



Acquisition Directorate

Research & Development Center

Report No. CG-D-16-13

Chicago Sanitary and Ship Canal (CSSC) Marine Safety Risk Assessment

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December 2013



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1. Report No. CG-D-16-13		2. Government Accession Number		3. Recipient's Catalog No.	
4. Title and Subtitle Chicago Sanitary and Ship Canal (CSSC) Marine Safety Risk Assessment				5. Report Date December 2013	
				6. Performing Organization Code Project No. 3329	
7. Author(s) M. J. Lewandowski, W. C. Heerlein, V. Guthrie, R. McKenna, M. Fitzpatrick, M. Siebert, N. Yankulein, M-B. E. Perry, E. E. Kamradt, D. L. Lersch				8. Performing Report No. R&DC UDI #1319	
9. Performing Organization Name and Address U.S. Coast Guard Research and Development Center 1 Chelsea Street New London, CT 06320		ABSG Consulting Science Applications International Corporation Shearwater Systems, LLC		10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Contract #: HSCG32-12-J-200113 Contract #: HSCG32-13-J-200121 Contract #: HSCG32-12-J-300033 Contract #: HSCG32-13-J-000010	
12. Sponsoring Organization Name and Address U.S. Department of Homeland Security				13. Type of Report & Period Covered Final	
				14. Sponsoring Agency Code CGD9 (dpi), EPA GLNPO	
15. Supplementary Notes The R&D Center's technical point of contact is M. J. Lewandowski, 860-271-2692, email: M.J.Lewandowski @uscg.mil					
16. Abstract (MAXIMUM 200 WORDS) The Coast Guard R&D Center (RDC) conducted four phases of a marine safety risk assessment for the waters of the Chicago Sanitary and Ship Canal (CSSC) in the vicinity of the Aquatic Invasive Species Electrified Dispersal Barrier (MM 296.5), Romeoville, IL. An overarching goal of this work is to determine the adequacy of present risk mitigation strategies, and if necessary, recommend alternatives to the present strategies. The work covered by this report includes: (1) a data-driven, event-tree based quantitative risk analysis, (2) review and analysis of three-months of canal transits through the barrier zone, (3) shore measurements to categorize electrical currents at the Oxbow Midwest Calcining barge loading facility and (4) a summary of regulatory development and rule changes since the initial operation of the barrier through the present.					
17. Key Words CSSC, dispersal barrier, marine safety, risk assessment,			18. Distribution Statement Distribution Statement A: Approved for public release; distribution is unlimited.		
19. Security Class (This Report) UNCLAS//Public		20. Security Class (This Page) UNCLAS//Public		21. No of Pages 132	22. Price



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EXECUTIVE SUMMARY

The U. S. Army Corps of Engineers (USACE) has been safely operating a series of electric barriers in the Chicago Sanitary and Ship Canal (CSSC). The electric fish barrier system was designed to limit the spread of various species, with a more-recent emphasis on the “lake-ward” influx of Asian Carp. The electrified waters present multiple, potential hazards to marine safety. Regulatory actions prescribe operating rules and guidance for navigation safety for commercial and recreational mariners transiting the CSSC in the vicinity of the barrier.

The Coast Guard Research and Development Center was tasked to conduct a marine safety risk assessment to determine Safety Zone and Regulated Navigation Area rule adequacy.

The emphasis of this report is a quantitative marine safety risk analysis pertaining to personnel and vessels operating in the vicinity of the fish barrier system in the CSSC. To accurately depict the frequency of initiating events (i.e., vessel transits) and the number of actual incidents, the project undertook a significant data-gathering effort that included review of USACE and USCG statistics and records, and a review of video recordings of activity in the CSSC barrier area. Risk experts also investigated consequence issues and risk scenarios (including, review of external scientific work and field measurements). With this information, fault tree and event tree analysis yielded preliminary risk values for six consequence types. The project then conducted a session with local subject matter experts and waterway users to review all assumptions (both event and consequence related), and validate the risk analysis.

The video-recording analysis provided significant, activity-related information. The project team noted instances where vessel activity did not necessarily comply with provisions of the 33 CFR 165.923, and noted other anomalies that may help identify areas for regulatory, risk mitigation improvements.

At the request of the local USCG field commander, the work includes an investigation as to whether electric fields associated with the dispersal barrier pose a hazard to workers at the Oxbow Midwest Calcining, LLC barge loading facility.

This report also includes a summary of the barrier navigation rules and regulation development from the first rule in 2006 thru 33 CFR 165.923, Safety Zone and Regulated Navigation Area, Chicago Sanitary and Ship Canal, Romeoville, IL of 1 December 2011.¹

The quantitative risk analysis indicates that with the existing rule, actual risk to human life expressed in dollar-per-year expected losses is extremely small, except for risks associated with person-in-the-water (PIW) electric shock; congestion-related collision, allision or sinking (CAS); and PIW Rescuer Electric Shock (ES). (See Table ES-1, next page.)

The video record implies that not all mariners clearly understand the intent of rule subsections, and their efforts to comply might actually exacerbate risk.

¹ This summary was completed before the regulatory update “Safety Zone and Regulated Navigation Area; Chicago and Ship Canal, Romeoville, IL. Federal Register Vol 78, No 135, 15 Jul 13, pg 42012.”



