOWN SOURCE	1	50	76	8.6%	805	91.4%	881	100.0%
607	90	GALVESTON	TX	NA	1	10	73	16.8%	360	83.2%	432	100.0%
640	86	SEATTLE	WA	UNNAMED	2	3	72	29.5%	172	70.5%	244	100.0%
203	86	SEATTLE	WA	PIONEER III	2	460	70	0.8%	8,805	99.2%	8,875	100.0%
563	89	GALVESTON	TX	NA	9	20	67	27.2%	179	72.8%	246	100.0%
512	86	SCAPPOOSE	OR	NA	4	30	66	4.3%	1,460	95.7%	1.527	100.0%
486	88	BODEGA BAY	CA	UNKNOWN SOURCE	2	40	66	6.9%	894	93.1%	960	100.0%
438	87	MIAMI	FL	UNION EXPRESS	4	50	64	3.0%	2,070	97.0%	2,134	100.0%
547	88	PITI	GU	NA	1	20	62	36.9%	106	63.1%	167	100.0%
235	89	CORPUS CHRISTI	TX	NA	1	252	59	2.8%	2,038	97.2%	2,097	100.0%
584	86	BALTIMORE	MD	NA	4	15	56	33.3%	112	66.7%	168	100.0%
651	87	AMELIA CITY	FL	NA	4	1	54	6.5%	779	93.5%	833	100.0%
482	87	PORT NECHES	TX	OVERSEAS CHICAGO	4	42	54	8.3%	590	91.7%	644	100.0%
405	87	JACKSONVILLE	FL	NA	1	70	53	28.3%	133	71.7%	186	100.0%
635	88	JUNEAU	AK	UNKNOWN SOURCE	4	6	52	25.4%	152	74.6%	203	100.0%
594	89	CORPUS CHRISTI	TX	NA	1	12	52	5.2%	936	94.8%	987	100.0%
556	88	HONOLULU	HI	NA	1	20	51	5.5%	872	94.5%	922	100.0%
562	87	SEATTLE	WA	UNKNOWN SOURCE	1	20	49	19.6%	203	80.4%	253	100.0%
636	88	CHANNELVIEW	TX	NA	1	6	48	23.3%	159	76.7%	208	100.0%
632	87	ROCKPORT	TX	NA	1	5	46	25.9%	131	74.1%	177	100.0%
641	87	TEXAS CITY	TX	TX7210ZU	1	3	46	48.8%	48	51.2%	94	100.0%
530	86	CHINCOTEAGUE	VA	UNKNOWN SOURCE	4	25	42	49.4%	43	50.6%	85	100.0%
629	87	FORT BRAGG	CA	UNKNOWN SOURCE	1	6	42	16.5%	210	83.5%	252	100.0%
638	86	ROCKPORT	TX	NA	1	5	41	42.2%	56	57.8%	97	100.0%
604	90	GALVESTON	TX	NA	4	10	41	18.6%	178	81.4%	219	100.0%
329	87	EUCLID	OH	NA	1	100	38	2.8%	1,348	97.2%	1,386	100.0%
246	86	HAMPTON	VA	NA	1	235	37	1.2%	3,186	98.8%	3,223	100.0%
630	86	CORPUS CHRISTI	TX	UNKNOWN SOURCE	1	5	36	8.0%	413	92.0%	449	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1
Distribution of Costs for Spills
With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
557	89	GALVESTON	TX	NA	2	20	35	6.3%	521	93.7%	556	100.0%
602	90	BOSTON	MA	WILCOX II	2	10	34	5.2%	616	94.8%	649	100.0%
513	88	MIAMI	FL	UNKNOWN SOURCE	1	30	30	38.0%	48	62.0%	78	100.0%
504	87	FORT PIERCE	FL	UNKNOWN SOURCE	4	30	28	13.4%	182	86.6%	210	100.0%
398	86	MIAMI	FL	HYBUR CLIPPER	1	75	24	15.3%	131	84.7%	154	100.0%
394	88	WEST ELIZABETH	PA	VULCAN	4	75	21	1.0%	2,197	99.0%	2,219	100.0%
625	88	BAYOU LA BATRE	AL	UNNAMED (AL7601SA)	1	8	17	15.1%	97	84.9%	114	100.0%
492	89	NY	NY	NA	1	40	15	1.6%	921	98.4%	936	100.0%
200	87	NORTH BRADDOCK	PA	NA	4	500	14	0.1%	13,184	99.9%	13,198	100.0%
525	88	TAMPA	FL	SEA QUEEN	1	25	11	14.9%	64	85.1%	75	100.0%
333	86	JACKSONVILLE	FL	NA	2	100	1	0.1%	1,459	99.9%	1,460	100.0%
257	87	PITI	GU	NA	1	200	1	0.0%	6,170	100.0%	6,171	100.0%
507	86	SEATTLE	WA	UNKNOWN SOURCE	2	30	1	0.0%	2,705	100.0%	2,706	100.0%
269	86	PAGO PAGO	AS	UNKNOWN SOURCE	4	200	1	0.0%	7,065	100.0%	7,066	100.0%
485	88	PITI	GU	JAIWON APOLLO	2	40	1	0.0%	2,313	100.0%	2,314	100.0%
511	87	JUNEAU	AK	TEDDY-BAR	2	30	1	0.2%	562	99.8%	563	100.0%
239	86	PORT SALERNO	FL	UNKNOWN SOURCE	2	250	1	0.0%	3,461	100.0%	3,462	100.0%
650	86	CLIFFWOOD	NJ	NA	1	1	1	0.1%	967	99.9%	968	100.0%
648	86	DULUTH	MN	NA	1	2	1	0.0%	2,324	100.0%	2,325	100.0%
367	88	BELLINGHAM	WA	LOCHINVAR	2	85	1	0.1%	2,154	99.9%	2,155	100.0%
581	86	HYANNIS	MA	UNKNOWN SOURCE	1	17	1	0.1%	1,026	99.9%	1,027	100.0%
387	86	PAGO PAGO	AS	UNKNOWN SOURCE	1	80	1	0.0%	2,806	100.0%	2,807	100.0%
559	87	NY	NJ	FELICIA	1	20	1	0.1%	1,094	99.9%	1,095	100.0%
300	88	WYANDOTTE	MI	NA	1	150	1	0.1%	1,684	99.9%	1,685	100.0%
552	88	FLOREFFE	PA	NA	4	20	1	0.1%	812	99.9%	813	100.0%
298	88	CHESAPEAKE	VA	STC 007	4	150	1	0.0%	3,660	100.0%	3,661	100.0%
268	86	PORT CHESTER	NY	NA	1	200	1	0.1%	782	99.9%	783	100.0%
285	87	ISLE OF PALMS	SC	NA	2	200	1	0.2%	693	99.8%	694	100.0%
429	86	BERKELEY	CA	NA	4	50	1	0.1%	972	99.9%	973	100.0%
261	88	PORT CANAVERAL	FL	UNKNOWN SOURCE	1	200	1	0.1%	1,659	99.9%	1,660	100.0%
548	87	KEY LARGO	FL	UNKNOWN SOURCE	1	20	1	0.1%	1,010	99.9%	1,011	100.0%
154	86	CHANNELVIEW	TX	NA	4	1,400	1	0.4%	281	99.6%	282	100.0%
214	86	NEW BEDFORD	MA	ALYDAR	2	372	1	0.0%	31,431	100.0%	31,432	100.0%
258	86	STURGEON BAY	WI	JOHN M. SELVICK	1	200	1	0.0%	9,224	100.0%	9,225	100.0%

[a] from Table A-1
[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown
[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.
[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills

With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG Cost [c]	USCG %	Cleanup Cost [d]	Cleanup %	Total Cost	Total %
276	89	PROVIDENCE	MA	NA	1	200	1	0.0%	5,498	100.0%	5,499	100.0%
226	87	BROOKLYN	NY	NA	1	300	1	0.0%	5,267	100.0%	5,268	100.0%
522	87	HONOLULU	HI	NA	1	29	1	0.0%	2,621	100.0%	2,622	100.0%
531	88	SACRAMENTO	CA	NA	4	25	1	0.1%	1,653	99.9%	1,654	100.0%
242	88	MIAMI	FL	JUDITE	2	250	1	0.0%	3,654	100.0%	3,655	100.0%
637	86	CORPUS CHRISTI	TX	NA	1	5	1	0.1%	1,763	99.9%	1,764	100.0%
366	87	PAGO PAGO	AS	UNKNOWN SOURCE	4	86	1	0.1%	1,015	99.9%	1,016	100.0%
610	86	JUPITER	FL	FL 80005 CH	1	10	1	0.2%	709	99.8%	711	100.0%
490	88	HONOLULU	HI	UNKNOWN SOURCE	2	40	1	0.1%	1,193	99.9%	1,194	100.0%
345	88	FT LAUDERDALE	FL	UNKNOWN SOURCE	3	100	1	0.1%	2,085	99.9%	2,086	100.0%
440	88	TAMPA	FL	RAVEN	2	50	1	0.0%	2,588	100.0%	2,589	100.0%
314	86	ROCKPORT	TX	UNKNOWN SOURCE	1	130	1	0.1%	1,738	99.9%	1,739	100.0%
290	87	PAGO PAGO	AS	UNKNOWN SOURCE	4	170	1	0.1%	1,989	99.9%	1,990	100.0%
450	87	TEXAS CITY	TX	STURGEON	1	50	1	0.1%	1,172	99.9%	1,174	100.0%
442	87	DANIA	FL	NA	1	50	1	0.2%	550	99.8%	551	100.0%
585	87	HOUSTON	TX	NA	1	15	1	0.2%	478	99.8%	480	100.0%
466	86	HONOLULU	HI	NA	4	50	1	0.1%	1,458	99.9%	1,460	100.0%
445	86	SABINE	TX	UNKNOWN SOURCE	1	50	1	0.3%	329	99.7%	330	100.0%
273	86	SAVANNAH	GA	NA	2	200	1	0.0%	2,707	100.0%	2,708	100.0%
352	87	ORANGE	TX	HENRY CLAY	4	100	1	0.2%	701	99.8%	702	100.0%
470	87	PAGO PAGO	AS	UNCLE LOUIE	1	45	1	0.1%	1,317	99.9%	1,318	100.0%
204	87	PAGO PAGO	AS	UNKNOWN SOURCE	4	430	1	0.0%	5,403	100.0%	5,404	100.0%
218	87	PITI	GU	JUDITH CAROL	2	350	1	0.0%	10,118	100.0%	10,119	100.0%
160	90	CORPUS CHRISTI	TX	CHAMPION T/S	2	1,050	1	0.0%	4,703	100.0%	4,704	100.0%
135	87	PAGO PAGO	AS	UNKNOWN SOURCE	1	3,000	1	0.0%	15,027	100.0%	15,028	100.0%
149	87	NEW BEDFORD	MA	NA	2	1,574	1	0.0%	20,893	100.0%	20,894	100.0%
136	88	NEWPORT NEWS	VA	NA	1	2,800	1	0.0%	17,074	100.0%	17,075	100.0%
358	87	PHILADELPHIA	PA	NA	1	100	1	0.0%	8,227	100.0%	8,228	100.0%
397	87	PORTSMOUTH	VA	NA	1	75	1	0.0%	4,053	100.0%	4,054	100.0%
356	87	BALTIMORE	MD	KEBAN	2	100	1	0.4%	238	99.6%	239	100.0%
391	88	MORRO BAY	CA	ANN	2	78	1	50.0%	1	50.0%	2	100.0%
537	86	SAN JUAN	PR	NA	1	25	1	0.0%	5,662	100.0%	5,663	100.0%
311	88	KAPAA	HI	UNKNOWN SOURCE	1	147	1	0.0%	15,818	100.0%	15,819	100.0%
536	87	DELRAY BEACH	FL	UNKNOWN SOURCE	1	25	1	0.0%	2,751	100.0%	2,752	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

TABLE B-1

Distribution of Costs for Spills With Coast Guard Involvement

Spill No. [a]	Year	Location of Spill	ST	Vessel(s)	Product Code [b]	Spill Size (Gallons)	USCG		Cleanup		Total	
							Cost [c]	%	Cost [d]	%	Cost	%
308	88	PITI	GU	KAZUTAKA MARU NO. 8	1	150	1	0.1%	849	99.9%	850	100.0%
231	87	PASCAGOULA	MS	NA	1	300	1	0.0%	2,600	100.0%	2,601	100.0%
181	88	DANIA,	FL	UNKNOWN SOURCE	1	700	1	0.0%	9,837	100.0%	9,838	100.0%
158	88	PAGO PAGO	AS	UNKNOWN SOURCE	1	1,100	1	0.0%	10,119	100.0%	10,120	100.0%
463	88	VALDEZ	AK	GULF WINDS	2	50	1	0.1%	1,969	99.9%	1,970	100.0%
519	86	NORFOLK	VA	ACONCAGUA	1	30	1	0.2%	520	99.8%	521	100.0%
207	88	NA	NA	NA	1	420	1	0.0%	13,663	100.0%	13,664	100.0%
501	88	PHILADELPHIA	PA	AMBIA FAIR	1	35	1	0.0%	15,002	100.0%	15,003	100.0%
420	87	PORT ISABEL	TX	UNKNOWN SOURCE	1	60	1	0.0%	2,977	100.0%	2,978	100.0%
590	88	HONOLULU	HI	UNKNOWN SOURCE	1	15	1	0.0%	2,706	100.0%	2,707	100.0%
616	88	MOBILE	AL	NA	9	10	1	0.0%	2,324	100.0%	2,325	100.0%
465	88	JACKSONVILLE	FL	NA	2	50	1	0.2%	626	99.8%	627	100.0%

[a] from Table A-1

[b] 1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR, assumed to be chemical); 9 = NA/unknown

[c] Coast Guard costs include costs for personnel and vehicle and equipment use, but may also include any cleanup supplies, equipment, or services paid for on a purchase order basis.

[d] Cleanup costs are not separately provided in the MPIR data base; they are calculated as the difference between total costs and Coast Guard costs.

Sources: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

APPENDIX C

DATA ON OIL

AND CHEMICAL SPILLS

WHERE NO SPILL QUANTITY IS REPORTED

(i.e., spill never occurred or was prevented by

response activities)

TABLE C-1
Cost of Spill Incidents Where
No Quantity Was Recorded as Spilled

Spill No.	Year	Location	ST	Vessel(s)	Product Code [b]	Cleanup Cost ($1990)
654	88	QUEENS	NY	NA	3	16,109
655	86	KEY WEST	FL	UNKNOWN SOURCE	2	11,604
656	87	PIRATES BEACH	TX	NA	5	9,568
657	88	LEWES	DE	NA	2	9,062
658	88	PROVIDENCE	RI	NA	4	8,948
659	86	GROTON	CT	NA	1	7,936
660	87	STOCK ISLAND	FL	UNKNOWN SOURCE	1	7,149
661	87	KANEOHE	HI	C'EST LA VIE	1	5,081
662	87	MAKAH BAY	WA	UNKNOWN SOURCE	4	4,066
663	88	MIAMI BEACH	FL	MEDOR HERODE	1	3,892
664	86	TARPON SPRINGS	FL	F/V LADY DAISY	1	3,615
665	86	KALALOCH	WA	UNKNOWN SOURCE	2	2,809
666	86	LOUISVILLE	KY	NA	3	2,549
667	87	SAN DIEGO	CA	NA	1	2,365
668	87	MARTHA'S VINEYARD	MA	NA	2	2,293
669	86	FORT CANBY	WA	NA	5	2,165
670	86	ATLANTIC BEACH	NC	UNKNOWN SOURCE	2	1,902
671	88	MILLVILLE	DE	NA	2	1,755
672	87	MEMPHIS	TN	NA	4	1,752
673	87	OLYMPIA	WA	UNKNOWN SOURCE	2	1,545
674	86	PROVINCETOWN	MA	NA	4	1,456
675	88	NA	NA	NA	3	1,394
676	88	PROVIDENCE	RI	NA	4	1,358
677	87	PORTLAND	OR	UNKNOWN SOURCE	2	1,343
678	86	BELLE TERRE	NY	NA	3	1,301
679	87	HULL	MA	NA	3	1,230
680	86	SURFSIDE BEACH	WA	NA	4	1,055
681	86	NA	NA	NA	4	1,028
682	87	INDIANOLA	WA	UNKNOWN SOURCE	1	990
683	88	NEWPORT	RI	NA	4	850
684	86	WEST PALM BEACH	FL	UNKNOWN SOURCE	4	805
685	88	GALVESTON	TX	UNKNOWN SOURCE	2	788
686	87	BARNSTABLE	MA	UNKNOWN SOURCE	2	695
687	86	YAQUINA BAY	OR	NA	4	586
688	88	EUREKA	CA	SEA CAT	1	1

1 = heavy petroleum; 2 = light petroleum; 3 = chemical; 4 = **** (user supplied to MPIR; assumed to be chemical);
9 = NA/unknown

Source: United States Coast Guard's Marine Pollution Incident Report data base; miscellaneous other published sources.

SECTION 8.

THE CONSEQUENCES OF CASUALTIES AFFECTING LNG AND LPG TANKERS

Prepared For:

The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

Prepared By:

Jack Faucett Associates
4550 Montgomery Avenue
Suite 300 North
Bethesda, MD 20814
April 1991

8. THE CONSEQUENCES OF CASUALTIES AFFECTING LNG AND LPG TANKERS

NOTE: This section documents the Jack Faucett Associates effort performed in support of Section 6 of the Port Needs Study (Volume I), under Contract DTRS-57-89-D-00089, OMNI Task No. RA0012.

TABLE OF CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

This report presents estimates of the consequences of casualties involving LNG and LPG tankers. Following this Introduction is a section that presents estimates of the probabilities of such casualties actually resulting in a release of gas, and the two subsequent sections present estimates of the expected consequences of such releases.

The estimates for LNG are developed by individual subzone for the subzones through which LNG tankers pass or will pass en route to LNG ports that are expected to be operating during the study timeframe. The analysis by individual subzone was made practical by the relatively small number of ports and subzones involved (twelve subzones en route to three LNG ports) and was made desirable by the need to understand the influence on the consequences of a release of varying spatial and development-density characteristics. The estimated consequences by subzone are summarized at the end of Section 3, and the underlying analyses by individual subzone are presented in Appendix A.

The estimates for LPG are developed in Section 4 by generic subzone type only — in part because of the larger number of ports and subzones involved, and in part because the consequences of a large LPG release have been less extensively studied.

As indicated in Section 2, most casualties affecting LNG or LPG tankers will not result in a release. Except for the greater cost of the vessels involved, the consequences of such casualties are the same as for similar casualties affecting any other type of vessel.