CSSC Marine Safety Risk Assessment

Finally, test measurements indicate that electric fields associated with the dispersal barrier do not pose a hazard to workers at Oxbow, under present operating procedures while following routine precautions.

Table ES-1. Risk results for each CSSC RNA marine safety decision factor/consequence type.

Decision Factors	Event Tree C: Commercial Vessel Transit of the Safety Zone [\$/year]		Event Tree R: Recreational Vessels Transit of the Safety Zone [\$/year]		Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA) [\$/year]	Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore [\$/year]	Totals [\$/year]
	Red Flag	Non-Red Flag	Greater than 20 feet	20 feet or less and PWCs			
<i>Activity-Related ES</i>	0.3	2	50	50	-	-	100
<i>Contact-Related ES</i>	0.003	0.02	-	-	-	-	0.03
<i>PIW-Related ES</i>	30	200	1,000	20,000	55,100	50,000	130,000
<i>PIW Rescuer-Related ES</i>	0.06	0.4	80	2,531	35	36	2,700
<i>Spark-Related Vapor Ignition</i>	0.002	-	-	-	-	-	0.002
<i>Congestion-Related CAS</i>	-	-	-	-	4,000	-	4,000



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LIST OF ACRONYMS AND ABBREVIATIONS

CAS	Collision, Allision, or Sinking
CERL	Construction Engineering Research Laboratory
CFR	Code of Federal Regulations
CG-521	Coast Guard Office of Design and Engineering Standards
CGBI	Coast Guard Business Intelligence
COTP	Captain of the Port
CSSC	Chicago Sanitary and Ship Canal
CY	Calendar year
ERDC/CERL	Engineer Research and Development Center - Construction Engineering Research Laboratory
ES	Electric Shock
FY	Fiscal year
GP	Group
HPC	Human powered craft
IL	Illinois
IMA	Incident Management Activity
MISLE	Marine Information Safety and Law Enforcement
MM	Mile marker
MSO	Marine Safety Office
MSU	Marine Safety Unit
NEDU	Navy Experimental Diving Unit
NMSRA	National Maritime Strategic Risk Assessment
NPRM	Notice of Proposed Rulemaking
PFD	Personal flotation device
PIW	Person in the water
PWC	Personal water craft
RBDM	Risk-based Decision-making
RDC	USCG Research and Development Center
RNA	Regulated Navigation Area
SLM	Sector Lake Michigan
SME	Subject Matter Expert
SME/UG	Subject Matter Expert and user-group
STA	Station
U.S.	United States
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
WCS	Waterborne Commerce Statistics



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1 INTRODUCTION

The U.S. Coast Guard Research and Development Center (RDC) conducted a marine safety risk assessment for the waters of the Chicago Sanitary and Ship Canal (CSSC) in the vicinity of the Aquatic Invasive Species Electrified Dispersal Barrier (MM 296.5), Romeoville, IL. An overarching goal of this work is to determine the adequacy of present risk mitigation strategies, and if necessary, recommend alternatives to the present strategies. The work includes: (1) a thorough review of the Coast Guard Marine Information for Safety and Law Enforcement (MISLE) data base, (2) analysis of U. S. Army Corps of Engineers (USACE) Waterborne Commerce Statistics (WCS), (3) review and analysis of three-months of canal transits through the barrier zone, (4) a data-driven, event-tree based quantitative risk analysis, (5) a series of shore measurements to categorize electrical currents at the Oxbow Midwest Calcining barge loading facility, and (6) a retrospective look at regulatory development and rule changes since the initial operation of the barrier through the present.

1.1 Background

Between 2002 and 2009, the U.S. Army Corps of Engineers (USACE) installed a system of electrified fish barriers in the CSSC near Romeoville, IL. The barriers' purpose is to limit the spread of various nuisance species, with a more-recent emphasis on preventing the "lake-ward" influx of silver and bighead carp, which could have a significant impact on the sport fishing and commercial fishery industries on the Great Lakes.

From the outset, USACE and the Coast Guard were aware that the actual effects of the high-voltage barriers on vessel traffic and marine safety were not well known. Before getting Coast Guard agreement that waterway navigation could safely continue during barrier operation, US Army Engineer Research and Development Center - Construction Engineering Research Laboratory (ERDC/CERL) conducted a series of engineering tests to determine the physical effects of waterway traffic interaction with the electrified waters near the barriers. USACE also funded research by the Navy Experimental Diving Unit (NEDU) to research the effects that the barriers would have on a person in the water. As USACE completed construction on the second and third barriers in the system, they continued engineering tests to document effects of the electrified water on vessel traffic. Table 1 lists these reports.

In 2009, Coast Guard field commands requested RDC support initially to provide an independent analysis of the existing studies, to characterize knowledge gaps regarding Coast Guard issues and assist in developing search and rescue policy near the barriers. At the same time, after test observation and discussion with field commands, the Coast Guard Office of Design and Engineering Standards (CG-521) compiled a list of potential hazards, tests to investigate the potential hazards, relative degree of the hazard, and mitigation measures, should the hazard exist.

These elements all became the basis for various provisions of 33 CFR 161.923 as the rule developed. Additionally, in 2010 and 2011, RDC conducted tests to identify the hazards associated with rescue of a person in electrified water, with operating guidance and recommendations for rescuer safety.

In the eight years of barrier operation and rulemaking, this is the first formal, quantitatively-based, marine safety risk assessment.



CSSC Marine Safety Risk Analysis

Table 1. Reports and technical documents associated with the CSSC barriers.

Date	Name	Performing Organization
May 2005	Engineering Analysis of the Chicago Sanitary and Ship Canal Electric Fish Barrier: Electrical Effects on Barges and Tow Vessels	ERDC/CERL
February 2006	Engineering Analysis of the Chicago Sanitary and Ship Canal Electric Fish Barrier: Electrical Effects on Personnel in the Water	ERDC/CERL
October 2006	Dispersal Barrier IIA Electrical Field Strength and Sparking Potential Testing	ERDC/CERL
June 2007	Dispersal Barrier IIA February 2007 Sparking Potential, Corrosion Potential, and Electric Field Strength Testing	ERDC/CERL
May 2008	Demonstration Dispersal Barrier & Dispersal Barrier IIA Sparking Potential and Long Tow Testing to Determine Safety Considerations	ERDC/CERL
June 2008	Evaluation of Risk that Electric Fish Barriers Pose to Human Immersion in the Chicago Sanitary and Ship Canal	Navy Experimental Diving Unit (NEDU)
December 2008	Summary of Safety Studies Completed at Chicago Sanitary and Ship Canal Dispersal Barrier IIA	USACE Chicago District
September 2009	Field Mapping Survey of the Aquatic Nuisance Species Dispersal Barrier IIA (presentation – no report)	ERDC-CERL
September 2009	Chicago Sanitary and Ship Canal (CSSC) Fish Barrier REACT Report	USCG RDC
December 2009	Recommendations to Sector Lake Michigan Captain of the Port (COTP)	USCG Office of Design & Engineering Standards
April 2010	Dispersal Barrier Efficacy Study INTERIM IIIA – Fish Dispersal Deterrents, Illinois & Chicago Area Waterways Risk Reduction Study and Integrated Environmental Assessment	USACE Chicago District
May 2011	TAR 24 – Safety Testing Final Report	USACE Chicago District
August 2011	2011 In-Water Testing of Aquatic Nuisance Species Dispersal Barriers IIA And IIB with Increased Voltage and Frequency Operating Parameters	ERDC/CERL
March 2011	CSSC Fish Barrier Simulated Rescuer Touch Point Results, Operating Guidance, and Recommendations for Rescuer Safety, Interim Report	USCG RDC
September 2011	CSSC Fish Barrier Simulated Rescuer Touch Point Results, Operating Guidance, And Recommendations For Rescuer Safety – Final Report	USCG RDC

1.2 Approach

To quantify safety risks pertaining to personnel and vessels operating in the vicinity of the fish barrier system in the CSSC, and to provide risk management information and guidance that can help inform decisions, RDC conducted a preliminary, quantitative marine safety risk assessment. The project team



applied a significant amount of effort to determine actual values for transits, casualties, events, and other reported instances that would accurately depict marine safety-related events in the CSSC. The preliminary risk values were based solely on available statistics, information, and data gathered through the course of this work. RDC then conducted a validation session in the Chicago area, with local stakeholders, user groups, and subject matter experts.

2 QUANTITATIVE RISK ANALYSIS

2.1 Overview

Quantitative risk analysis requires (a) a model that allows input of data for event occurrence and loss value, (b) actual or “best-estimated” event occurrence data and loss value data, and (c) validation of the input data and model results. The purpose of this work is to provide information that may help inform decisions regarding the current CSSC regulations and potentially support decisions regarding future or alternative CSSC RNA marine safety risk analyses. After review of the background studies listed in Table 1, review of 33 CFR 165.923, Safety Zone and Regulated Navigation Area, Chicago Sanitary and Ship Canal, Romeoville, IL of 1 December 2011 (and its regulatory predecessors), and after multiple meetings and discussions with waterway stakeholders, the project determined that the analysis should address risks associated with the following consequence types (also called risk “decision factors”):

- Commercial or Recreational Activity-Related Electric Shock (ES)
- Contact-Related Electric Shock
- Person in the Water (PIW)-Related Electric Shock
- PIW Rescuer-Related Electric Shock
- Spark-Related Vapor Ignition
- Congestion-Related Collision, Allision, or Sinking (CAS)

To address these issues, the project began with a multi-faceted data collection effort.

2.2 Data Gathering

The key in quantifying initiating events and probabilities of incident occurrences for the analysis is determining, as best possible, the number of annual vessel transits, and the number of reported incidents in the vicinity of the barrier. The project team gathered a variety of data to determine transit-based, event probabilities. Primary data sources included Coast Guard Business Intelligence (CGBI) data, USCG Marine Information for Safety and Law Enforcement (MISLE) records, and US Army Corps of Engineers (USACE) Waterways Commerce Statistics.

Though the project team spent a significant amount of time and effort correlating data from official data and sets to accurately depict the actual number of transits and reported incidents, the project also conducted a real-world cross-check by video recording vessel movements and activity near the barrier area.



2.2.1 Marine Information Safety and Law Enforcement (MISLE) Data

To determine the probability of loss events occurring (a basis for the marine safety risk assessment), we analyzed seven years of information as reported to the USCG, who has the primary incident response role on the CSSC. Circumstances surrounding loss events can be reported in multiple ways, and in some cases, details of the loss event are reported as separate entries (e.g., an investigation vice an incident). To make sure we had the complete picture, and to glean as much information about the loss event circumstances as possible, we reviewed all entries (and the category of entry) for events in the vicinity of the barrier.