2. PROBABILITY OF A RELEASE FOLLOWING A TANKER CASUALTY

Collisions, rammings and groundings can all result in a release of LNG or LPG. The estimates of probabilities of a release for all three types of casualties are based on data on pollution-causing incidents (PCIs) for petroleum tankers.

Meade, LaPointe and Anderson[1] examined worldwide tanker casualties for the period 1969 to 1978. Data on PCI's were collected by type and location of casualties. A summary of tanker casualties by casualty type and location is presented in Exhibit 2.1.

The probability of release is calculated by dividing the number of PCI's by the total number of casualties. At piers and harbors, the probabilities of release for collisions, rammings and groundings are 0.09, 0.09 and 0.10, respectively. In coastal locations, the probabilities are 0.25, 0.08 and 0.22, respectively.

It is noted that these probabilities are derived from data based on petroleum tankers with single-hull construction. LNG and LPG tankers are required to have double-hull construction which provides a higher degree of protection for the cargo containment system[2], and the recently passed Tanker Safety Act requires the phased replacement of all single-hull tankers by double-hull vessels. A study done by the Norwegian Ship Owners Association[3] found that, for a double-hull tanker, the probability of rupturing one cargo tank is one-third as great as it is for a single-hull tanker. The probabilities calculated previously are multiplied by one-third to obtain estimates of probabilities of release following a casualty affecting a double-hull tanker. The estimated probabilities of an LNG or LPG release by type of casualty and location are summarized in Exhibit 2.2.

---

[1]Norman Meade, Thomas LaPointe, and Robert Anderson, "Multivariate Analysis of Worldwide Tanker Casualties," *Proceedings of the 1983 Oil Spill Conference*, March 1983, pp. 553-557.

[2]Robert J. Lakey, "The LNG Peril: Fact or Fiction?," *Proceedings of the Marine Safety Council*, November 1982, pp. 305-310.

[3]Norwegian Shipowners' Association, *Status Report for Studies on Accidental Pollution from Crude Oil Tankers*, Oslo, Norway, February 1990.

EXHIBIT 2.1

SUMMARY OF TANKER CASUALTIES BY TYPE AND LOCATION

Location	Type of Casualty					
	Collisions		Rammings		Groundings	
	PCI's	All Casualties	PCI's	All Casualties	PCI's	All Casualties
Piers and Harbors	53	620	43	500	50	513
Coastal Waters (harbor entrances out to 50 miles)	73	295	6	73	111	515

Source: N. Meade, T. LaPointe, and R. Anderson, "Multivariate Analysis of Worldwide Tanker Casualties," Proceedings of the 1983 Oil Spill Conference, March, 1983, pp. 553-557.

EXHIBIT 2.2

PROBABILITY OF LNG OR LPG RELEASE

Location	Type of Casualty		
	Collision	Ramming	Grounding
Piers and Harbors	0.03	0.03	0.03
Coastal Waters	0.08	0.03	0.07

3. CONSEQUENCES OF AN LNG RELEASE

There are two likely scenarios after a release of LNG on water following a tanker casualty. During a high-energy collision or ramming, it is likely that sparks or flames could ignite the LNG vapor cloud at the release site. This is the "pool-fire scenario". The second scenario results in an unignited LNG vapor cloud drifting downwind and dispersing laterally and vertically. This is the "vapor-cloud" scenario.

Analyses of the effects of these two scenarios are presented in the first subsection below, and the expected consequences by subzone are summarized in the second subsection. The estimates of the expected consequences by subzone are developed in the appendix. Separate estimates are developed for all subzones that would be traversed by tankers en route to any of the three LNG terminals that are currently operating or expected to be operating during the forecast period.

The analyses of the two scenarios are based largely on a risk analysis of the pool-fire scenario performed in 1977 by the Federal Power Commission (FPC)[1]. The FPC performed a worst-case analysis of the effect of instantaneous release of an entire cargo tank of LNG, with evaporation occurring within six minutes. Release over a longer period reduces the hazards. The possibility that a pool fire resulting from the release of one tank would cause additional tanks to fail was not considered by the FPC.

U.S. flagged LNG tankers currently in operation typically carry five storage tanks, each with a capacity of about 25,000 cubic meters. For purposes of the present analyses, an average release of one tank has been assumed.

---

[1]Federal Power Commission, Bureau of Natural Gas, *Supplement to the Final Environmental Impact Statement for the Construction of An LNG Import Terminal at Raccoon Island, Gloucester County, New Jersey*, Docket Nos. CP-73-258 et al, Washington, D.C., December 1976.

The Two Scenarios

Pool-Fire Scenario

When there is a release of LNG on water, it will spread to a maximum pool size and evaporate as it spreads. Following the FPC risk analysis[2], we assume that collisions have a 90 percent probability of resulting in immediate ignition of the LNG vapor cloud at the release site. Because the mechanisms involved in rammings are similar to collisions, the same probability of ignition applies. For groundings, because damage occurs beneath the water surface, ignition is unlikely, and so FPC assumed that immediate ignition would not occur.

There is no way to extinguish a large LNG fire except letting it burn itself out[3]. We presume that such a fire would cause significant damage to the tanker and total loss of the tanker crew. Expected damage to the tanker is presumed to equal half the cost of a new tanker ($225 million for an LNG tanker with a capacity of 125,000 cubic meters[4]). Damage could be greater for ships using membrane tanks. In addition, the thermal radiation emitted by the pool fire would likely injure or kill people and damage buildings and structures in a wide area.

For each of several types of structure or land use, the Code of Federal Regulations (49 CFR 193.2057)[5] specifies limits on the amount of thermal radiation to which the structure or users of the land would be subjected in the event of a fire at an LNG storage facility. For public streets, highways, railroads, and fire-resistent structures, the allowable thermal radiation level is 6,700 BTU/hr ft^2. Such structures and land uses are required to be far enough from an LNG storage facility so that an LNG fire would not subject them to this thermal radiation level. For buildings that are not fire-resistant, including buildings made of cellulosic materials and most residential buildings, the

---

[2]Ibid.

[3]Robert J. Lakey, "The LNG Peril: Fact or Fiction?," *Proceedings of the Marine Safety Council*, November 1982, pp. 305-310.

[4]Data from *Lloyd's Shipping Economist*, Volume 12, July 1990, pp. 35.

[5]Sami Atallah and Jatin N. Shah, Risk & Industrial Safety Consultants, Inc., *LNGFIRE: A Thermal Radiation Model for LNG Fires*, prepared for Gas Research Intitute, Chicago, Illinois, June 29, 1990.

allowable thermal radiation level is 4,000 BTU/hr ft^2. For outdoor areas occupied by 20 or more persons during normal use, the allowable thermal radiation level is 1,600 BTU/hr ft^2.

A thermal radiation model for LNG fires developed for the Gas Research Institute (GRI) by Risk and Industrial Safety Consultants, Inc.[6], calculates the distances at which thermal radiation due to an LNG fire over land drops to each of the above levels. For an LNG release on water, the flame surface emissive power increases and radiant heat reaches longer distances; we have assumed a twenty percent increase in the distance reached by thermal radiation of a given level. For an LNG release of 25,000 cubic meters ignited immediately, the FPC procedure indicates that the maximum radius of fire is 1352 feet and the radius when the fire is at maximum intensity is 1134 feet. Based on a radius of 1134 feet and assuming a wind speed of 12 mph, temperature at 15° C, and relative humidity at 65 percent, the distances (including the twenty percent adjustment) at which thermal radiation drops to the 6,700, 4,000 and 1,600 BTU/hr ft^2 levels are 3,241, 4,077 and 6,139 feet, respectively.

To estimate the potential fatalities from the radiant heat hazard, the FPC assumed that 20 percent of the population in areas receiving more than 5,300 BTU/hr ft^2 would be unshielded by structures and would be severely burned or die. Ten seconds of exposure to such heat is normally fatal. In our analysis, thermal radiation at this level would extend about 3600 feet (0.68 mile) from the source. We estimate that 18 percent of the population in this area would die and two percent would receive nonfatal burns.

To estimate the damage to buildings and structures due to radiant heat, it is assumed that commercial, industrial, and government-owned equipment and structures within 3,241 feet (0.61 mile) radially and residential buildings within 4,077 feet (0.77 mile) radially would be damaged to some extent. We assume that the average loss to buildings in these areas would be 25 percent. By way of comparison, the smaller 1944 Cleveland release of 6,200 cubic meters of LNG resulted in igniting and damaging buildings up to one quarter of a mile from the release[7].

---

[6]Ibid.

[7]Lee Niedringhaus Davis, *Frozen Fire: Where Will It Happen Next?*, Friends of the Earth, San Francisco, California, 1979.

Vapor-Cloud Scenario

If unignited at the release site, the LNG vapor cloud initially would roll out on the ground and eventually lengthen and rise into a plume. It is generally accepted that the plume would be flammable in its downwind portion when it is at a mixture of 5 to 15 percent LNG to air, though there is evidence that localized fires could be ignited at appreciably lower concentrations[8].

Information obtained from the FPC study and from GRI suggest that, when the wind speed is 12 mph, an LNG vapor cloud resulting from an instantaneous release of 25,000 cubic meters of LNG onto water is likely to travel about three-quarters of a mile before the 5 percent lower flammable limit is reached. (A lower wind speed decreases dispersion and thus allows the cloud to travel further. The maximum distance that can be traveled is about one mile and occurs when the wind speed is about 5 mph.)

Since lighted cigarettes and warm automobile engines are both potential ignition sources, if an LNG cloud reaches a populated area, it is likely to ignite before spreading over very much of the area. Once ignited, experiments have shown that a flame front burns back through the vapor cloud toward the source of release[9]. For our analysis, we presume that the flame front normally reaches the tanker (the source of release), causing the death of 20 percent of the crew members, nonfatal burns to 40 percent of the crew, and modest additional damage to the tanker. Expected total damage to the tanker is presumed to represent 10 percent of the cost of a new ship. Crew members that are not burned may receive other casualty-related injuries that are assumed to have the same costs per person as similar casualties affecting petroleum tankers; these costs are not estimated in this paper.

The heat produced by a vapor-cloud fire is less intense than that of a pool fire and generally affects only the area covered by the cloud. Because of the high availability of ignition sources in populated areas, only a relatively small portion of any populated area is likely to be affected by any vapor-cloud fire. We presume that, when a vapor-cloud fire occurs in a densely populated area, it causes significant damage over an area of 0.1 square miles, on average, destroying 25 percent of the property in this area, fatally burning 20 percent of the population in this area, and causing nonfatal burns to

---

[8] Ibid.

[9] Elisabeth Drake and Robert C. Reid, "The Importantation of Liquefied Natural Gas," *Scientific American*, Volume 236, April 1977, pp. 22-29.

another 20 percent of the population. In less densely populated areas, the area affected could be appreciably greater, perhaps 0.25 to 0.5 square miles.

A Summary of the Consequences

Estimates of the expected consequences of a typical release of 25,000 cubic meters of LNG from a 125,000 cubic-meter tanker are developed in Appendix A. Exhibit 3.1 presents a summary of these estimates. The consequences are shown by type of casualty (collision and grounding), study subzone, and type of consequence (property damage, fatalities, and nonfatal burns). As stated in Footnote 2 to the exhibit, the expected consequences of a release due to the ramming of a dredge or a stationary vessel are the same as those for a collision. The consequences of bridge rammings have not been estimated since it does not appear possible for deep-draft vessels to ram any of the bridges in the affected subzones. Where they exist, the cost of vehicular delays due to bridge damage (due to heat) are included in the property-damage figures.

Exhibit 3.1 also shows the expected number of crew members that are not burned. These crew members may receive less serious injuries. The expected number and cost of these injuries can be estimated by TSC using the same procedure as is used to estimate these consequences for casualties affecting conventional tankers. These consequences could be a significant portion of the total consequences of groundings, but they would be an insignificant portion of the total consequences of collisions and rammings. In areas where collisions are possible, the consequences of these injuries are likely to be insignificant in relation the consequences of all casualties of LNG tankers. Accordingly, omission of these consequences from the overall analysis is not likely to have a significant effect on overall results.

The final column in Exhibit 3.1 shows the probability used in our analysis that a vapor cloud resulting from a grounding would be ignited after encountering a second vessel. Because we have no information about the characteristics of other vessels, the impacts on the second vessel have not been estimated. We suggest that these effects be estimated by assuming that a vapor-cloud fire would have the same consequences for the second vessel as it would for the LNG tanker: fatal burns for 20 percent of the persons aboard, nonfatal burns for 40 percent of these persons, and property damage equal to 10 percent of the cost of a new vessel. As indicated in a footnote to the exhibit, the probability of a second vessel being involved is shown only for those subzones for which the presence of the second vessel is the most likely cause of ignition. For other subzones, the expected

EXHIBIT 3.1

EXPECTED CONSEQUENCES OF AN LNG RELEASE FROM A 125,000 CUBIC-METER LNG TANKER[1]

LNG Terminal Location and Study Subzone	Collisions[2]				Groundings				
	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members	Probability of Several Vessels Involved[3]
Everett, Mass.									
0101A	$100	27	--	3	$2.5	0.06	0.12	29.82	1%
0102B	100	27	--	3	2.7	0.12	0.24	29.64	2%
0103C	106	76	6	2.8	4.4	1.2	1.8	28.2	2%
0104D	260	3700	430	1.4	32	275	280	14	--
0105E	230[4]	3500	420	1.2	32.5[4]	320	320	12	--
Lake Charles, LA									
0501A	100	27	--	3	2.5	0.06	0.12	29.82	1%
0503C	100	32	1	2.8	2.5	0.07	0.13	29.82	--
Cove Point, MD									
0801A, 0802B[5]	100	27	--	3	2.5	0.06	0.12	29.82	1%
Ches. Bay Bridge-Tunnel	105[4]	50	23	2.85	4.3[4]	1.6	2.2	28.2	--
0803C[5]	100	27	--	3	2.9	0.2	0.4	29.5	2%
0901C	100	27	--	3	2.7	0.12	0.24	29.64	2%

[1]Excludes effects on vessels other than the LNG tanker. In the case of collisions, there is a 90 percent probability of significant damage to the second vessel as a result of a pool fire. (See text.)

[2]The expected effects of a release resulting from ramming a dredge or disabled vessel are assumed to be the same as those due to a collision (except for effects on the second vessel).

[3]Probability shown is that assumed in our analysis. Probability of a second vessel being involved in a fire due to a grounding is not shown when the impacts on the second vessel are insignificant in relation to overall impacts.

[4]Includes cost of delays.

[5]Excludes Chesapeake Bay Bridge-Tunnel portion of the subzone.

consequences to any second vessel are unlikely to represent a significant portion of the total expected consequences of a grounding. In subzones for which a percentage is shown, the expected consequences to the second vessel are likely to represent a significant portion of the expected consequences of a grounding, but, in areas where collisions are possible, these consequences are likely to be insignificant in relation to the consequences of all casualties of LNG tankers.

Although the expected consequences to any second vessel involved only in a potential vapor-cloud fire may not be significant, the expected consequences to a second vessel that is directly involved in a collision are likely to be significant. As indicated in Footnote 1 to Exhibit 3.1, the consequences shown in the exhibit for collisions (and vessel and dredge rammings) exclude the effects on the other vessel(s), their crew, and any passengers. There is a 90 percent probability that an LNG release resulting from any casualty of this type would result in a pool fire that would envelop the other vessels with intense heat and that might result in secondary fires on the other vessels. We suggest that the expected consequences of a pool fire on involved vessels other than the LNG tanker be estimated as consisting of property damage equal to one quarter the value of the other vessel, fatal burns to half the persons on board, and routine collision-related injuries to the remainder.

In the case of a collision that does not result in a pool fire, there is some probability (varying by subzone) that the resulting vapor cloud would eventually ignite and some probability (depending on wind direction) that such a fire would affect the other vessel involved in the collision. Such a vapor-cloud fire would cause appreciably less damage to the other vessel than would a pool fire and, because of the relatively low probability of such a fire occurring and affecting the other vessel, we suggest not adjusting the consequences analysis for the effects of such a fire on the other vessel. Instead, we suggest assuming that, in the absence of a pool fire, the damage to the other vessel and to persons on board would be limited to those due to the collision or ramming.

Exhibit 3.1 treats the area in the vicinity of the Chesapeake Bay Bridge-Tunnel as a separate subzone. The expected consequences of an LNG release in this subzone are appreciably greater than they are for releases in the adjoining subzones, 0802B and 0803C, of which this area is actually a part. For each casualty type, the expected consequences of a casualty in the original Subzone 0802B (or 0803C) can be obtained by taking appropriately weighted averages of the expected consequences shown for the non-bridge-tunnel portion of Subzone 0802B (or 0803C) and those shown for the bridge-tunnel subzone.

It should be observed that Exhibit 3.1 shows the expected consequences of an LNG release. As shown in Exhibit 2.2, the probability that a casualty involving an LNG tanker (all of which are double hulled) would actually result in a release is only three to eight percent, depending on location and type of casualty. We suggest that the probabilities of release shown in Exhibit 2.2 for "piers and harbors" be used for all subzones of type D, E and F and for the area surrounding the Chesapeake Bay Bridge-Tunnel, and that the probabilities for "coastal waters" be used for subzones of type A, B and C.

The expected consequences of an LNG release shown in Exhibit 3.1 are expressed per 125,000 cubic meter LNG tanker. If all LNG tankers are of this size and the probabilities of LNG tanker casualties resulting in a release are known for each subzone, then probabilities can be combined with the figures in Exhibit 3.1 to get estimates of the expected consequences of these casualties. More generally, however, what is likely to be known are the casualty probabilities for any large tanker and the expected amount of LNG carried by a large tanker traversing each subzone (obtained by dividing the annual amount of LNG transported by the annual number of passages of large tankers). To use this information to derive the expected consequences of LNG releases in a subzone, it is necessary to combine it with the probability of an LNG casualty resulting in a release (from Exhibit 2.2) and the expected consequences per ton or per thousand tons of LNG transported.

Since a cubic meter of LNG normally weighs 1023.3 pounds, 125,000 cubic meters of LNG weighs about 63,956 tons. Hence, dividing the figures in Exhibit 3.1 by 63.956 produces estimates of the expected consequences of LNG releases per thousand tons of LNG carried by tankers that suffer a release. These estimates are presented in Exhibit 3.2.