There are (or, before organizational realignment, have been) a number of units responsible for USCG missions in the geographic area of the CSSC barrier. Marine Information Safety and Law Enforcement (MISLE) records included investigation, incidents, cases, and events from the following units: Marine Safety Office (MSO) Chicago, Marine Safety Unit (MSU) Chicago, Sector Lake Michigan, Station (STA) Calumet Harbor, MSO Milwaukee, and Group (GP) Milwaukee.

The project used Coast Guard Business Intelligence (CGBI) to retrieve MISLE data. CGBI includes pre-sorted “cubes” of data taken from the USCG’s MISLE records. Cubes dynamically extract, compile, and display data including activity and outcome. CGBI presents the information in a multidimensional format according to mission, organization, and enterprise data system and/or unit type. Cubes use a variety of interdependent filters to drill to the specific type and level of information needed. These data sets include specific incident types that resulted in a “record.” Analysts looked at four specific types of incidents and cases to gather information related to risks in the CSSC. The four “cubes” and their CGBI definitions are:

MISLE Incident Investigations

This cube displays detail data on incident investigations entered into MISLE. It contains several measures that involve property damage amounts, casualties, and investigation subjects.

MISLE Pollution Incidents

This displays a distinct count of MISLE Incident Investigation activities that contain one or more Damage to the Environment events in the Investigation Timeline (Findings of Fact).

MISLE Response Cases

This displays program measures for Coast Guard Response to marine events, such as oil spills, groundings, flare sightings, etc. A MISLE Response Case contains at least one Incident Management Activity (IMA).

MISLE Vessel Events

This cube displays Vessel Event data that has been entered as part of an Incident Investigation activity in the MISLE application.

The data available in the CGBI cubes varied considerably for the different types of incidents.

Table 2 shows the MISLE data fields used in our analyses for each type of incident. The table lists event entry categories across the top, and the data fields we examined (down the left side). The blocks with an “x” indicated which data field could be found with each entry category.

As shown, certain elements of information were unique to a particular entry category, while other data elements were common to multiple categories. *Reviewing the information in this way allowed the project team to capture all loss event circumstances without duplication.*



CSSC Marine Safety Risk Analysis

Table 2. Information fields used from MISLE.

Fields Used	Response Cases	Incident Investigation	Vessel Events	Pollution Incidents
Case ID	X	X	X	X
Activity ID	X	X	X	X
Activity Title		X		X
Case Open/Activity Date	X	X	X	X
Originating Department	X	X		X
Originating COTP Zone	X			
Owner Department	X	X	X	
Owner COTP Zone	X			
Controlling Department		X		
Case Title	X	X		X
Activity Status			X	
Notification/Event Type	X		X	
Case Distress Class	X			
Case Distress Type	X	X (Initial Event Type)		
Incident Cause Type	X			
Incident Location Type	X			
Initial Event Class		X	X	
Initial Event Subclass		X	X	
1st Requested Sortie Activity ID	X			
Lives Saved	X			
Lives Assisted	X			
Lives Lost	X	X (persons dead)		
Lives Unaccounted For	X	X (persons missing)		
Lives at Risk	X	X		
Total Persons Injured		X		
Total Lives Affected	X			
Property Saved	X			
Property Otherwise Assisted	X			
Property/Vessels Damaged	X	X (five categories)		
Vessels Undamaged		X		
Property/Vessels Lost	X	X		
Property Unaccounted for	X			
Property at Risk	X			
Total Property Affected	X			
Total Gallons Chemicals Spilled in Water		X		
Serious Marine Incident Designation		X		
Latitude	X	X	X	X
Longitude	X	X	X	X
Involved Vessel Name			X	X
Official Number			X	
IMO Number			X	
Involved Vessel Call Sign			X	



CSSC Marine Safety Risk Analysis

Table 2. Information fields used from MISLE (Cont.).

Fields Used	Response Cases	Incident Investigation	Vessel Events	Pollution Incidents
Involved Vessel Class			X	
Involved Vessel Type			X	
Involved Flag			X	
Involved Hailing Port			X	
Vessel Characteristics			X	
Activity Role			X	
Damage Status			X	
Serious Marine Incident			X	
Waterway Name			X	
Waterway Detail			X	
Involved Facility				X
Involved Other Subject				X
Involved Mystery Spill				X
Involved Oil				X
Involved Chemical				X
Involved Other Substance				X
No Details Filed				X
Total # Fields used	29	22	24	16

The USCG units involved in these incidents and cases, and the years of available data based on calendar year (CY) or fiscal year (FY) are:

MISLE Incident Investigations

- MSO Chicago (CY1997-CY2005)
- MSU Chicago (CY2005-CY2011)
- Sector Lake Michigan (CY2005-CY2011)

MISLE Pollution Incidents

- MSO Chicago (CY2001-CY2005)
- MSU Chicago (CY2005-CY2011)

MISLE Response Cases

- Group Milwaukee (FY2002-FY2005)
- MSO Chicago (FY2003-FY2005)
- MSU Chicago (FY2005-FY2011)
- Sector Lake Michigan (FY2005-FY2011)

MISLE Vessel Events

- MSO Chicago (CY1997-CY2005)
- MSU Chicago (CY2005-CY2011)
- Sector Lake Michigan (CY2005-CY2011)

Table 3 shows the number of MISLE Cases in the RNA vicinity² per specific hazard for the years 1997 to 2011. Appendix A provides some of the details of these incidents from the MISLE case files.