The total expected consequences of a release from a tanker carrying a known quantity of LNG can be obtained by multiplying the number of thousands of tons being carried by the sum of:

- fatalities multiplied by the value of life;
- nonfatal burns multiplied by the cost per burn: $500,000[10];

[10]An analysis of the costs of nonfatal highway-accident injuries by Ted Miller of the Urban Institute indicates that the average cost of all non-minor injuries (all injuries with Maximum Abbreviated Injury System (MAIS) code of 2-5) is $140,000 (in 1990 dollars), and the cost of critical injuries (MAIS code 5) is $1.9 million. Allowing for the high proportion of very severe injuries likely to result from an LNG fire, a relatively high average cost per injury of $500,000 is recommended for use in the study.

EXHIBIT 3.2

EXPECTED CONSEQUENCES OF LNG RELEASES PER 1000 TONS OF LNG CARRIED BY TANKERS THAT SUFFER A RELEASE[1]

	Collisions[2]				Groundings			
LNG Terminal Location and Study Subzone	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members	Property Damage (thousands of dollars)	Fatalities	Nonfatal Burns	Other Crew Members
Everett, Mass.								
0101A	$1.56	0.4	--	0.05	$39	0.001	0.002	0.5
0102B	1.56	0.4	--	0.05	42	0.002	0.004	0.5
0103C	1.66	1.2	0.1	0.04	69	0.02	0.03	0.4
0104D	4.07	57.9	6.7	0.02	500	4.3	4.4	0.2
0105E	3.60[3]	54.7	6.6	0.02	508	5.0	5.0	0.2
Lake Charles, LA								
0501A	1.56	0.4	--	0.05	39	0.001	0.002	0.5
0503C	1.56	0.5	0.02	0.04	39	0.001	0.002	0.5
Cove Point, MD								
0801A, 0802B[4]	1.56	0.4	--	0.05	39	0.001	0.002	0.5
Ches. Bay Bridge-Tunnel	1.64[3]	0.8	0.04	0.04	67	0.025	0.035	0.4
0803C[4]	1.56	0.4	--	0.05	45	0.003	0.006	0.5
0901C	1.56	0.4	--	0.05	42	0.002	0.004	0.5

[1]Excludes effects on vessels other than the LNG tanker. In the case of collisions, there is a 90 percent probability of significant damage to the second vessel as a result of a pool fire. (See text.)

[2]The expected effects of a release resulting from ramming a dredge or disabled vessel are assumed to be the same as those due to a collision (except for effects on the second vessel).

[3]Includes cost of delays.

[4]Excludes Chesapeake Bay Bridge-Tunnel portion of the subzone.

- expected number of other crew members multiplied by the expected cost of other injuries per crew member (if known);
- costs of property damage and any vehicular delays; and
- adding to this result any significant consequences to other vessels.

4. CONSEQUENCES OF AN LPG RELEASE

LPG (liquefied petroleum gas) normally consists of a mixture of propane and butane cryogenically stored in liquid form at about -42° C. The propane content of LPG usually is substantially greater than the butane content. Butane is somewhat denser than propane.

Under normal conditions, propane is about 2.5 times as dense as methane (the primary constituent of LNG) and contains about 2.75 times as much potential energy. However, since methane is much less readily liquefied than propane, LNG is stored at much lower temperatures (about -162° C) than LPG. Accordingly, at their respective storage temperatures, LPG contains only about 1.23 times as much potential energy as LNG.

LPG is currently transported by LPG tankers, LPG tank barges, and (for some small shipments) in pressurized cylinders. For foreign and coastwise shipments, our Task 2 analysis distinguishes between the use of tankers and cylinders on the basis of annual volume. However, for internal movements, the current version of our Task 2 analysis assigns all movements to tank barges, regardless of annual volume.

The sizes of LPG tankers vary more widely than those used for transporting LNG, with most LPG tankers carrying between 24,000 and 75,000 cubic meters. The largest of these tankers have four 18,750 cubic-meter tanks. Our analysis of the consequences of an LPG release assumes an instantaneous release of one 18,750 cubic-meter tank.

Although a large LPG tank is 25 percent smaller than a large LNG tank, the differing energy intensities of the two gases result in a difference in total potential energy stored of only about eight percent. Furthermore, because of the greater energy intensities of the constituent gases of LPG, once ignited, an LPG flame can travel faster than the speed of sound; *i.e.*, LPG gases released from a tanker can produce a true explosion. LNG, on the other hand, can produce an explosion only when released into a confined space.

An LPG release, like an LNG release, results in forming a pool of liquid that spreads and evaporates as it spreads. The heavier LPG, however, spreads and evaporates somewhat more slowly than LNG. Since these gases can burn only when they have mixed with air, the slower evaporation rate reduces the amount of gas that can burn at any one time. Thus, the destructiveness due to LPG's greater energy density is at least partially balanced by the slower evaporation rate.

LPG fires have been subjected to far less scrutiny than LNG fires, and none of our sources can provide any clear guidance as to the relative magnitude of the consequences of the two types of fires or of the appropriate assumptions to be made concerning the consequences of an LPG fire. Accordingly, on the basis of the above discussion, we estimate the effects of ignition of a release of 18,750 cubic meters of LPG at the release site as being similar to those of a release of 25,000 cubic meters of LNG.

If unignited at the release site, an LPG vapor pool will spread along the ground. Because LPG gases are heavier than air, they do not rise, and dispersion is much slower. On the other hand, the initial density of the leading edge of the vapor pool is limited by the lower evaporation rate of LPG. Our information suggests that, because of this last factor, the density of the vapor pool may well drop below its lower emission limit <u>closer</u> to the source in the case of LPG than in the case of LNG; *i.e.*, the distance from the release site at which the gas ceases to be flammable is shorter for LPG than for LNG. On the other hand, the slower evaporation rate and the lack of upward dispersion should make an LPG vapor pool flammable for a much longer period of time than an LNG vapor cloud. Furthermore, because of the greater energy density of LPG gases and the lack of upward dispersion, ignition of an LPG vapor pool is likely to be more destructive than ignition of an LNG vapor cloud.

A Summary of the Consequences

Estimates of the expected consequences of a typical release of 18,750 cubic meters of LPG from a 75,000 cubic-meter tanker are developed in Appendix B. The consequences are estimated by generic subzone type but not by individual study subzone. Exhibit 4.1 presents a summary of these estimates. The consequences are shown by type of casualty (collision/ramming or grounding), subzone type, and type of consequence (property damage, fatalities, and nonfatal burns). Where they exist, the cost of vehicular delays due to bridge damage are included in the property damage figures.

Also shown in Exhibit 4.1 is the expected number of crew members that are not burned. These crew members may receive less serious injuries. The expected number and cost of these injuries can be estimated by TSC using the same procedure as is used to estimate these consequences for casualties affecting conventional tankers. These consequences could be a significant portion of the estimated

EXHIBIT 4.1

EXPECTED CONSEQUENCES OF AN LPG RELEASE FROM A 75,000 CUBIC-METER LPG TANKER[1]

Subzone Type	Collisions and Rammings				Groundings				
	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members	Probability of Several Vessels Involved[2]
A. Open Approach	$ 41	22.5	---	2.5	$ 1.0	0.12	0.03	22.85	1%
B. Convergence	41	22.5	---	2.5	1.1	0.24	0.06	22.7	2%
C. Open Harbor or Bay	42	25	1	2.5	1.2	0.5	0.1	22.6	2%
D. Enclosed Harbor	58	390	42	1.75	16	21	17	17.5	---
E. Constricted Waterway	50	200	21	2.1	8	10	8	20	---
F. River	50	200	21	2.1	8	10	8	20	---

[1]Excludes effects on vessels other than the LPG tanker. In the case of collisions and vessel rammings, there is a 90 percent probability of significant damage to the second vessel as a result of a pool fire. (See text.)

[2]Probability shown is that assumed in our analysis. Probability of a second vessel being involved in a fire due to a grounding is not shown when the impacts on the second vessel are insignificant in relation to overall impacts.

consequences of grounding in subzones of Type A, B or C, but not for groundings in subzones of Type D, E or F, or for collisions and rammings.

The final column of Exhibit 4.1 shows the probability used in our analysis that an LPG vapor pool resulting from a grounding would be ignited after encountering a second vessel. Because we have no information about the characteristics of other vessels, the impacts on other vessels have not been estimated. We suggest that these effects be estimated by assuming that ignition of an LPG vapor pool would have about the same consequences for the second vessel as it would for the LPG tanker: fatal burns to half the crew, nonfatal burns to ten percent of the crew, and property damage equal to 30 percent of the cost of a new vessel. (These consequences are higher than those of an LNG vapor-cloud fire.) As indicated in a footnote to the exhibit, the probability of a second vessel being involved is shown only for those subzone types for which the presence of the second vessel is the most likely cause of ignition. The expected consequences to such a vessel are likely to represent a moderately significant portion of expected total consequences of a release due to a grounding in these subzone types, but not in the other subzone types.

Although expected consequences to any second vessel involved only in igniting an LPG vapor pool may not be significant, the expected consequences to the second vessel involved in a collision <u>are</u> likely to be significant. As indicated in Footnote 1 to Exhibit 4.1, the consequences shown in the exhibit for collisions and vessel rammings exclude the effects on the other vessels. There is a 90 percent probability that an LPG release resulting from a casualty of this type would result in an immediate LPG explosion that would damage the second vessel and injure or kill those on board. We suggest that the expected consequences of immediate ignition on these other vessels be estimated as consisting of damage equal to 30 percent of the value of the vessel, fatal burns to 40 percent of the persons on board, nonfatal burns to 10 percent of these persons, and potential routine collision-related injuries to the remainder.

Although there is some probability that delayed ignition of a vapor pool will also produce significant consequences for the vessel with which the LPG tanker has collided, the probability is not high and the expected consequences will be much smaller than those for the LPG tanker. Accordingly, in the case of delayed ignition, we suggest ignoring the expected consequences to the second vessel involved in a collision.

A comparison of Exhibits 3.1 and 4.1 indicates that the expected consequences of an LPG release are much lower that those of an LNG release. This does <u>not</u> mean that LPG is less dangerous than LNG.

The primary reasons for the differences in the consequences are: the very high expected consequences of a release in Boston's Inner Harbor or on the Mystic River (Subzones 0104D and 0105E); and, in subzones of Type A, B or C (where nearly all the expected consequences are vessel-related), the substantially greater value and slightly larger crew size of LNG tankers relative to LPG tankers.

As in the case of LNG, the values shown in Exhibit 4.1 are converted to estimates of the expected consequences per 1000 tons of LPG released. Since a cubic meter of LPG normally weighs about 1370 pounds, 75,000 cubic meters of LPG weighs about 51,375 tons. Dividing the figures in Exhibit 4.1 by 51.375 produces estimates of the expected consequences of LPG releases per thousand tons of LPG carried by tankers that suffer a release. These estimates are presented in Exhibit 4.2. The values shown in this example can be used to estimate the total expected consequences of a release from a tanker carrying a known quantity of LPG using the same procedure as used for LNG.

EXHIBIT 4.2

EXPECTED CONSEQUENCES OF LPG RELEASES PER 1000 TONS OF LPG CARRIED BY TANKERS THAT SUFFER A RELEASE[1]

Subzone Type	Collisions and Rammings				Groundings			
	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members	Property Damage (thousands of dollars)	Fatalities	Nonfatal Burns	Other Crew Members
A. Open Approach	$ 0.80	0.4	---	0.05	$ 19	0.002	0.001	0.4
B. Convergence	0.80	0.4	---	0.05	21	0.005	0.001	0.4
C. Open Harbor or Bay	0.82	0.4	0.02	0.05	23	0.01	0.002	0.4
D. Enclosed Harbor	1.13	7.6	0.8	0.03	311	0.4	0.33	0.3
E. Constricted Waterway	0.97	3.9	0.4	0.04	156	0.2	0.16	0.4
F. River	0.97	3.9	0.4	0.04	156	0.2	0.16	0.4

[1]Excludes effects on vessels other than the LPG tanker. In the case of collisions and vessel rammings, there is a 90 percent probability of significant damage to the second vessel as a result of a pool fire. (See text.)

APPENDIX A

EXPECTED CONSEQUENCES OF AN LNG RELEASE BY SUBZONE

LNG terminals currently are operating in Everett, Massachusetts (Boston Study Zone), and Lake Charles, Louisiana (Port Arthur Study Zone). A third terminal has previously operated at Cove Point, Maryland (Chesapeake Bay Study Zones), and is expected to reopen in 1992. It has also been proposed that a terminal be built at Point Concepcion, California, outside of all study zones, though we do not know the current status of this proposal.

Estimates of the expected consequences of an LNG release resulting from a collision, bridge ramming, or grounding en route to the Everett, Lake Charles or Cove Point terminals are developed in this appendix. The estimates developed for a collision also should be used for a release resulting from the ramming of a dredge or stationary vessel. The estimates developed in this appendix are summarized in Exhibit 3.1 in the body of this paper.

The Everett Terminal (Zone 1)

The Everett LNG import terminal is located on the northern bank of the Mystic River across from Boston in an area of heavy population and industrial activity[1]. The terminal has been operating since 1971. Though it received very little LNG in 1986 and 1987, receipts have been rising since then. In 1990, it has been receiving LNG at an annual rate of 1.78 million tons (76 million cubic feet of gas)[2]. Collisions, groundings and vessel rammings, can occur in all five subzones (though current traffic control procedures used for LNG tankers on this route minimize the probability of a collision with another major vessel). There is also a remote possibility of ramming the side wall of the South Boston Channel (in Subzone 0103C), but it does not appear possible to ram the supports for the Mystic River Bridge (in Subzone 0105E).

The expected consequences of an LNG tanker casualty in each of the Boston subzones are developed below.

[1]U.S. General Accounting Office, *Report to the Congress of the United States: Liquefied Energy Gases Safety*, Volume 2: Appendixes, Washington, D.C., July 31, 1978.

[2]Estimates derived from information obtained from the Office of Oil and Gas, Energy Information Administration, U.S. Department of Energy, Washington, D.C., October 1990.

Subzone 0101A — Open Approach

Collisions

An LNG release resulting from a collision has a 90 percent probability of resulting in a pool fire and a 10 percent probability of forming a vapor cloud. A pool fire would cause major damage to both vessels but is very unlikely to affect any land area. Such a fire is likely to cause the death of the entire crew of the LNG tanker, normally about 30 persons[3], and many persons on the second vessel. The current (July 1990) cost of a new 125,000 cubic meter LNG tanker is $225 million[4]. We estimate a pool fire would cause $112.5 million in damage to the LNG tanker and 30 fatalities among its crew. The damage to the second vessel would be substantially greater than that of an ordinary collision; we suggest that damage to that vessel be estimated as equaling one-quarter the cost of a replacement vessel and that half the crew would die, one quarter would receive nonfatal burns, and some of the remainder would receive more typical vessel-collision injuries.

If not ignited immediately, an LNG vapor cloud would form and drift downwind toward the open sea. There would be a small probability that the vapor cloud would encounter an ignition source on another vessel or one of the harbor islands before the concentration drops below the lower flammability limit. This limit usually would be reached within about three-quarters of a mile from the release site. The probability of the vapor cloud being ignited depends primarily on the density of other vessels in the area. For purposes of analysis, we take this probability to be one percent. This possibility has an insignificant effect on the expected consequences of a collision and may be ignored (though the effect on the expected consequences of a grounding, discussed below, is somewhat more significant). Ignoring the possibility of ignition, the expected consequences of the collision/vapor-cloud scenario is one percent of the cost of the LNG tanker, or $2.25 million, plus routine collision consequences for the other vessel and for both crews.

Combining the above information, excluding the effects on the second vessel, the expected consequences of an LNG release due to a collision or vessel ramming in Subzone 0101A are about $100 million plus 27 fatalities plus routine collision-related injuries to an equivalent crew size of three

---

[3]Information obtained from the Office of Maritime Labor and Training, Maritime Administration, U.S. Department of Transportation, Washington, D.C.

[4]*Lloyd's Shipping Economist*, Volume 12, July 1990.

persons (30 persons times 10 percent). There is a 10 percent probability that damage to the second vessel would be limited to routine collision damage and a 90 percent probability that it would be much greater. In the latter event, we suggest estimating the expected cost as equaling one quarter the cost of a new vessel plus fatal burns to half the persons on the vessel and routine collision injuries to the remainder.

Exhibit A.1 summarizes the estimates developed above for the expected effects on the LNG tanker of a pool fire and of a release that does not cause a fire. Also shown in the exhibit are estimates developed below of the corresponding effects of a vapor-cloud fire.

Groundings

An LNG release resulting from a grounding in Subzone 0101A would be expected to form a vapor cloud that would drift toward the open sea. As in the case of a collision, we take the probability of the vapor cloud being ignited to be one percent. The ignition source could be on one of the harbor islands or, more likely, on another vessel. We consider only the latter possibility.

In the absence of ignition, the cost of the grounding is expected to be one percent of the cost of the vessel, or $2.25 million, plus the cost of non-fire-related injuries to the 30-member crew.

In the body of this paper it was estimated that, for both affected vessels, a vapor-cloud fire would cause fatal burns to 20 percent of the crew, nonfatal burns to 40 percent of the crew, and damage equal to 10 percent of the value of the vessels. In the case of the LNG tanker, these consequences correspond to six fatalities, nonfatal burns to twelve crew members, and $22.5 million in property damage. In addition, some of the twelve other members of the tanker's crew might receive more routine grounding-related injuries. The estimated consequences for the LNG tanker are shown in Exhibit A.1. We suggest estimating the expected costs to the second vessel and its crew and passengers as consisting of fatal burns to 20 percent of the persons aboard, nonfatal burns to another 40 percent, and property damage equal to 10 percent of the value of vessel.

Taking a weighted average of the effects on the LNG tanker of no fire (99 percent probability) or a vapor-cloud fire (one percent probability) yields our estimate of the expected effects on the LNG tanker of 0.06 fatalities, 0.12 nonfatal burns, other potential grounding-related injuries to 29.82 crew members, and about $2.5 million in damage to the vessel.

EXHIBIT A.1

EXPECTED CONSEQUENCES FOR THE LNG TANKER AND ITS CREW OF A CASUALTY RESULTING IN A RELEASE FROM A 125,000 CUBIC-METER TANKER

Scenario	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members
Pool Fire	$112.5	30	--	--
Vapor-Cloud Fire	22.5	6	12	12
No Fire	2.25	--	--	30

Subzone 0102B — Convergence

The density of vessels in Subzone 0102B is higher than in 0101A and there is a slightly greater probability of a casualty occurring in the vicinity of one of the harbor islands. These differences increase the expected consequences of a collision by an insignificant amount (which we have not estimated) and those of a grounding by a slightly more significant amount. The greater consequences are due primarily to a somewhat greater probability of vapor-cloud ignition. Using two percent as the probability of ignition of an LNG release due to grounding and taking a weighted average of the ignition and no-ignition costs estimated previously yields estimates of impacts on the LNG tanker of 0.12 fatalities, 0.24 nonfatal burns, other potential grounding-related injuries to 29.64 crew members, and $2.7 million in damage to the vessel. In addition, in the event of ignition caused by another vessel, twenty percent of the persons aboard the second vessel would be expected to sustain fatal burns and forty percent nonfatal burns, and damage to this vessel is estimated to be ten percent of its value.