² In this report RNA “vicinity” refers to the waters of the CSSC from MM 295 to 297.9. This allows the report to use the same geographic boundaries for MISLE and WCS data sets, while fully encompassing the actual RNA.



Table 3. MISLE Cases related to hazards in RNA vicinity.

Hazard - (MISLE entry between MM 295-297.9)	97/98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	TOTAL
Capsizing															
Collision (with another vessel)	1	1									1				3
Allision (with stationary object)						1		1			2				4
Collision with a floating object															
Grounding															
Sinking								1							1
Fire or explosion									1	1					2
Drowning															
Person overboard															
Spill of material		1	1	3	1		1	3	1	3	1	2			17
Acute hazard exposure: workers															
Acute hazard exposure: public															
Nonconformance leading to loss of commerce															
Material failure								1		2	2	1	1	1	8
Crew injury		1					2	1	3						7
TOTAL	1	3	1	3	1	1	3	7	5	6	6	3	1	1	42

2.2.2 USACE Waterborne Commerce Statistics

USACE collects, compiles, and publishes waterborne commerce statistics (WCS) based on legal authority in Section 11 of the Rivers and Harbors Appropriations Act of 1922 (42 Stat. 1043), as amended, and codified in 33 U.S.C. 555. We looked at WCS data from annual and composite reports for 2006 to 2010 and data files for 2005 to 2009 presenting detailed data (e.g. locale, freight traffic, commodity, tonnage, etc.) on the movements of vessels and commodities at the ports and harbors, the CSSC, and the waterways and canals of the United States; and 2010 detail data and charts on towboat traffic.

The information in the WCS annual reports was very general and did not provide the level of detail we needed to determine the number of vessels transiting the barrier area. We asked USACE personnel at the WCS Statistics Center for data regarding vessels transiting through, loading, or discharging on the Illinois Waterway, mile marker (MM) 295-297 (Chicago Sanitary and Ship Canal). We requested the timeframe CY 2006-2011 (the years for which we had MISLE data), with indicators to sort on a monthly basis (either by shipping date or discharge date). They provided us with the number of vessels and their names, their direction (upbound/downbound), the vessel size (max length, max beam, light and loaded drafts, highest point, and capacity (or horsepower for towboats)), the name of commodity carried (to determine loaded flammable liquid barges), and actual draft.

The RDC received the requested information broken down into two data types, a “commerce” data set that identified the cargo and load for each barge and a “trips” data set that identified the nature of the trip in relation to the boundaries of Mile Marker (MM) 295 to 297. Data significant to the risk analysis associated with operating within the designated area were:



Trip Direction

- Upbound Through – Trip started below MM 295 and transited up and through MM 297
- Upbound Outbound – Trip started between MM 295 and MM 297 and transited upbound beyond MM297
- Upbound Local – Trip started and ended between MM 295 and MM 297
- Upbound Inbound – Trip started below MM295 and ended between MM 295 and MM 297
- Downbound Through – Trip started above MM 297 and transited down and through MM2 95
- Downbound Outbound – Trip started between MM 297 and MM 295 and transited down through MM 295
- Downbound Local – Trip started and ended between MM 297 and MM 295
- Downbound Inbound – Trip started above MM 297 and ended between MM 295 and MM 297

Load

The percent cargo load was calculated by taking the difference between actual draft and load draft and dividing the result by the difference between loaded draft and light draft. Any barge with less than 10% load was characterized as No Load and a barge with greater than 10% load was characterized as Loaded. Figure 1 summarizes the number of trips by direction and loaded or not loaded.

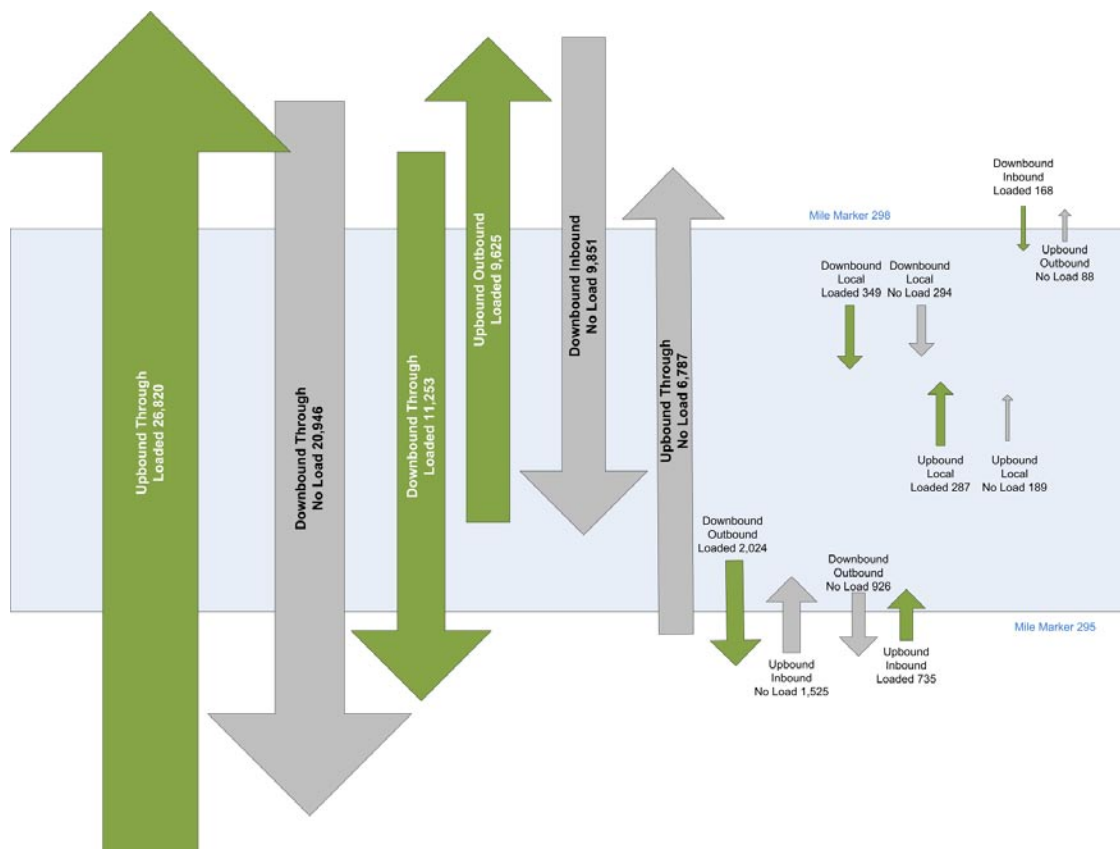


Figure 1. Analysis of WCS for load or no load - CY 2006-2011.

Cargo

Publication Group Number and Publication Group Name information was included in the commerce data. The project used this to categorize cargoes as “red-flag” or not, according to the “bow-boat” requirement of 33 CFR 165.923.³ Figure 2 summarizes the number of barge trips by direction and “red-flag” determination.

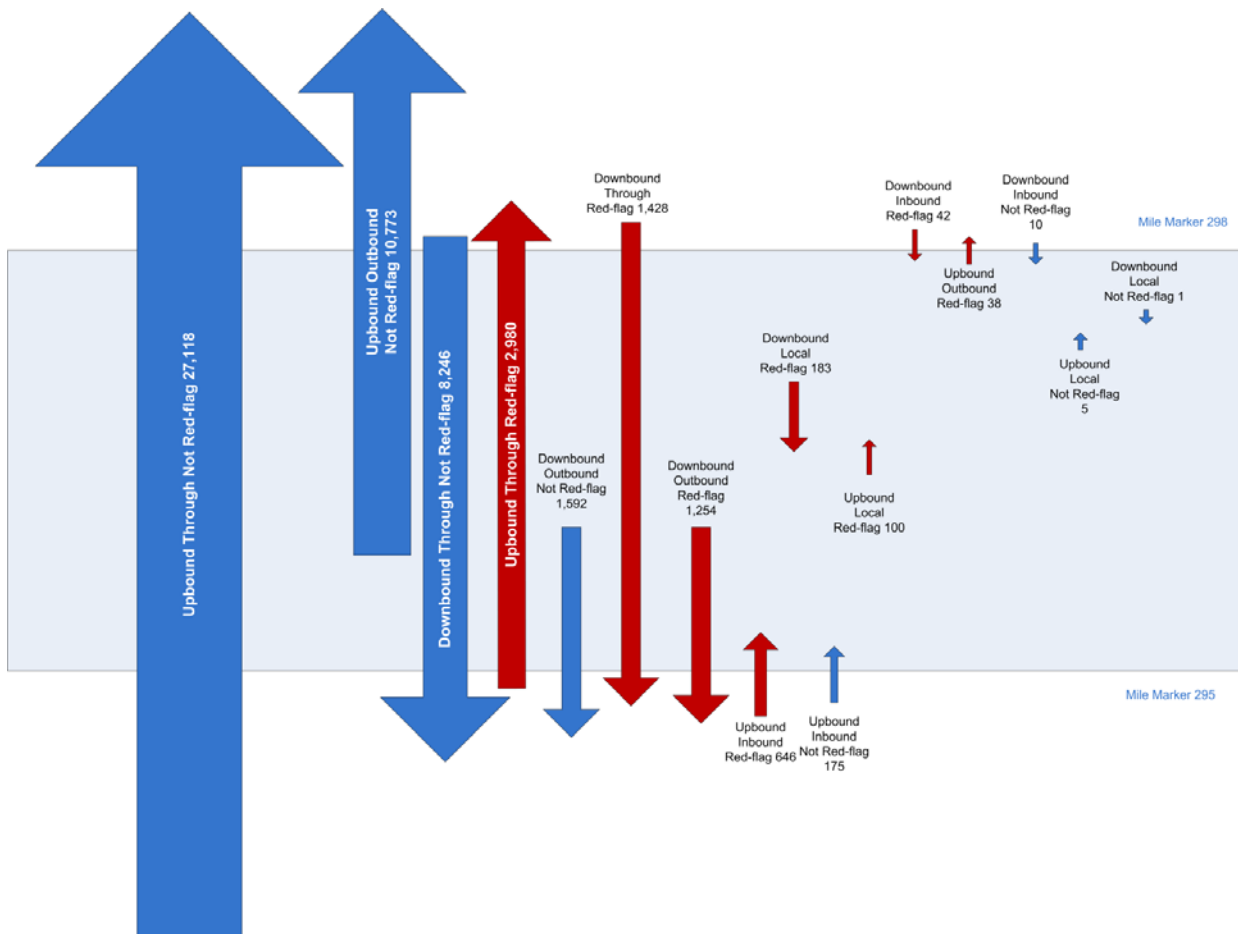


Figure 2. Analysis of WCS for red-flag or no red-flag (loaded barges) - CY 2006-2011.