Subzone 0103C — Open Harbor

Groundings

Should a grounding in Subzone 0103C result in an LNG release, there is about a ten percent probability that the LNG tanker would be close enough to land or to another vessel for the plume to be ignited. There is also some possibility that a vapor-cloud plume would be ignited by a plane taking off or landing at Logan Airport, a possibility that we have excluded from our analysis.

Should a vapor-cloud fire be ignited on reaching land or encountering another vessel, the fire would be most likely to affect Castle Island Park or the adjoining South Boston waterfront or the northern tip of Long Island. The most serious onshore damage would occur if the vapor cloud were ignited in the immediate vicinity of a containership berthed in South Boston. Overall, however, the expected onshore consequences are likely to be quite modest — perhaps an average of $1 million in property damage, ten fatalities, and ten nonfatal burns. Adding this estimate to our previous estimate of the impacts of a vapor-cloud fire on the LNG tanker, and taking a weighted average with our estimate of the impacts of such a release in the absence of a fire, yields our estimate of expected consequences: $4.4 million in property damage, 1.2 fatalities, 1.8 nonfatal burns, and other potential grounding-related injuries to 28.2 crew members. The suggested probability of additional costs being incurred by a second vessel in the area is two percent.

Collisions

A pool fire in Subzone 0103C is almost certain to have some effect on one or more of the harbor islands or on the eastern end of South Boston. There is about a 10 percent probability that the collision would occur immediately off the South Boston shore, and about an additional 25 percent probability that it would occur close enough to this shore to create some threat to life and property.

The most serious consequences of a pool fire in Subzone 0103C clearly would occur if it were centered immediately off the South Boston shore. Such a fire would affect all of Castle Island Park (at the tip of the peninsula) and the adjoining Castle Island Terminal, as well as much of adjoining terminal areas and the eastern end of the South Boston Army Base. The land area within 3600 feet of the center of the fire is likely to be between 0.1 and 0.15 square mile.

The nighttime population density of Boston is 12,150 persons per square mile[5]. The average daytime population of the affected area is appreciably lower. However, relatively few of these persons would be shielded by structures, so fatality and injury rates would be much higher than average. Assuming these two adjustments would balance each other, we estimate expected fatalities my multiplying 12,150 by 0.125 and by 0.18, and expected nonfatal injuries by multiplying 12,150 by 0.125 and by 0.02. The resulting estimates are 273 fatalities and 30 nonfatal injuries.

The area that would be affected by a pool fire off the South Boston shore contains berths for seven cargo vessels and two less frequently used berths for military vessels. The largest share of property damage due to a fire would likely be to any vessels at these berths, with additional damage to their cargo and to additional cargo in the terminal area. Assuming that the expected amount of property in the affected area at any one time is about $100 million (equivalent to the approximate value of two new 2500-TEU containerships[6]) and estimating a 25 percent loss to this property yields an estimate of overall property damage of $25 million.

There is only about a ten percent probability that an LNG release due to a collision in Subzone 0103C would occur immediately off the South Boston shore. A pool fire anywhere else in the subzone would

---

[5]*County and City Data Book: 1988*, Bureau of the Census, U.S. Department of Commerce, Washington, D.C.

[6]*Lloyd's Shipping Economist*, Volume 12, July 1990.

have appreciably smaller onshore consequences; in much of the subzone these consequences would be less than ten percent of the above estimates. Averaged over the whole subzone, the expected onshore consequences are probably about 20 percent of the above estimates. Taking 20 percent of the above estimates and adding the expected consequences to the LPG tanker (from Exhibit A.1) yields an estimate of total consequences of a pool fire (excluding those to the second vessel involved in the collision): 85 fatalities, 6 nonfatal burns, and $117.5 million in property damage.

Finally, taking a 90/10 weighted average of the expected consequences of a pool fire and the previously estimated consequences of a vapor-cloud release yields our estimate of the overall consequences, excluding those to the second vessel, of an LNG release due to a collision in Subzone 0103C: 76 fatalities, 6 nonfatal burns, other potential collision-related injuries to 2.8 crew members, and $106 million in property damage.

Subzone 0104D - Enclosed Harbor

The width (from pier to pier) of the harbor in Subzone 0104D varies from about 350 yards to about 1000 yards. The surrounding land includes much of East Boston (including part of Logan Airport), part of Charlestown, most of Boston's North End, part of downtown Boston, and an industrial area between downtown and South Boston.

<u>Collisions</u>

Pool-Fire Scenario

If a pool fire in Subzone 0104D were to be centered in the middle of the channel at a point where the width is 700 yards, about 0.92 square miles of land area would be within 3600 feet of the center of the fire and bout 0.70 square miles of land area would lie within 3241 feet of the center of the fire.

The average daytime (weekday and weekend) population density of the area that could be affected by a pool fire is probably about twice the nighttime population density of Boston, or about 24,300 persons per square mile. Hence, the expected number of persons within 3600 feet of the center of a pool fire would be 22,356. Our expected eighteen percent fatality rate and two percent injury rate for these persons yield estimates of 4024 fatalities and 447 nonfatal burns onshore.

The average assessed value of equipment and structures in Boston is $409 million per square mile[7]. The average actual value per square mile of all equipment and structures in the area that could be affected by a pool fire (including half of downtown Boston) is probably about twice as high, or about $1 billion per square mile. Multiplying this last value by the 0.7 square miles of land area expected to lie within 3241 feet of the center of the fire and our estimated 25 percent loss rate for equipment and structures in this area yields an estimate of $175 million of onshore property damage.

The above estimates of onshore fatalities, nonfatal burns, and property damage must be added to corresponding values for the LNG tanker (30 fatalities and $112.5 million in damage) and for the second vessel (to be estimated by TSC) to obtain an estimate of the total expected cost of a pool fire in Subzone 0104D.

Vapor-Cloud Scenario

There is about a 90 percent probability that an LNG vapor cloud released as the result of a collision in Subzone 0104D would reach land and be ignited before dissipating below its lower flammable limit. Prevailing winds and distance from the waterfront make downtown Boston the least likely of the nearby land areas to be the site of such ignition, thus the expected daytime population density and property values of the affected land area would be lower than for the pool-fire scenario. Using a daytime population density of 15,000 persons per square mile, total property value of $500 million per square mile, and our standard assumptions about the consequences of a vapor-cloud fire yield estimates of expected onshore consequences of 300 fatalities, 300 nonfatal burns, and $12.5 million in property damage. To obtain an estimate of the total expected cost of a vapor-cloud fire, these estimates are added to the expected consequences for the LNG tanker and its crew (shown in Exhibit A.1) and, for a collision, to the expected consequences for the second vessel (to be estimated by TSC). Total expected consequences, excluding those for the second vessel, are 306 fatalities, 312 nonfatal burns, other potential injuries to 12 crew members, and $35 million in property damage.

Taking a 90/10 weighted average of the expected consequences of a vapor-cloud fire and those of an unignited vapor cloud (shown in Exhibit A.1) yields our estimate of the expected consequences of the vapor-cloud scenario exclusive of those on the second vessel. These estimates are: 275 fatalities, 281 nonfatal burns, other potential injuries to 14 crew members, and $32 million in property damage.

---

[7]Derived from the *County and City Data Book: 1988*, op. cit., and data obtained from the Massachusetts Department of Revenue, Division of Local Services, October 1990.

Overall Consequences

The expected overall consequences of an LNG release resulting from a collision in Subzone 0104D are obtained by taking a 90/10 weighted average of the estimates for the pool-fire and vapor-cloud scenario. Excluding the effects on the second vessel, the estimated consequences are about 3700 fatalities, 430 nonfatal burns, other potential injuries to 1.4 crew members, and $260 million in property damage. It should be borne in mind that these high consequences are the expected effects of a collision that results in a release of LNG, and not those of any collision of an LNG tanker.

Groundings

An LNG vapor cloud released as the result of a grounding in Subzone 0104D has about the same probability (90 percent) of being ignited before dissipating as one released as the result of a collision. Furthermore, except for the lack of a second vessel, the expected consequences of an ignited or unignited vapor cloud are the same as they are when the vapor cloud is released as a result of a collision. Accordingly, the expected consequences of an LNG release as the result of a grounding in Subzone 0104D are about 275 fatalities, 280 nonfatal burns, other potential injuries to 14 crew members, and $32 million in property damage.

Wall Rammings

The South Boston Channel, at the entrance to Boston's Inner Harbor, contains a section of unprotected wall that can be rammed by an off-course vessel. However, any such ramming is much more likely to occur on a vessel's outbound trip than on its inbound trip. The possibility of a ramming by a loaded (inbound) LNG tanker appears to be too remote to warrant estimation. However, it should be observed that a ramming of this wall, at the entrance to the Inner Harbor, would have significantly less onshore costs than a similar casualty anywhere else in the subzone.

Subzone 0105E - Constricted Waterway

The final leg of the trip to the Everett LNG Terminal is through Subzone 0105E, classified as a constricted waterway. This leg represents a trip about three-quarters of a mile up the Mystic River, the boundary between Boston and the industrialized suburbs of Chelsea and Everett. This portion of the river is about 400 yards wide from shore to shore and passes under the Tobin Memorial (Mystic River) Bridge, about 300 yards after entering the subzone.

The supports for the Mystic River Bridge lie near the river's edge. They apparently are in shallow enough water to prevent them from being rammed, and they have only a minor effect on waterway width. Hence, the probability of a casualty occurring at the bridge appears to be no higher than it is anywhere else in the subzone. However, because of the small size of the subzone, there is a high probability that any casualty in the subzone would affect the bridge.

Collisions

Pool-Fire Scenario

It is assumed that any collision resulting in an LNG release has a 90 percent probability of producing a pool fire. In the case of Subzone 0105E, there is a probability of about 90 percent that any pool fire would be centered within 3241 feet of the Mystic River Bridge and so would cause at least some damage to the bridge and to vehicles on the bridge. To analyze these effects, we consider first the effects of a pool fire centered directly beneath the bridge.

The bridge cost $26 million to build in 1950, or $175 million after adjustment to 1990 dollars (using the U.S. Department of Commerce's Composite Construction Cost Index)[8]. Assuming that a pool fire directly beneath the bridge results in repair costs equaling ten percent of the cost of a new bridge indicates that such a fire would produce expected bridge-repair costs of $17.5 million.

The expected daytime traffic density on the bridge and its approaches is estimated to be about 50 vehicles per mile (based on an average speed of 35 miles per hour and average traffic volume of 31,000 vehicles per day[9], suggesting a daytime average of about 1750 vehicles per hour). Assuming that all vehicles within 4077 feet of the LNG release at the time of ignition are completely destroyed and that all vehicles further away are completely spared yields an estimate of about 40 vehicles destroyed. Considering the depreciated value of affected automobiles and trucks and adding the value of the contents of these vehicles suggests an average property loss of about $10,000 per vehicle, or

[8]*Historical Statistics of the United States: Colonial Times to 1970*, Bureau of the Census, U.S. Department of Commerce, Washington, D.C., 1975; *Statistical Abstract of the United States 1988*, Bureau of the Census, U.S. Department of Commerce, Washington, D.C., 1987; and Current Business Statistics, *Survey of Current Business*, Bureau of Economic Analysis, U.S. Department of Commerce, Volume 70, January 1990.

[9]Massachusetts Port Authority-Tobin Bridge, personal communication, October 1990.

a total of $400,000. Assuming an average of 1.2 persons per vehicle with a 50 percent fatality rate indicates that 23 vehicle occupants would die and an equal number would receive nonfatal burns.

Damage to the Mystic River Bridge would also cause significant delays for all traffic between downtown Boston and several suburbs lying to the north and northeast. Average daily traffic on the bridge is 31,000 vehicles, and average daily traffic in the Callahan and Sumner Tunnels, a major alternate to the east, is 43,000 vehicles. Closing the Mystic River Bridge would result in significant delays for all traffic that normally would take either of these routes and somewhat smaller delays for traffic that normally would cross the Mystic River on any of several routes to the west of the affected bridge. Assuming that average daily delays would be 37,000 vehicle-hours (equivalent to half an hour delay for every vehicle that normally would use the Mystic River Bridge or the parallel tunnels), and using an average cost of delay of $12 per vehicle-hour[10], produces an estimate of delay costs of $444,000 per day that the bridge is closed. The length of time the bridge is closed would depend on the extensiveness of the damage to the bridge. Assuming an expected closure of 180 days yields an estimate of overall delay costs of $80 million.

The preceding analysis implies that a pool fire directly below the bridge would have expected bridge-related consequences totaling about $98 million in delay and property-damage costs and would result in 23 fatalities and an equal number of nonfatal burns. A pool fire centered within 500 feet of the bridge would likely have consequences that are only slightly below the above estimates, but the consequences would drop nonlinearly with increasing distance between the pool-fire center and the bridge. As previously estimated, there is a ten percent probability that a pool fire in Subzone 0105E would be more than 3241 feet from the bridge, a distance at which the fire would be unlikely to damage the bridge but could still kill some vehicle occupants.

The above information suggests that it is reasonable to estimate the expected bridge-related consequences of a pool fire anywhere in Subzone 0105E to be about $50 million in delay and property-damage costs plus ten fatalities and an equal number of nonfatal burns. To these figures, it is necessary to add the onshore and vessel-related consequences.

---

[10]Adapted from Jack Faucett Associates, *The Highway Economic Requirements System*, Task D Report: Documentation of Model Structure, prepared for the Federal Highway Administration, Washington, D.C., January 1990, Exhibit 8.9.

If a pool fire is centered in the middle of a 400-yard wide channel, about 1.15 square miles of land area would be within 3600 feet of the center of the fire and 0.90 square miles of land area within 3241 feet of this point.

The average nighttime population density of Chelsea and Everett, combined, is 12,150 persons per square mile[11], the same as that of Boston. Assuming that the average (weekday and weekend) daytime population density of the industrial area surrounding the river is 50 percent higher produces an estimated density of 18,225 persons per square mile, or 20,959 persons within 3600 feet of the center of the fire. Our expected eighteen percent fatality rate and two percent injury rate for these persons yields estimates of 3773 fatalities and 419 nonfatal burns onshore.

The average assessed value of equipment and structures in Chelsea and Everett (combined) is $235 million per square mile, somewhat lower than the $409 million per square mile for Boston. Assuming the actual value of onshore equipment and structures in the area adjacent to the river to be $400 million per square mile, and multiplying by the 0.9 square miles of land area expected to lie within 3241 feet of the center of the fire and our estimated 2.5 percent loss rate for equipment and structures in this area yields an estimate of $90 million of onshore property damage.

Adding the above estimates of onshore and bridge-related consequences to our estimates of LNG tanker consequences in Exhibit A.1 produces overall estimates of pool-fire consequences, excluding those to the second vessel, of: 3813 fatalities, 429 nonfatal burns, and $253 million in property damage and delays.

Vapor-Cloud Scenario

The probability that an LNG vapor cloud released in Subzone 0105E would reach land or the Mystic River Bridge and be ignited before dissipating below its lower flammable limit would appear to exceed 95 percent. For our analysis, we will simply take the probability to be 100 percent.

There is about an 85 percent probability that the vapor cloud would be ignited after reaching land, most likely along the Mystic River but possibly in some part of Chelsea or East Boston that lies near the confluence of the Mystic and Chelsea Rivers. Using an average daytime population density of

[11] *County and City Data Book 1988*, op. cit.

18,225 persons per square mile for these areas, total value of equipment and structures of $400 million per square mile, and our standard assumptions about the consequences of a vapor-cloud fire yield estimates of expected onshore consequences of 365 fatalities, 365 nonfatal burns, and $10 million in property damage.

There is about a 15 percent probability that the vapor cloud would be ignited by a vehicle on the Mystic River Bridge before reaching land. Such an event would cause relatively limited damage to a small section of the bridge. The bridge-related property-damage and delay costs are likely to be no more than 10 percent of what they are in the case of a pool fire centered under the bridge, and the injury and fatality consequences no more than 20 percent. Thus, expected bridge-related consequences are estimated to be $9.8 million in property damage and delay costs, 3.6 fatalities and 3.6 nonfatal burns.

Taking an 85/15 weighted average of the above estimates yields an estimate of non-vessel-related consequences of $10 million in property damage and delay costs, 311 fatalities, and 311 nonfatal burns. Adding the LNG tanker consequences (from Exhibit A.1) produces estimates of overall consequences for the vapor cloud scenario, exclusive of consequences to the second vessel, of $32.5 million, 317 fatalities, 323 nonfatal burns, and potential other collision-related injuries to 12 members of the LNG tanker crew.

Overall Consequences

The expected overall consequences of an LNG release resulting from a collision in Subzone 0105E are obtained by taking a 90/10 weighted average of the estimates for the pool-fire and vapor-cloud scenarios. Excluding the effects on the second vessel, the estimated consequences are about 3500 fatalities, 420 nonfatal burns, other potential injuries to 1.2 crew members, and $230 million in property damage and delay costs. It should be borne in mind that these high consequences are the expected effects of a collision that results in a release of LNG, and not those of any collision of an LNG tanker.

Groundings

An LNG vapor cloud released as the result of a grounding in Subzone 0105E has about the same probability of being ignited after reaching shore (85 percent) or after reaching the Mystic River Bridge (15 percent) as a vapor cloud released as the result of a collision. Furthermore, except for the lack of a second vessel, the expected consequences of an ignited vapor cloud are essentially the same as they are when the vapor cloud is released as a result of a collision. Accordingly, the expected consequences of an LNG release as a result of a grounding in Subzone 0105E are about 320 fatalities, 320 nonfatal burns, other potential burns to 12 crew members, and $32.5 million in property damage and delay costs.

The Lake Charles Terminal (Zone 5)

The Lake Charles LNG Terminal is located on an industrial channel about 1100 yards from the Gulf Intracoastal Waterway (GIWW), several miles southwest of Lake Charles, Louisiana. The terminal was operated in 1982 to 1984, but it was then closed because of changing market conditions. Deliveries were resumed in 1989. Receipts for 1990 are running at an annual rate of 1.5 million short tons[12].

The Lake Charles terminal is reached via the Calcasieu Pass and a one-half mile deepwater section of the GIWW. The Calcasieu Pass is a deepwater channel extending about 25 miles from the GIWW to the Gulf of Mexico and continuing southward several miles into the Gulf. The entire route from about 10 miles offshore to the Lake Charles terminal lies in Subzone 0503E, classified as a constricted waterway. Access to this subzone is via Subzone 0501A, an open approach. The expected consequences of an LNG tanker casualty in each of these two subzones are estimated below.

Subzone 0501A — Open Approach

Subzone 0501A is very similar to 0101A except that there are no offshore islands in 0501A. As in the case of Subzone 0101A, the consequences of a release in Subzone 0501A would be dominated by the effects on the LNG tanker and the effects on any other vessel involved in a collision or in igniting an LNG vapor cloud. The expected consequences in this subzone, shown in Exhibit 3.1 of the body of this paper, are estimated to be essentially the same as those in Subzone 0101A.

[12]Marine Operation and Safety, Trunkline Company, Lake Charles, Louisiana, October 1990.

Subzone 0503E — Constricted Waterway

Collisions

Collisions in Subzone 0503E are very unlikely. The onshore portion of the Calcasieu Pass allows only one-way traffic and the entire route is supposed to be cleared of other vessels when it is being used by an LNG tanker. If a collision were to occur in this subzone, it would most likely occur on the short GIWW section of the route, where control of other traffic may well be incomplete. Other possible locations for a collision are the offshore portion of the Calcasieu Pass or at a ferry crossing near the southern end of the onshore portion of the channel.

A pool fire in the GIWW section of the route would have relatively limited onshore consequences. The hamlet of Burtons Landing lies about 600 yards from one end of this half-mile long section of waterway, while the LNG terminal and several other industrial facilities lie 500 to 1100 yards from the other end. Somewhat greater consequences would be likely in the event of a pool fire located at the ferry crossing. This crossing is about 1.5 miles from the center of the town of Cameron (population 1736), but there is some development along much of the road (State Routes 27 and 82) from Cameron to the ferry landing.

The above information suggests that expected consequences of a pool fire in Subzone 0503E would be small — perhaps five fatalities, one nonfatal burn, and $500,0000 in property damage. Significant consequences to the second vessel would occur if it were a ferry, but a ferry is presumed to be the vessel <u>least</u> likely to violate the prohibition against using the channel when the LNG tanker is passing. Total expected consequences of a pool fire, exclusive of those on other vessels, are obtained by adding the above estimates to the expected consequences for the LNG tanker (from Exhibit A.1). The expected total is 35 fatalities, one nonfatal burn, and $113 million in property damage.

There is about a ten percent chance that an LNG vapor cloud released as a result of a collision in Subzone 0503E would be ignited before dissipating. The most likely ignition sources are in the vicinity of the ferry landing, along the industrial channel, or aboard a vessel on the GIWW to the east of the industrial channel. The total expected consequences of such a fire, including those on the LNG tanker (shown in Exhibit A.1) but excluding those on the second vessel involved in the collision, are about 7 fatalities, 13 nonfatal burns, other potential collision-related injuries to 12 crew members, and $23 million in property damage. Taking a 10/90 weighted average of these consequences and the expected consequences of an unignited vapor cloud (shown in Exhibit A.1) produces our estimates of the expected consequences of the vapor-cloud scenario, exclusive of those to the second vessel: 0.7 fatalities, 1.3 nonfatal burns, other potential collision-related injuries to 28 crew members, and $4.3 million in property damage.

Overall consequences of an LNG release resulting from a collision in Subzone 0503E, excluding those on the second vessel, are estimated by taking a 90/10 weighted average of the pool-fire and vapor-cloud consequences. The resulting estimates are: 32 fatalities, one nonfatal burn, other potential collision-related injuries to 2.8 crew members, and about $100 million in property damage.

Groundings

Groundings in Subzone 0503E are considered very unlikely to result in an LNG release because the channel is soft mud. Should a release occur, there is less than a ten percent probability that it would occur within a mile of any area containing ignition sources, and if it occurred in such an area, there is still only a small probability of actual ignition. Overall, the probability of ignition is on the order of one percent, the same as for Subzone 0501A. A vapor-cloud fire in Subzone 0503E would produce a modest amount of onshore damage, and so the expected onshore and LNG-tanker-related consequences of a release due to a grounding in this subzone are very slightly greater than they are for Subzone 0501A. We estimate these consequences to be about 0.07 fatalities, 0.13 nonfatal burns, potential grounding-related injuries to 29.82 other crew members, and $2.5 million in property damage.

Jetty Rammings

The first mile-and-a-half of the offshore portion of Subzone 0503E is protected on both sides by jetties, but it appears that shallow water adjacent to these jetties makes a direct ramming impossible. The consequences of a release due to such a ramming, were it to occur, would be essentially the same as those of a collision in Subzone 0501A (the previous subzone), except for the lack of involvement of a second vessel.

Cove Point (Zones 8 and 9)

The Columbia Gas LNG terminal is located in deep water off Cove Point, Maryland, on the west shore of the Chesapeake Bay. The terminal is about four miles north of the mouth of the Patuxent River and a similar distance southeast of the Calvert Cliffs Nuclear Power Plant. The terminal received LNG between 1978 and 1980 but was then shut down because of a dispute with the gas supplier and changes in the natural gas market. Columbia Gas now expects to reopen the terminal in 1992.

To reach Cove Point, tankers pass through three subzones of the Chesapeake South Zone (Zone 5) and one subzone (0901C) of Chesapeake North. The Chesapeake Bay Bridge-Tunnel forms the boundary between two of the Chesapeake South subzones (0802B and 0803C). The potential costs of an LNG release in the vicinity of the bridge-tunnel are appreciably greater than those elsewhere within these two subzones, and the probability is relatively high that a release occurring in either of these subzones actually would occur in the vicinity of the bridge-tunnel. However, TSC has better data than we do on this probability[13]. Accordingly, we have chosen to analyze the area surrounding the bridge-tunnel as if it were a separate subzone, allowing TSC the opportunity to combine the resulting estimates with those obtained for Subzones 0802B and 0803C using appropriately weighted averages.

Subzone 0801A - Open Approach

Any release in Subzone 0801A is likely to be sufficiently far offshore to present only a negligible hazard to land. Accordingly, the expected consequences of an LNG release in this subzone are the same as they are for Subzone 0101A.

Subzone 0802B - Convergence

Separating the area surrounding the Chesapeake Bay Bridge-Tunnel from Subzone 0802B (as discussed above) leaves a subzone in which any LNG release is likely to pose a negligible hazard to land. Accordingly, the expected consequences of an LNG release in this subzone are the same as they are for Subzones 0101A and 0801A.

---

[13]It should be noted that the bridge-tunnel subzone has the characteristics of a constricted waterway. Hence, vessels are likely to be traveling more slowly in this subzone than in 0802B and 0803C, and the probability that a collision or grounding would result in an LNG release is appreciably smaller than it is in the adjoining subzones. (Compare the Exhibit 1.1 probabilities shown for "piers and harbors" with those shown for "coastal waters.")

The Chesapeake Bay Bridge Tunnel

The Chesapeake Channel passes between two artificial islands spaced about 1.25 miles apart. The channel itself is about half a mile wide. LNG tankers heading for Cove Point and other vessels heading up the Bay use this channel, while those bound for the Hampton roads area use the more southerly Thimble Shoal Channel.

Highway vehicles using the Chesapeake Bay Bridge-Tunnel (CBBT) pass under both channels in tunnels, entering each channel at an island and leaving it at a second island. Thus, the bridge-tunnel actually consists of a set of three bridges and two tunnels. Their total length, from shore to shore, is about 17.5 miles.

The entire system is currently being "twinned" at an estimated cost of $2 billion; i.e., a second set of bridges and tunnels is being constructed in order to increase capacity. The entrances to the new tunnels will be 250 to 300 feet from the entrances to the existing tunnels. The second bridge-tunnel route is expected to be in operation within four years. For purposes of analysis, we consider only the case of casualties occurring after this second route is in use.

Because of shallow water in the vicinity of the bridges, rammings by deep draft vessels appear to be impossible. Thus, the only types of casualties in the CBBT Subzone to be considered are collisions and groundings.

Collisions

Pool-Fire Scenario

A collision in the CBBT Subzone is not likely to be much less than three-quarters of a mile from either end of the two tunnels under the Chesapeake Channel. At this distance, a pool fire is not likely to cause any significant structural damage to the bridges or tunnels, but there is some possibility that pavement damage would be sufficient to cause the short-term closure of one or both bridge-tunnel routes. More importantly, at this distance, vehicles and their occupants entering or leaving the tunnel would likely be burned.

Average daily traffic in the CBBT Subzone is 12,000 vehicles per day and the speed limit is 45 miles per hour. Assuming that LNG tankers pass through the channel only during daylight hours, the expected traffic volume at the time of a casualty would be about 750 vehicles per hour, and the density of vehicles would be about 16.7 per mile. For each roadway, we assume that all vehicles on a 1.5 mile stretch of road at the time of ignition are affected, primarily because these vehicles are unable to stop before reaching an area of intense heat; and we further assume that all other vehicles are unaffected. Then the expected number of affected vehicles is 25. Assuming an average of two occupants per vehicle and a 50 percent fatality rate yields estimates of 25 deaths and 25 nonfatal burns. An average property loss of $10,000 per vehicle produces an estimate of $250,000 in property damage.

The fire is likely to result in the temporary closing of the entrances to both tunnels, followed by a gradual reopening of the tunnels, one lane at a time. We estimate resulting delays by assuming average delays of six hours for one day after the collision, one hour for the next week, and 30 minutes for the next two weeks. With these assumptions, total expected delay is expected to be 240,000 hours. Multiplying by $12 per vehicle-hour produces an estimate of $2.4 million in delay costs.

Assuming $1 million in bridge and tunnel repair costs and adding the above estimate to our estimates of LNG tanker consequences in Exhibit A.1 produces our estimates of the overall consequences of a pool fire, excluding those to the second vessel, of: 55 fatalities, 25 nonfatal burns, and $116 million in property damage and delays.

Vapor-Cloud Scenario

A vapor cloud released three-quarters of a mile from a tunnel entrance has a relatively small probability, perhaps five percent, of both spreading toward the tunnel entrance and reaching the entrance or an adjoining section of road before the LNG vapor concentration drops below the lower flammability limit. If the tunnel entrance or an adjoining section of roadway is reached, ignition is likely. The consequences of such a vapor-cloud fire would be appreciably less severe than those of a pool fire. We estimate the consequences, excluding those on the second vessel, to be: 16 fatalities, 22 nonfatal burns, other potential collision-related injuries to 12 crew members, and $23 million in property damage and delay costs.

Taking a 95/5 weighted average of the consequences of no fire (from Exhibit A.1) and those of a vapor-cloud fire gives us our estimate of the expected consequences, excluding those of the second vessel, of a collision resulting in the release of a vapor cloud: 0.8 fatalities, 1.1 nonfatal burns, other potential collision-related injuries to 29.1 crew members, and $3.3 million in property damage and delay costs.

Overall Consequences

The expected overall consequences of an LNG release resulting from a collision in the CBBT Subzone are obtained by taking a 90/10 weighted average of the estimates for the pool-fire and vapor-cloud scenarios. Excluding the effects on the second vessel, the estimated consequences are about 50 fatalities, 23 nonfatal burns, other potential collision-related injuries to 2.85 crew members, and $105 million in property damage and delay costs.

Groundings

An LNG vapor cloud released as a result of a grounding in the CBBT Subzone is likely to be released closer to a tunnel entrance than one released as a result of a collision, and so is more likely to be ignited. Using a ten percent probability of ignition and other information from the estimates of the consequences of a vapor cloud produced by a collision, we estimate the expected consequences of an LNG release due to a grounding in the CBBT Subzone to be: 1.6 fatalities, 2.2 nonfatal burns, other potential collision-related injuries to 28.2 crew members, and $4.3 million in property damage and delay costs.

Subzone 0803C - Bay

Subzone 0803C consists of the southern end of Chesapeake Bay. This portion of the bay is nearly 15 miles wide at its narrowest point. For reasons discussed above, we have excluded the area surrounding the Chesapeake Bay Bridge-Tunnel from this subzone.

Collisions in Subzone 0803C would almost certainly occur too far from land to have any effect on land. Accordingly, the expected consequences of an LNG release resulting from a collision in this subzone are the same as for the open approach and convergence subzones addressed previously.

In general, groundings in this subzone are also likely to occur too far from land to result in a vapor cloud being ignited over land. There is, however, a small portion of the Eastern Shore, near the southern end of Cape Charles, that will allow groundings within one mile of shore. The probability that a grounding would occur here and that a resulting vapor cloud would reach land and be ignited before the LNG concentration drops below its lower flammable limit is no greater than one percent. A vapor-cloud fire in this area could affect the bayshore communities of Cape Charles (population 1512) or Silver Beach, but is most likely to occur at a much more sparsely developed location along the coastline. In addition, there is the possibility of ignition by another vessel, which we take to be two percent. Taking a 97/3 weighted average of the expected effects on the LNG tanker of no ignition or a vapor-cloud fire, and adding one percent of an estimate of the expected consequences of a fire on the Eastern Shore, produces estimated consequences of a release due to a grounding in Subzone 0803C of about 0.2 fatalities, 0.4 nonfatal burns, other potential grounding-related injuries to 29.5 crew members, and $2.9 million in property damage.

Subzone 0901C - Bay

Subzone 0901C consists of the central portion of the Chesapeake Bay, extending north as far as Annapolis. Cove Point is on the western shore of the bay, not quite at the midpoint of the zone, so LNG tankers need only negotiate the southern half of this zone. In this zone, the bay is generally narrower than in 0803C, with the portion traversed by LNG tankers narrowing to about six miles at Cove Point, the narrowest stretch in the southern half of the zone.

Collisions in Subzone 0901C would almost certainly occur too far from land to have any effect on land. Accordingly, the expected consequences of an LNG release resulting from a collision in this subzone are the same as for the open approach and convergence subzones addressed previously.

Groundings are also likely to occur too far from land to have any affect on land. There is some possibility of a grounding off Cedar Point, on the western shore of the bay about five miles south of Cove Point. However, prevailing westerlies make it unlikely that a vapor cloud released off Cedar Point would actually encounter land. An LNG vapor cloud in Subzone 0901C is thus likely to be ignited only if it encounters another vessel. Assuming the probability of such an event is about two percent produces estimates of expected consequences that are the same as those for Subzone 0102B (in the Boston Zone): 0.12 fatalities, 0.24 nonfatal burns, potential grounding-related injuries to 29.64 other crew members, and $2.7 million in property damage.

APPENDIX B

EXPECTED CONSEQUENCES OF AN LPG RELEASE BY SUBZONE TYPE

Our estimates of the consequences of an LPG release are developed for the case of an instantaneous release of one 18,750 cubic-meter tank of LPG aboard a 75,000 cubic-meter LPG tanker. As in the case of LNG, we assume that, even if ignited, no additional LPG tanks are ruptured. Since, when ignited, LPG produces a true explosion, we are somewhat less comfortable with this assumption than in the case of LNG. However, the limited information available does not give us any basis for assuming the rupture of additional tanks.

Consequences for the LPG Tanker and Its Crew

The average cost of a new 75,000 cubic-meter LPG tanker is about $75 million (appreciably less than the cost of a large LNG tanker) and that of a similar three-year-old tanker is $58 million[1]. A typical crew is only about 25 persons (instead of 30 for an LNG tanker). For these reasons, the consequences of a release for an LPG tanker and its crew are appreciably lower than they are for an LNG tanker. Our estimates of expected consequences are presented in Exhibit B.1 and discussed below.

Immediate ignition of LPG would generally result in an explosion that would cause extensive damage to the tanker and would likely kill the entire 25-person crew. Our estimate of $45 million in property damage represents 60 percent of the value of a new vessel and 78 percent of the value of a three-year-old vessel.

Delayed ignition of the vapor pool released by an LPG tanker also would generally result in an explosion. However, in the case of delayed ignition, the tanker is likely to be near the periphery of the vapor pool, or possibly outside of the pool, and so may well incur less damage; and the crew may have had time to abandon ship. Accordingly, as shown in Exhibit B.1, the expected consequences of delayed ignition are estimated to be appreciably lower than those of immediate ignition.

Finally, as in the case of an LNG release, an LPG release that is not ignited is assumed to be accompanied by property damage equaling one percent of the value of a new vessel.

---

[1] *Lloyd's Shipping Economist*, Volume 12, July 1990, p. 35.

EXHIBIT B.1

EXPECTED CONSEQUENCES FOR THE LPG TANKER AND ITS CREW OF A CASUALTY RESULTING IN A RELEASE FROM A 75,000 CUBIC-METER TANKER

Scenario	Property Damage (millions of dollars)	Fatalities	Nonfatal Burns	Other Crew Members
Immediate Ignition	$ 45	25	--	--
Delayed Ignition	30	12	3	10
No Fire	0.75	--	--	25

Consequences by Subzone Type

Estimates of the total expected consequences of an LPG release, exclusive of the consequences to any other vessels involved, are developed below by subzone type. Separate estimates are developed for collisions and groundings. The estimates for collisions should also be used for rammings. (They are appropriate for the ramming of a dredge or a disabled vessel, though they might be slightly low for the ramming of a bridge.)

A summary of the expected consequences is presented in Exhibit 4.1 in the body of this paper.

Subzone Type A - Open Approach

An LPG release due to a collision has a ninety percent probability of immediate ignition. In a Type A subzone, there is little probability of such ignition affecting any land area or a vessel not involved in the collision; and, in the absence of immediate ignition, there is an insignificant probability of subsequent ignition. Accordingly, the expected consequences of a collision in Type A subzones are obtained by taking a 90/10 weighted average of the expected consequences to the tanker and its crew of immediate ignition or no ignition. Excluding the effect on the second vessel, the expected consequences are: 22.5 fatalities, potential collision-related injuries to 2.5 crew members, and about $41 million in property damage.

An LPG release due to a grounding in a subzone of Type A has, perhaps, a one percent probability of being ignited by another vessel and a 99 percent probability of not being ignited. Excluding the effects on the second vessel, the expected consequences are obtained by taking a 99/1 weighted average of the consequences to the tanker and its crew of no ignition or delayed ignition. The resulting estimates are: 0.12 fatalities, 0.03 nonfatal burns, potential grounding-related injuries to 22.85 other crew members, and about $1 million in property damage.