Summary

The WCS data provided meaningful information about the commodities and loads associated with barge traffic through, into, and out of the barrier area. However, early in the data collection and analysis phase, the project team decided that “transit,” in terms of an initiating event, would treat a multiple-barge tow the same as a single-vessel transit. From the WCS data, project analysts could not easily determine which barges (and towboats) made up a single, particular tow. As “transit” is key as an initiating event for the quantitative risk analysis, the project decided that additional data was required.

³ The term “red flag” barge generally refers to a vessel carrying flammable or combustible liquid. For the purpose of this report, the term “red flag” barge is associated with the “bow boat” requirement in 33 CFR 165.923(b), that is, a barge carrying flammable liquid cargo (Grade A through C, flashpoint below 140 degrees Fahrenheit, or heated to within 15 degrees Fahrenheit of flashpoint). Since Grade “C” Cargoes have a flashpoint of 80 degrees or below, we assumed the bow boat requirement included Grade D cargoes having a flashpoint of up to 140 degrees Fahrenheit, and included these cargoes from WCS records..



2.2.3 Video Analysis

Because a significant portion of the vessel traffic that transits the barrier stays within the confines of the CSSC between the USACE Lockport Lock and either the Chicago Harbor Lock or the O’Brien Lock on the Calumet River, and because the Waterborne Commerce Statistic database does not provide the fidelity for determining the actual make up of individual tows, nor when a towboat transits as an assist boat, the project did a series of three, month-long video recordings, piggy-backing on the USACE video cameras at the barrier operations building to capture actual vessel transit counts. “Transits,” either by individual vessels or a combination of vessels in a tow, are the basis for event-probabilities in the risk assessment analysis.

Table 4 is an example of the spreadsheet entries for the video footage analysis. Data for each transit included date and time, direction of travel, type of vessel(s), tow configuration (if any), bow boat (if any), and any other relevant notes.⁴

Table 4. Example of video analysis data.

Date	Time	Dir	Barges			Boat Only	Bow Boat	Rec Vsl	Othr	Type	Other	Tow Makeup			
			L	W	Addl										
05-Aug-12	11:44:55	UP	4	1					hopper			cover	coal		
05-Aug-12	12:04:15	UP				TB			t						
05-Aug-12	13:54:10	DOWN						REC	powerboat-30?						
05-Aug-12	17:38:15	DOWN						REC	cabin cru-35?						
05-Aug-12	17:39:30	DOWN	2	2	1				hopper		light	light	light		
05-Aug-12	18:16:00	UP				TB			t			light	light		
05-Aug-12	20:59:40	UP						REC	powerboat-30?						
05-Aug-12	22:31:10	DOWN	4	2					combo		cover	?	?	cover	
06-Aug-12	0:12:30	DOWN	4	1					hopper		tank?	cover	cover	cover	
06-Aug-12	3:46:25	DOWN				TB			t						
06-Aug-12	4:17:05	UP	2	1			BB		jumbo tank		tank	tank			
06-Aug-12	5:51:15	UP	2	2	1				hopper?						
06-Aug-12	7:49:20	DOWN				TB			CW Swaby						
06-Aug-12	8:05:15	UP	2	1					jumbo tank		tank	tank			
06-Aug-12	8:34:30	ODOWN				TB			O	Oxbow fleeting					
06-Aug-12	11:29:30	ODOWN							O	Oxbow fleeting					
06-Aug-12	13:25:20	DOWN				TB			t						
06-Aug-12	13:42:10	UP	3	1			BB		jumbo tank		tank	tank	tank		
06-Aug-12	13:48:50	DOWN	1	1						BB disconnected and took 1 tank up					
06-Aug-12	14:18:00	DOWN						REC	cabin cru-35?						
06-Aug-12	15:51:15	ODOWN				TB			O	Oxbow fleeting					
06-Aug-12	16:16:10	UP	4	1					hopper		cover	cover	cover	cover	
06-Aug-12	16:44:30	DOWN				TB			t						
06-Aug-12	17:13:45	DOWN	1	2					hopper		cover				
06-Aug-12	17:22:40	DOWN				TB			t		cover				
06-Aug-12	18:03:25	UP	2	1			BB		tank				tank	tank	
06-Aug-12	18:08:15	DOWN				TB			t	former bow boat headed down					
06-Aug-12	18:11:40	DOWN	2	2			BB		combo		tank	cover			
06-Aug-12	18:23:55	UP				TB			t		coal	cement?			
06-Aug-12	18:25:50	UP				TB			CW Swaby						
06-Aug-12	18:33:50	UP	3	2					hopper		coal	coal	coal		
06-Aug-12	18:41:30	UP						REC	cabin cru-30?		coal	coal	coal		

⁴ In Table 4, “Rec Vsl” designates recreational vessel; “Othr” vessels include government, passenger vessels, workboats, etc.