Subzone Type B - Convergence

In general, Type B subzones differ from Type A subzones only in that there is a somewhat greater probability of delayed ignition occurring as the result of contact between the vapor pool and a nearby vessel or an offshore island. The result is an insignificant increase (relative to Type A subzones) in the expected consequences of an release due to a collision, and a slight increase in the expected consequences of a release due to a grounding. The expected consequences of the latter event are estimated by assuming a two percent probability of delayed ignition, most likely due to a second vessel, and taking a 98/2 weighted average of the consequences of no ignition or delayed ignition. Excluding the effects on the second vessel, the resulting estimates are: 0.24 fatalities, 0.06 nonfatal burns, potential grounding-related injuries to 22.7 other crew members, and about $1.1 million in property damage.

Somewhat greater consequences would occur in the immediate vicinity of the Chesapeake Bay Bridge-Tunnel, a portion of Subzones 0802B and 0803C that has the characteristics of a constricted waterway. The consequences of an LPG release in the vicinity of the bridge-tunnel probably would be in between the expected consequences estimated for subzones of Types B and C and those estimated for subzones of Type E (constricted waterways). If convenient, it would be reasonable to treat this area as a separate subzone, classified as a constricted waterway; however, within the accuracy of our analysis, it is also quite reasonable to treat this area as belonging to Subzones 0802B and 0803C.

Subzone Type C - Open Harbor or Bay

In most cases, the consequences of a release in a Type C subzone is very similar to those of a release in a Type B subzone. However, in some cases (*e.g.*, 1103C and 1106C in New York City, 0205C in Puget Sound and 0803C in Chesapeake South) there is some small probability of affecting a populated area -- either from the heat of an explosion near the shore or as a source of delayed ignition of a vapor pool. However, even in subzones where significant onshore involvement is possible, it is relatively unlikely. Except in Subzone 1106C, collisions are most likely to occur far enough from land to produce few if any onshore consequences, and groundings are likely to occur far enough from shore to minimize the probability of onshore ignition. Accordingly, we estimate the expected consequences of a release in a Type C subzone to be only slightly greater than a release in a Type B subzone: for a collision, 25 fatalities, one nonfatal burn, other potential collision-related injuries to 2.5 crew members, and $42 million in property damage; and, for a grounding, 0.5 fatalities, 0.1 nonfatal burns, other potential grounding-related injuries to 22.6 crew members, and $1.2 million in property damage.

Subzone Type D - Enclosed Harbor

Most of the enclosed harbors traversed by LPG tankers are small enough to present significant probability of onshore consequences in the event of an LPG release. However, the average density of development in the potentially affected areas of these subzones is much lower than it is in Subzone 0104D (Boston's Inner Harbor). Presuming average onshore consequences of LPG releases in these subzones to be about ten percent of the consequences in Subzone 0104D, the expected onshore consequences of immediate ignition would be 402 fatalities, 45 nonfatal burns, and property damage of $17.5 million; and the expected onshore consequences of delayed ignition would be 30 fatalities, 30 nonfatal burns, and property damage of $1.25 million.

For a collision, there is a 90 percent probability of immediate ignition and, for LPG, perhaps a five percent probability of delayed ignition and an equal probability of ignition. Combining the above estimates with the estimated consequences for the vessel and its crew (from Exhibit B.1) and taking a 90/5/5 weighted average of the consequences of the three alternative outcomes, produces our estimates of expected consequences, excluding those to the second vessel, of an LPG release due to a collision in a subzone of Type D: 390 fatalities, 42 nonfatal burns, potential collision-related injuries to 1.75 other crew members, and $58 million in property damage.

For groundings, we estimate the probability of delayed ignition of the LPG vapor pool to be about 50 percent. Combining the above estimates of onshore consequences of delayed ignition with the estimates of consequences for the tanker and its crew of delayed ignition or no ignition, and taking a 50/50 average of the consequences of these two possible outcomes, produces our estimates of the expected consequences of an LPG release due to a grounding in a subzone of Type D: 21 fatalities, 17 nonfatal burns, potential grounding-related injuries to 17.5 other crew members, and $16 million in property damage.

Subzone Type E - Constricted Waterway

The constricted waterway subzones through which LPG tankers pass present an extreme range of onshore consequences, from negligible in Subzones 0602E (New Orleans) and 2002E (Wilmington, NC) to very high in 0805E (Portsmouth and Norfolk, VA). Overall, the expected onshore consequences and hazards are probably about half what they are for a subzone of Type D. The estimates of expected overall consequences shown in Exhibit 4.1 for Type E subzones are adapted from those for Type D subzones accordingly.

Subzone Type F - River

There appear to be only four subzones of Type F through which LPG tankers travel (0603F, 1004F, 1304F and 2003F). These four subzones present a set of onshore conditions that is only slightly less diverse than those presented by the larger collection of subzones of Type E. Onshore consequences and hazards for Type F subzones range from slight in Subzone 2003F (Wilmington) to high in Subzone 1304F (Philadelphia). Overall, the expected consequences are taken to be the same as those for Type E subzones.

SECTION 9.

INTEGRATED MODEL FOR PROJECTING VTS AVOIDED VESSEL CASUALTIES, CONSEQUENCES, LOSSES, BENEFITS AND VTS COSTS

Prepared By:

Philip Howells (UNISYS)
Philip Pitha (UNISYS)
The U.S. Department of Transportation,
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142
July 1991

9. INTEGRATED MODEL FOR PROJECTING VTS AVOIDED VESSEL CASUALTIES, CONSEQUENCES, LOSSES, BENEFITS AND VTS COSTS

NOTE: This section documents Philip Howells' and Philip Pitha's (UNISYS) efforts in support of the Port Needs Study (Volume I).

SECTION 9. TABLE OF CONTENTS

Section | Page

LIST OF ILLUSTRATIONS

9 Port Needs Study Integrated Model Description

9.1 Introduction

The integrated model was conceived as central data processing system for the port needs study. This function pulls together the data and algorithms produced by all the other tasks in a single system. This concept allows for quicker response to changes, traceability on how the results were produced and systematization of the process for producing the study results.

9.2 Functional Description

The model calculates the probability of vessel casualties, from historical and physical parameters of the ports. Given the probability of a casualty, the model calculates the probability of the results of the casualties and assigns economic values to those results. These calculations are made directly for the casualties predicted to be averted through the use of a VTS system. The economic value of the averted casualties, benefits, are then compared with the cost of installation of a VTS system giving the cost benefit analysis.

The flow diagram shown in Figure 1 illustrates the major data inputs, processing algorithms and output of the integrated model. The processes shown as input to the model represent the output of the other major tasks in the port needs study. The major operations performed by the integrated model are described later in this section :

Vessel Traffic Processing
Avoided Casualty Projection
Projection of Consequences
Assignment of Values to the Consequences
Net Benefit Calculation
Benefit Cost Relationships
Sensitivity Analysis

9.2.1 Vessel Traffic Processing

Data to be transformed into projected vessel traffic for the study comes into the integrated model in two forms. The first is cargo vessel data, which has vessel transit values projected at five year

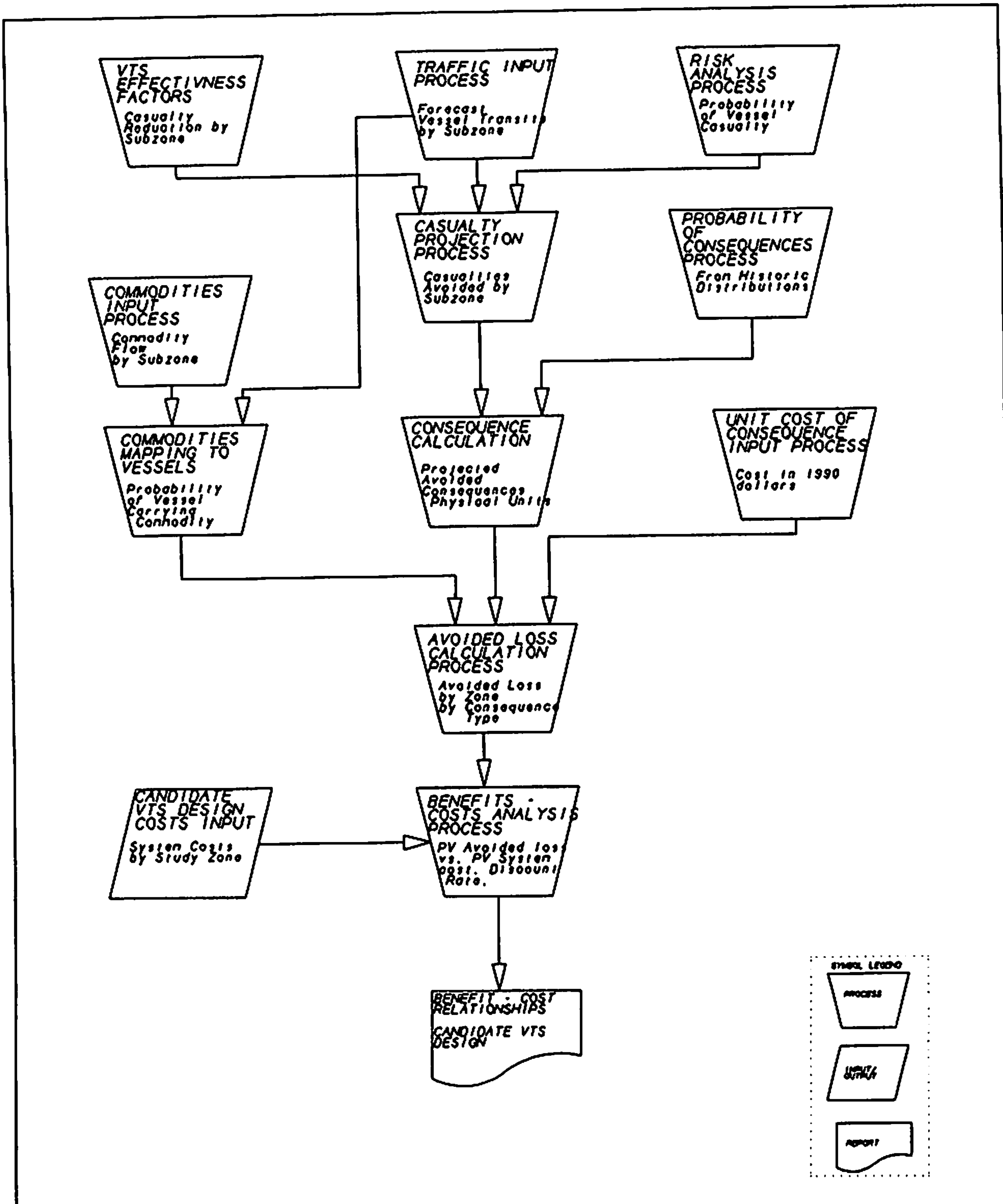


Figure 1 Top Level Data Flow Diagram.

intervals through the study period. This data was projected from the base year data through economic forecasting methods. The second is passenger vessel data for the year 1990 which was obtained through a port by port survey of passenger carriers. Both these sources are transformed by the model into annual transits for each year of the study these figures detailed by vessel type, vessel size and subzone location. With the data in this format the rest of the calculation process may proceed.

The projected vessel traffic processing is illustrated in Figure 2, Figure 3. The cargo vessel traffic projections as received are based upon Army Corps of Engineers (COE) data. This data is gathered at arrival/departure points within the study zones. This vessel data has been forecasted in accordance with the economic forecasts for the ports involved. These economic forecasts are available in five year increments and thus the vessel traffic has also been projected in these five year increments.

The first step is to eliminate any double counting of vessels. Some of the COE data collection points include vessel passing through the area destined for other locations in the study zone. This transiting "daughter" traffic is first subtracted from the data for the data collection points that are passed through ("mother").

Second, the barges are teamed up with tow boats to form tows. In many areas a towboat may propel more than one barge which is accomplished through the use of tow factors established for the COE data collection points. The tow boat transits are reduced by the number of tows. The resulting counts of tow boat transits represent movements without barges in tow, not the number of towboats in the study area.

The cargo vessel data is then interpolated to supply transit data for the intervening years. This is necessary in order to produce an annual stream of figures for later analysis.

Incoming passenger vessel data is processed differently. The base year transits are projected using the Coast Guard estimates of the population growth in the study zone areas. Passenger vessel traffic is considered to be directly proportional to the population of the area. Another difference is that the passenger vessel data is not gathered on the basis of COE data collection points. Ferry and charter transits are gathered according to the study subzone location of their operating area. Only cruise ships can generally be associated with COE data collection points; however, the growth in transits is still associated with population growth.

After the cruise ship data has been combined with the cargo ship data the vessel transits are assigned to the subzones (Figure 2, Figure 3). Each COE data collection point has been assigned a route and in some cases two routes [1]. Data has been gathered in great detail on these routes, however the

[1] Generally, the second route is for smaller vessels and barges that do not travel on the open ocean.

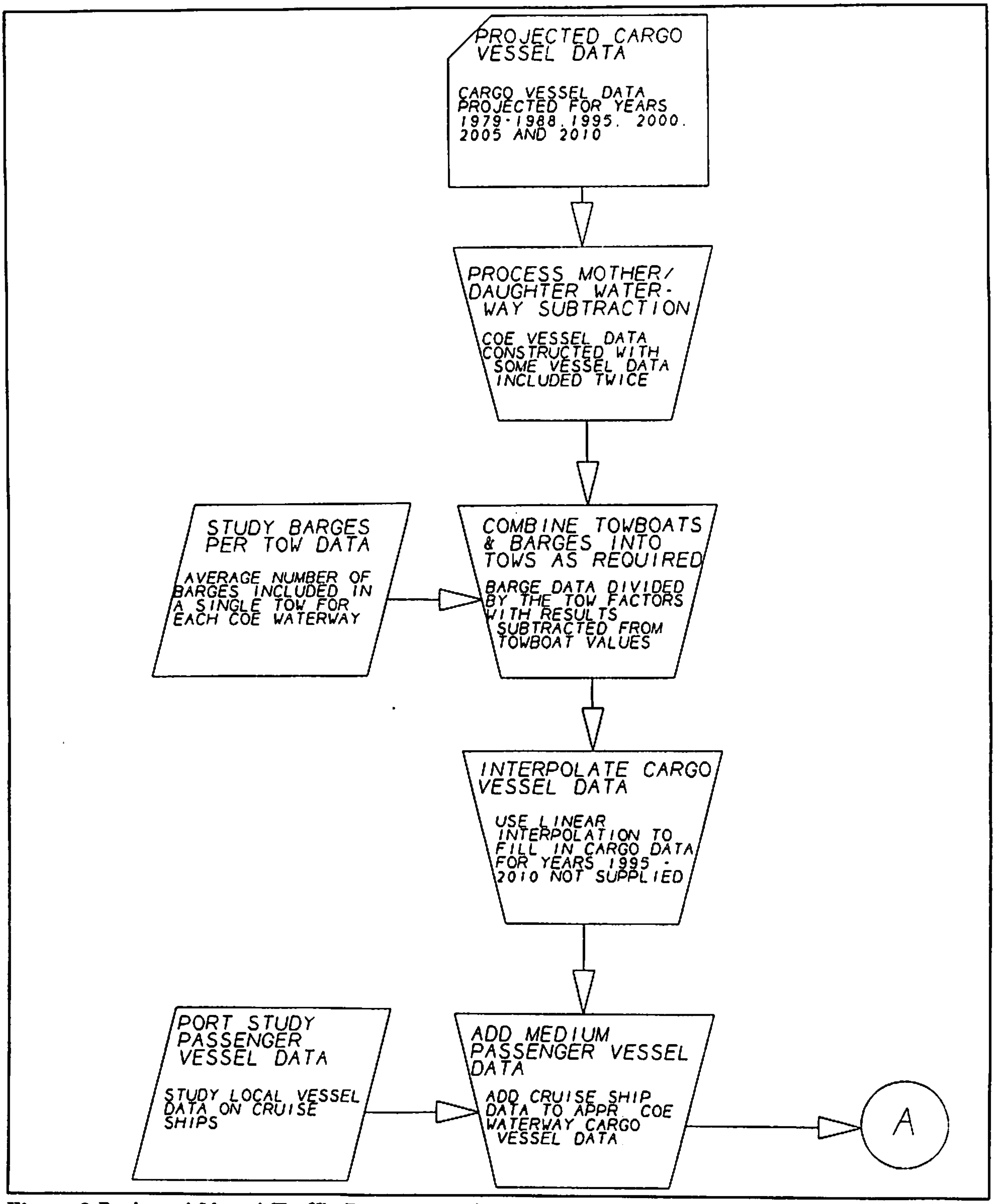


Figure 2 Projected Vessel Traffic Data Processing (part 1)

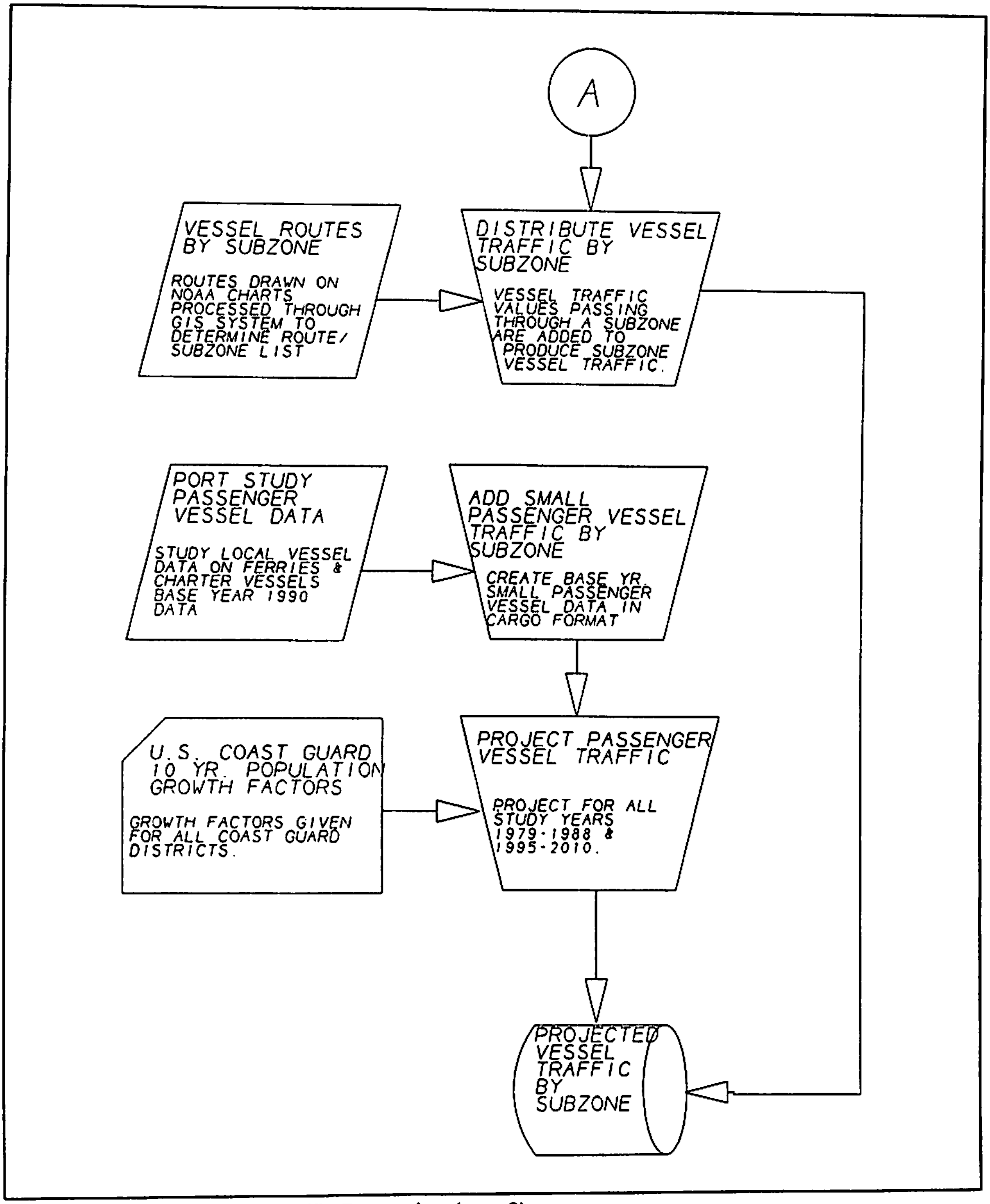


Figure 3 Projected Vessel Traffic Processing (part 2)

only significance of the routes in this case is to designate which subzone areas the route passes through. This is how vessel transits are assigned to subzones.

Small passenger vessel transits (ferries and charter boats) are now added to the data by subzone as appropriate. At which point all passenger vessel transit counts are grown according to the population growth figures for the study area.

This processing results in vessel transits by subzone, year, vessel type and vessel size.

9.2.2 Avoided Casualty Projection

Figure 4 illustrates the process of computing projected avoided casualties. One of the inputs to the model are the risk probability values. These values are the results of the risk analysis task and have the dimensions of number of casualties per 100,000 vessel transits. These numbers are used by the model as the expected future casualty rates for the various subzones for all the years in the port needs study. Casualties are categorized into three basic categories in the integrated model collision, ramming and grounding. The risk probability values are detailed by subzone, casualty type, vessel type and vessel size. These values when applied to the vessel traffic result in expected casualties with no VTS system in place[2].

Another input is the estimated effectiveness of VTS systems, for both the candidate and existing systems in various ports around the U.S. The effectiveness is measured as a percentage factor by which the VTS system in question would reduce the expected casualties in a given area. The different levels of VTS systems were assigned different effectiveness values. This was done for both the candidate and existing systems.

For the proposed candidate VTS systems, a certain coverage of each subzone can be defined over which they would be effective. A similar coverage mapping for the existing VTS systems can also be made. This further extends to the period of time a VTS system is (or will be) in operation. The coverage further modifies the effectiveness of VTS systems in reducing expected casualties.

From these factors, the projected avoided casualties through the use of VTS systems was calculated. Two distinct scenarios were projected: continuing with the existing VTS systems in the ports where they are currently installed and functioning, and implementing the candidate VTS systems in all study ports, at the levels defined. For each scenario, the projected avoided casualties represents the number of casualties that the given VTS system would prevent.

---

[2] The risk values have been determined with the effects of existing VTS systems mathematically removed.

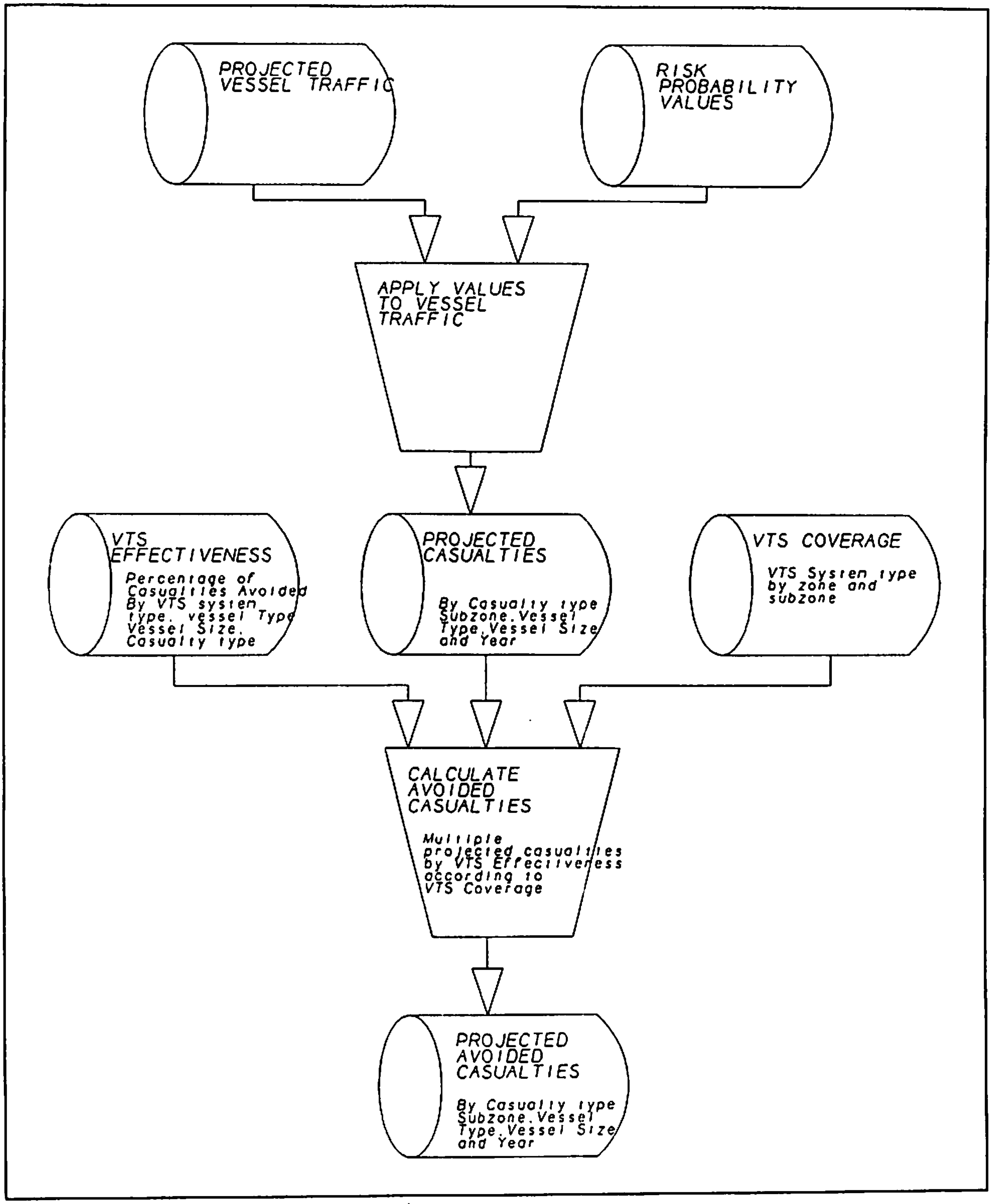


Figure 4 Projection of Avoided Casualties

9.2.3 Projection of Consequences

Figure 5 shows the process for projecting avoided consequences of casualties. In general, consequences arising from vessel casualties can be categorized: for example, vessel damage, human injury, hazardous spill. Each consequence type has a certain probability of occurring. Furthermore, consequences occur at different severity levels. In the integrated model, we have distinguished between four different severity levels for most consequence types: catastrophic, severe, moderate, and light.

In addition to the historical casualty data on the consequences of historical casualties was also gathered. From this data, a probability of consequence was determined for each consequence type. Where there was sufficient data, a different probability for each combination of vessel type, size, and casualty type was calculated. For some consequences, however, there were not enough observations to justify such detail. In these cases, the probability was determined for aggregates of vessel and casualty classifications.

Spills of hazardous materials represented a special case, since there was no direct historical data on spills. A surrogate measure of spill was the number of casualties involving both vessel damage and cargo loss. It was believed that this number under counted the actual rate of spills by as much as a factor of 3, due to under counting of the cargo loss data. To compensate for this, a factor of 3 was applied to the number of cargo loss incidents and thus to the surrogate measure, and this was used as the probability of hazardous spill.

The historical data held similar information about the severity of each consequence. In a separate analysis, the distribution of severities for each consequence type was calculated from this data. For most consequence types, the variations due to vessel type, size, and casualty type were ignored. The distribution of severities was expressed as a percentage - for example, 30% of all vessel damage might be expected to be severe.

The number of avoided consequences, for each consequence type and severity level, could now be calculated from the number of avoided casualties. This was done by multiplying the number of avoided casualties by the probability of a consequence occurring (for each consequence type), which was then multiplied by the distribution of severity for each severity level.

9.2.4 Assignment of Values to Consequences

Each consequence avoided in the above section has a value or cost. Cost assignment to consequences by severity is straightforward in many cases, such as human injury. Other consequences, such as vessel

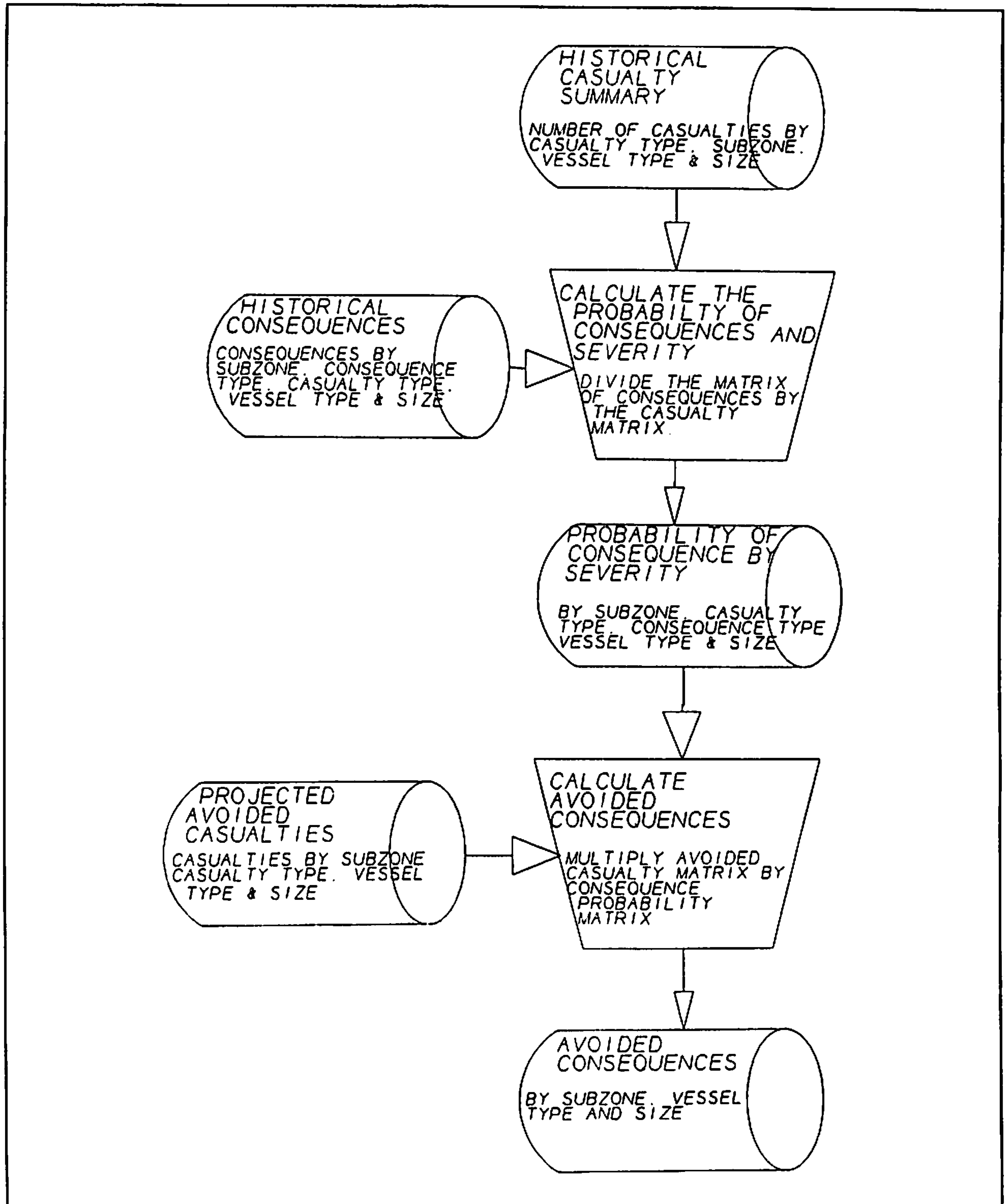


Figure 5 Projection of Avoided Consequences

damage, require additional information such as the type and size of vessel. Assigning costs to the consequences of a cargo spill requires a complex algorithm. See Figure 6.

Cargo spill casualties are rare events, thus the probability of a cargo spill is calculated on a highly aggregated basis. For a given casualty, only the probability of spillage is given; however, the cost of the consequences is highly dependent on what commodity is spilled. The probability of spillage must be combined with the probability of the vessel carrying various environmentally dangerous commodities. Also, non-environmentally dangerous and dangerous commodities are assessed values for the cost of the cargo.

The third category of "cargo" loss is fuel spillage in the event of a casualty. This fuel loss is treated the same as a cargo loss of the appropriate commodity.

This results in three broad categories of avoided losses due to projected consequences. These are avoided simple losses, avoided environmental losses and avoided cargo losses.

9.2.5 Benefit Calculation

The benefits are determined by adding up the avoided loss values for each year, taking the present value as of the begining of FY1993 and then adding the present value results together for a benefit. The benefits may be split into various categories or aggregated in various ways without affecting the accuracy of the calculation. The primary benefit result from the integrated model is the total benefit accruing for an entire study zone.

9.2.6 Benefit Cost Relationships

This benefit is then compared to the present value of the VTS costs on a study zone basis. The net benefit is the difference between the benefit and the present value of the VTS costs.

9.2.7 Senstivity Analysis

How dependent the results of the study are on the accuracy of the input data to the model is the subject of sensitivity analysis. Broad sensitivity factors are introduced that will scale an input such as vessel traffic up or down. The degree to which this affects the final benefit-cost relationships is a measure of the sensitivity to the input data.

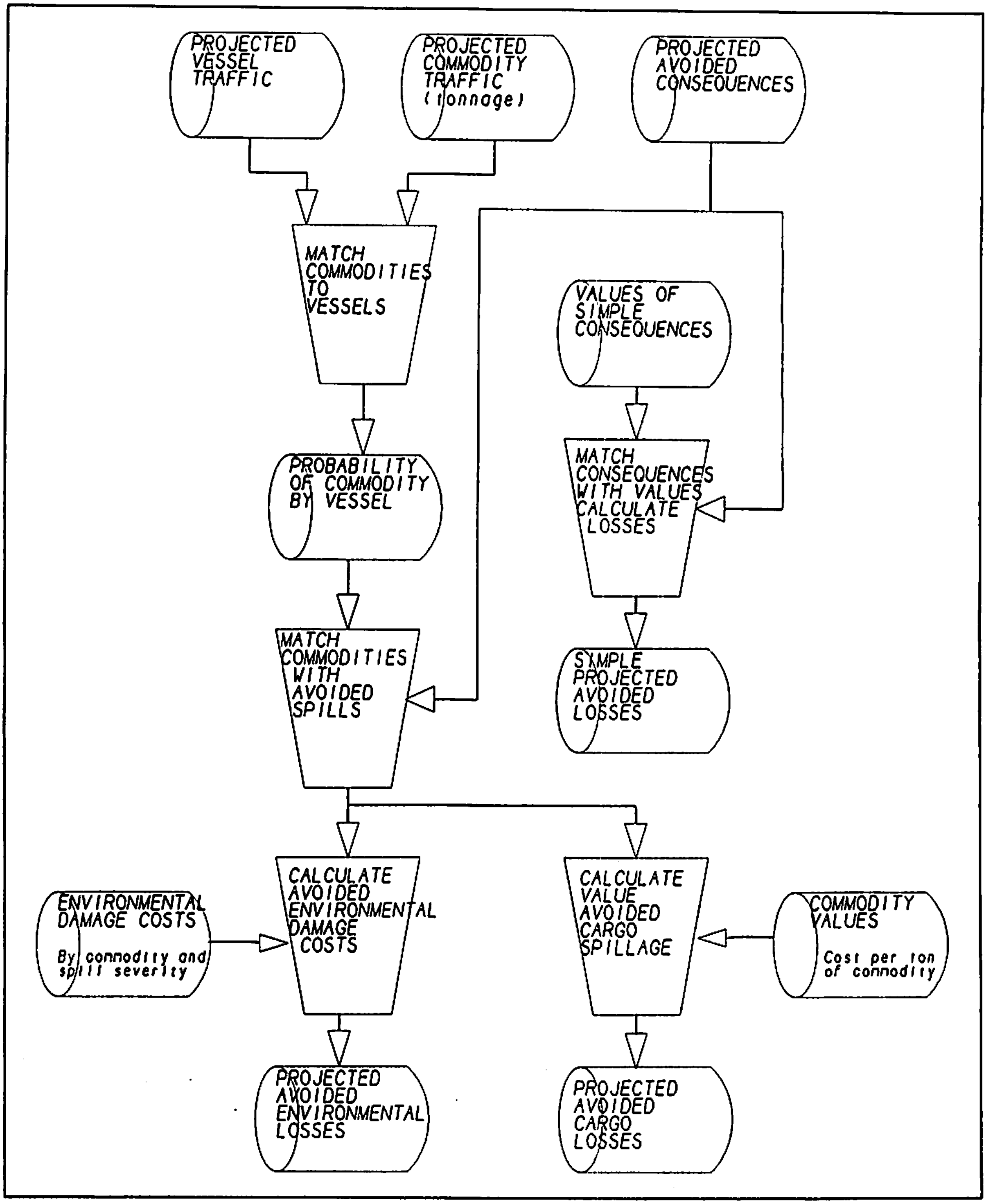


Figure 6 Assignment of Costs of Consequences for Hazardous Spills.

9.3 Integrated Model Processing Function

9.3.1 Description

The Port Needs Study integrated model processes data through a matrix multiplication technique. This process is documented in the following pages.

9.3.2 Main Processing Function

The first element considered is the vessel traffic. Vessel traffic has been projected from the base year data for all the study period years by means outside of the integrated model. The number of ships passing through a subzone has been determined by vessel type, size and year. Not all types of vessels are present in all the study areas and not all sizes of vessels exist. The existing vessel types and sizes are shown in the following table marked with an 'X'.

Vessel Type	Large	Medium	Small
Passenger	-	X	X
Dry Cargo, Fishing and Other	X	X	X
Tanker	X	X	X
Dry Cargo Barge Tow	X	-	X
Tanker Barge Tow	X	-	X
Tow/Tug Boat	-	-	X

This leaves a net result of 13 vessel size and type combinations in the vessel traffic matrix. The vessel traffic consists of a value given for each vessel type and size for each study subzone for each year of the study leading to a maximum possible 19,305 values in the matrix for the 15 years.

$$TRF_{P_{zsy}} = VesselTraffic$$

(1) Vessel Traffic Matrix

The next element to consider is the probability of vessel casualty which takes the mathematical form of a rate per vessel transit. These probabilities have been established outside the integrated model, using risk analysis of historical observations, for each sub<z>one, vessel <t>ype, vessel <s>ize and <y>ear. These rates are also established for the three major types of vessel casualties being considered by the study. This leads to a matrix of 3,861 values.

$$RSK_{ztsc} = Risk\ Probability\ Value$$

(2) Risk Probability matrix .

The matrix of risk probability values is then multiplied by the vessel traffic matrix to produce a matrix of expected vessel casualties. This casualty matrix is by for each subzone, vessel type, vessel size, <c>asualty type and year.

$$CAS_{P_{tscy}} = TRF_{P_{tsy}}\ X\ RSK_{ztsc}$$

(3) <P>rojected Vessel Casualty equation

The effectiveness of both the candidate VTS system and the existing VTS systems for preventing vessel casualties have been established . These values have been determined as a percentage reduction in the numbers of casualties given a VTS system in place.

$$EFF_{C_{tsc}} = Candidate\ VTS\ Effectivness$$
$$EFF_{E_{tsyc}} = Existing\ VTS\ Effectivness$$

(4) VTS Effectiveness matrices for <C>andidate and <E>xisting Systems.

These values have been utilized in two ways. First to determine what the numbers of historical casualties would have been, for areas where a VTS system was in operation during the study's casualty base period, if there were no VTS system. This is the casualty "Base Case". The base case casualties were used to determine the risk values in equation (2) used in equation (3). The projected casualties are therefore the "No VTS" casualty values.

These are the casualties used to produce the risk probability values defined earlier in a process outside this model.

$$CAS_{B_{zscy}} = \frac{CAS_{H_{zscy}}}{(1 - EFF_{E_{zscy}})}$$

(5) <B>ase Case Casualty calculation from <H>istorical Casualties.

The avoided casualties are determined by multiplying the projected casualties (Equation (3)) by the effectiveness of the candidate VTS System or the existing VTS System.

$$CAS_{AC_{zscy}} = CAS_{P_{zscy}} \; X \; EFF_{C_{zsc}}$$

(6) <A>voided Casualty Calculation Candidate VTS System.

$$CAS_{AE_{zscy}} = CAS_{P_{zscy}} \; X \; EFF_{E_{zscy}}$$

(7) Avoided Casualties Existing VTS System.

The port needs study has established a set of potential consequences which can arise from a given vessel casualty. Using analysis of historical casualties, probabilities for each of these consequences have been established. The major categories of these consequences are detailed elsewhere. These consequence probabilities are specific to zone, subzone, vessel type, vessel size, casualty type and co<n>sequence type depending on the amount of historical observations. This matrix is further differentiated into severity levels (<m>).

$$CON_{zscnm} = Probability \; of \; Consequence$$

(8) Probability of consequence matrix.

The avoided consequences are determined by multiplying the avoided casualties matrix by the probability of consequences matrix for both the candidate and existing VTS systems. This gives the probability of avoided consequences.

$$CON_{AC_{ztscynm}} = CON_{ztscnm}\ X\ CAS_{AC_{ztscy}}$$
$$CON_{AE_{ztscynm}} = CON_{ztscnm}\ X\ CAS_{AE_{ztscy}}$$

(9) Probability of Avoided Consequences Calculation.

Each consequence has been assigned an economic value through research in current (1990) dollars. In some cases the determination of the consequence loss value may involve more processing [3]. Avoided losses are determined by multiplying the probability of avoided consequences matrix by the consequence loss value matrix.

$$LOSS_{AC_{ztscynm}} = LVAL_{tscnm}\ X\ CON_{AC_{ztscynm}}$$
$$LOSS_{AE_{ztscynm}} = LVAL_{tscnm}\ X\ CON_{AE_{ztscynm}}$$

(10) Calculation of the loss value matrices.

The present value of these avoided losses is computed based upon the year of the avoided loss and aggregated for the study period to produce the benefits. This operation is performed for both the benefits of the candidate design and the existing VTS.

$$BEN_{AC_{ztscnm}} = PV(\ LOSS_{AC_{ztscynm}})$$
$$BEN_{AE_{ztscnm}} = PV(LOSS_{AE_{ztscynm}})$$

(11) Calculation of Benefits from Avoided Losses

Where the present value is calculated according to the formula (using DR to represent the discount rate:

The total transfer function can be derived by substitution as follows.

[3] Such as a determination of the likely commodities on board a vessel involved to determine the value of a cargo loss. This and other calculations are covered in later sections.

$$PV(LOSS_{ztscynm}) = LOSS_{ztscynm} \; X \; (1+DR)^{-(y-1993)} \; X \; (1+\frac{DR}{2})^{-1}$$

(12) Details of present value formula.

$$BEN_{AC_{ztscynm}} = PV(\; TRF_{P_{ztsy}} \; X \; RSK_{ztsc} \; X \; EFF_{C_{ztsc}} \; X \; CON_{ztscnm} \; X \; LVAL_{tscnm})$$

(13) Candidate design VTS integrated model transfer function.

The benefits can be calculated for the continued operation of the existing VTS systems by changing only the levels of the effectiveness factors.[4]

$$BEN_{AE_{ztscynm}} = PV(\; TRF_{P_{ztsy}} \; X \; RSK_{ztsc} \; X \; EFF_{E_{ztsc}} \; X \; CON_{ztscnm} \; X \; LVAL_{tscnm})$$

(14) Benefits calculation for the existing VTS systems.

The "<M>arginal" benefits are defined as the difference between the benefits with the candidate design in place and the benefits resulting from the continued operation of the existing system during the study period. This calculation is shown below:

$$BEN_{AM_{ztscynm}} = BEN_{AC_{ztscynm}} - BEN_{EC_{ztscynm}}$$

(15) Marginal benefits calculation.

[4] This calculation is only performed for the study zones with existing systems.

9.3.3 Probability of Vessel Carrying Commodity Calculation

The flow of commodities into and out of ports, like the flow of vessel traffic, is a separate input to the integrated model. Once the commodity and vessel traffic within in a study subzone are established and the casualties for that subzone are projected, the next required step is to establish a probability of a given commodity being on the vessels involved in the casualties. Each projected casualty has a probability of spilling the cargo into the water. Given this probability of spill it is necessary to establish the probabilities for the commodities which the involved vessel might have been carrying and therefore might have spilled into the waterway.

This is done by establishing a probability for each of the commodities traveling within the subzone for each of the vessel types and sizes that it might be traveling on. All commodity traffic is specified to be traveling on the specific type and size of vessel by commodity type.

$$TRF_{ztsy} = \text{Vessel Traffic}$$
$$COM_{ztsyl} = T_l = \text{Total Commodity}$$

For each commodity by vessel type and size a Tank/Hold capacity has been established. This is an average hold capacity for the vessel type and size and varies by the type of commodity being carried.

$$S_l = \text{Tank/Hold Size}$$

This allows us to establish the amounts of commodity movements in terms of the number of vessel holds/tanks needed to carry them.

$$T_l/S_l = NT_l \ \text{Number of Tanks of Commodity}$$

Commodity movements are specified as receipts or shipments corresponding to the Corps of Engineers <U>p bound or <D>own bound. On average the number of holds/tanks loaded or unloaded at a waterway varies by whether or not it is being shipped or received. The vessel traffic through the subzone has a shipment capacity and a receipt capacity.

$$NT_{v_p} = Number\ Shipment\ Tanks\ Available$$
$$NT_{v_r} = Number\ Receipt\ Tanks\ Available$$

The Commodity movements through a subzone have a volume in terms of the number of tanks required to carry them for both shipments and receipts.

$$NT_{l_p} = T_{l_p}/S_l \quad Number\ of\ Shipment\ Tanks\ Required$$
$$NT_{l_r} = T_{l_r}/S_l \quad Number\ of\ Receipt\ Tanks\ Required$$

This allows us to compute the simple ratios of the number of available tanks/holds to the tanks/holds filled with a specific commodity. However we must account for other commodities traveling on the same vessels and the lack of directionality in our casualty predictions resulting in the following equation.

$$\frac{NT_{l_p}/NT_{v_p} + NT_{l_r}/NT_{v_r}}{\sum_{1}^{ALL} COMMODITY(NT_{l_p}/NT_{v_p} + NT_{l_r}/NT_{v_r})}$$

9.3.4 Port Needs Study Sensitivity Analysis System

This section of the document outlines the proposed system to allow VNTSC and Coast Guard analysts adjust the key variables used in the Port Needs Study and report how the study's results are affected. This system is intended to allow the user to gauge the importance of the various key variables in the study to point out areas where further research may be required.

This analysis will be implemented using portions of the integrated model being used by the analysis staff to process the data for the study. The integrated model data flow diagram appears on the following page. This diagram highlights the sections of the model which will be used to implement the sensitivity analysis. This data flow diagram shows the key study variables and how they are combined to produce the study results.

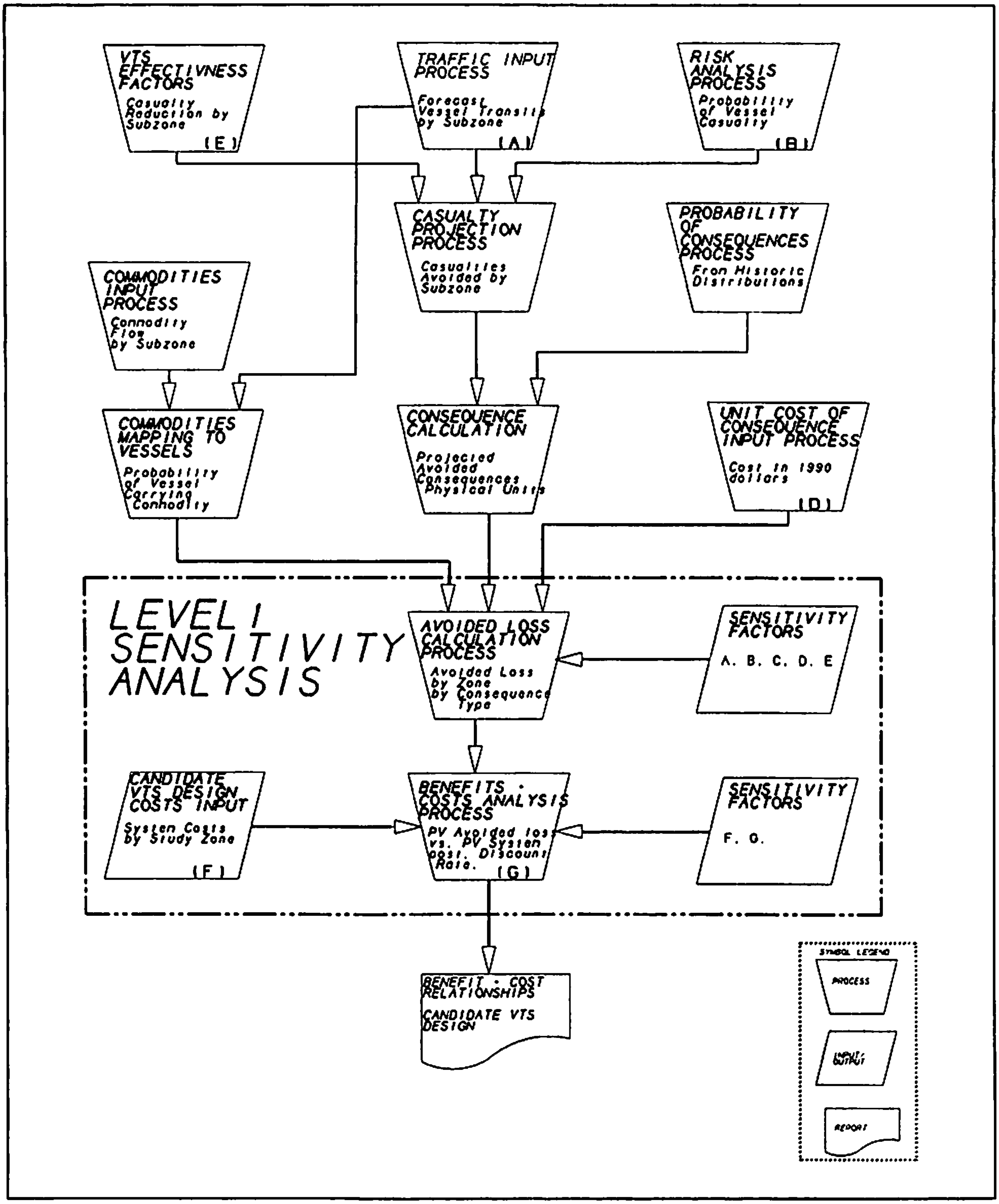


Figure 7 Data Flow Diagram Showing Sensitivity Analysis Application.

9.3.4.1 Sensitivity Factors

The following outline details the sensitivity factors to be included in the sensitivity analysis system.

A. **Vessel Traffic** - by a single adjustment factor to all traffic.

- Intended for testing the effects of the overall level of all projected vessel traffic.

- Factors applied to all vessel casualty consequence benefits before the cost benefit analysis is performed.

B. Vessel Casualty Risk Probability Values - by a single adjustment factor applied to all probability values.

- Intended for testing the effects of overall level of risk probability values.

- Factors applied to all vessel casualty consequence benefits before the cost benefit analysis is performed.

C. **Consequence Probability Values** - Human fatalities, human injuries, vessel damage, bridge damage, damage to aids to navigation, cargo damage and hazardous commodity spill - by a single adjustment factor to all probability values.

- Intended for testing effects of the overall level of the consequence probability consequence values.

- Factors applied to all vessel casualty consequence benefits before the cost benefit analysis is performed.

D. **Unit Cost of Consequences** - by a single adjustment factor to all unit costs.

- Intended for testing effects of the overall level of unit cost values.

- Factors applied to all vessel casualty consequence benefits before the cost benefit analysis is performed.

E. VTS Effectiveness Factors Candidate VTS Design - by a single adjustment factor to all effectiveness factors.

- Intended for testing the effects of the overall level of the projected avoided casualties which are made through these casualty reduction factors.

- Factors applied to all vessel casualty consequence benefits before the cost benefit analysis is performed.

F. Candidate VTS Design Costs - by a single adjustment factor to all costs.

- Intended for testing the effects of the overall level of the candidate VTS design costs.

- Factors applied to all vessel casualty consequence benefits before the cost benefit analysis is performed.

G. Discount Rate - Value change

- Change the value of the discount rate used in calculating the present value of benefits and costs .
- Results in a new cost benefit analysis using new discount rate.

9.3.4.2 Application of Sensitivity Factors

Mathematically these sensitivity factors can be applied to the benefits and costs after the present value has been taken and before the benefits-cost analysis is performed. This can be shown starting with the final benefits equation in the integrated model transfer function appendix shown below.

Sensitivity factors A - E are applied to this equation as follows:

(22) Benefits Calculation Equation (Candidate design)

$$BEN_{AC_{ztcynm}} = PV(\ TRF_{P_{zsy}}\ X\ RSK_{ztsc}\ X\ EFF_{C_{tsc}}\ X\ CON_{ztscnm}\ X\ LVAL_{tscnm})$$

(23) Benefits calculation with sensitivity factors applied.

$$BEN_{AC_{ztcynm}} = PV(\ (S_A\ X\ TRF_{P_{zsy}})\ X\ (\ S_B\ X\ RSK_{ztsc})\ X\ (\ S_C\ X\ EFF_{C_{tsc}})\ X\ (\ S_D\ X\ CON_{ztscnm})\ X\ (\ S_E\ X\ LVAL_{tscnm}))$$

Which is mathematically equivalent to the following :
(24) Alternative application of the sensitivity factors.

$$(S_A\ X\ S_B\ X\ S_C\ X\ S_D\ X\ S_E)\ X\ BEN_{AC_{ztcynm}} = PV(\ TRF_{P_{zsy}}\ X\ RSK_{ztsc}\ X\ EFF_{C_{tsc}}\ X\ CON_{ztscnm}\ X\ LVAL_{tscnm})$$

The important point is that the sensitivity factors can be applied after the vast majority of data processing is completed by the integrated model. Loss values can be aggregated and the present value taken before the sensitivity factor is applied. This reduces the complexity of the sensitivity analysis and therefore the computational time necessary to produce the results. This allows the application of the sensitivity factors at the time of the report generation.

9.3.5 Subscript Definition Summary

Case designation subscripts (upper case)

A	<A>voided due to VTS system in place.
B	<B>ase Case without any VTS system in place
C	<C>andidate VTS design in place
E	<E>xisting VTS system only in place.
P	<P>rojected value
M	<M>arginal difference between existing Systems and Candidate design
V	<V>essel value

Matrix dimension subscripts (lower case)

c	<c>asualty type.
l	commodity (<l>oad)
m	consequence <m>odifier (severity)
n	co<n>sequence type
p	shi<p>ments
r	<r>eciepts
s	vessel <s>ize.
t	Vessel <t>ype.
y	study period <y>ear.
z	study <z>one/subzone.

9.4 Integrated Model Implementation

The integrated model for the port needs study implementation is described in the following list of specifications

DataBase Management System	:	Paradox 3.01
Hardware Environment	:	486/25 633 MB Disk Hardware Cache 8 MB Ram
Lines of Program Code	:	~9000
Program Modules	:	12
Number of Data Tables	:	183
Size of Largest Data Table (records)	:	800,000
Time to Run (All Study Zones)	:	~80 hours
Floating Point Calculations	:	3.36×10^{8}

The integrated model software is documented with a data dictionary, users guide, complete documented program code listing, procedure/Module dictionary and data flow diagrams. This documentation consists of approximately 400 pages of material.

©U.S. GOVERNMENT PRINTING OFFICE: 1991-501-521/40029