CSSC Marine Safety Risk Analysis

These data were sorted in a variety of ways. Table 5 shows the actual number of transits recorded.

Table 5. Video-recorded transits.

	Jul 24-Aug 21, 2012			Sep 25-Oct 24, 2012			Nov 19-Dec 20, 2012			Totals		
	Transits	Down	Up	Transits	Down	Up	Transits	Down	Up	Transits	Down	Up
Total	594	303	291	598	320	278	443	227	216	1635	850	785
Rec	85	47	38	69	65	4	3	3	0	157	115	42
Other	18	6	12	48	21	27	3	1	2	69	28	41
All Commercial	491	250	241	481	234	247	437	223	214	1409	707	702
Tow Boat only	174	83	91	162	77	85	134	66	68	470	226	244
All tows	317	167	150	319	157	162	303	157	146	939	481	458
Tow w/Bow Boat	46	22	24	54	30	24	35	19	16	135	71	64
Other Tows	271	145	126	265	127	138	268	131	129	804	403	393

Table 6 shows the *estimated* annualized electrified barrier transits based on the 3 months of video-recordings. Most values in Table 6 are approximately equal to recorded transits x 4, with rounding. For recreational vessels, the project roughly factored seasonal considerations, including peak summer activity, fall and spring long-distance transits, and recreational transits near zero for three winter months.

Table 6. *Estimated* annual CSSC barrier transits.

	Transits	Down	Up
Total	6500	3400	3100
Recreational	470	250	220
Other	280	110	170
All Commercial	5600	2800	2800
Tow Boat only	1900	900	1000
All tows	3800	1900	1800
Bow Boat Tows	540	280	260
Other Tows	3200	1600	1600

Table 7 gives a summary of tow configurations observed during the 3, one-month video-recordings, however, the project did not find a need to actually apply this breakdown to the quantitative analysis. Of general note, the three most-observed tow configurations are 3 x 2, 2 x 1, and 1 x 1. Of the 939 tows observed, only 81 (9%) were configured with 4 or 5 barges in-line. Of 135 tows with bow boats, 10 (7%) were configured with more than 3 barges in-line. The project had hoped to provide stakeholders insight with respect to overall tow length (including the additional length resulting from a bow boat) for use in future regulatory development, but this requires significant additional data review and analysis to equate tow configuration to overall length. E.g., the video analysis data in table 4 shows a 3 x 1 configuration of jumbo tank barges with boat and bow boat for an estimated overall length of 1150 feet, while another record on the previous day shows a 4 x 2 configuration of standard barges and no bow boat for an estimated overall length of approximately 900 feet. (The breakdown highlights the most-common tow configurations in bright yellow.)



Table 7. Tow configuration summary.

Tow Configuration	Jul 24-Aug 21, 2012					Sep 25-Oct 24, 2012					Nov 19-Dec 20, 2012				
	Transits	Downbound	Upbound	With Bow Boat Downbound	With Bow Boat Upbound	Transits	Downbound	Upbound	With Bow Boat Downbound	With Bow Boat Upbound	Transits	Downbound	Upbound	With Bow Boat Downbound	With Bow Boat Upbound
5 x 2	1	1	—	—	—	—	—	—	—	—	1	—	1	—	—
5 x 1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—
4 x 2	12	6	6	1	1	22	4	18	1	3	4	—	4	1	—
4 x 1	17	5	12	—	2	15	1	14	—	1	8	—	8	—	—
3 x 2	89	45	44	8	6	74	37	37	9	6	72	33	39	6	6
3 x 1	32	14	18	1	2	19	8	11	3	1	30	13	17	2	1
2 x 2	39	24	15	3	4	45	25	20	6	3	34	25	9	—	2
2 x 1	61	36	25	7	8	74	36	38	4	8	71	37	34	7	3
1 x 2	7	5	2	—	—	10	10	—	1	—	12	8	4	1	1
1 x 1	58	30	28	2	1	60	36	24	5	2	71	41	30	2	3

2.3 CSSC RNA Marine Safety Quantitative Risk Model

The purpose of the CSSC Fish Barrier RNA Marine Safety Risk Model is to provide information that can help inform decisions regarding the current regulation and support decisions regarding future/alternative CSSC RNA marine safety regulations. As previously stated, this analysis considered the following “decision factors” (i.e., risks associated with consequence types):

- Commercial or Recreational Activity-Related Electric Shock (ES)
- Contact-Related Electric Shock
- Person in the Water (PIW)-Related Electric Shock
- PIW Rescuer-Related Electric Shock
- Spark-Related Vapor Ignition
- Congestion-Related Collision, Allision, and Sinking (CAS)

A risk model qualitatively shows how these consequence types can occur and quantitatively expresses the expected losses or risk associated with these factors.

2.3.1 Risk-Based Decision-Making Model

The first step to developing a risk-informed methodology was to choose a Risk-Based Decision-Making (RBDM) model. The RBDM tool is determined by decisions to be addressed and the risk information needed to inform those decisions. Using USCG RBDM Guidelines, the analysis team selected an event tree/fault tree approach for the analysis.



CSSC Marine Safety Risk Analysis

For this project, the key decisions address, “Is the current CSSC RNA regulation appropriately balanced to best manage the marine safety risks to personnel and vessels posed by the fish barrier system?” While this decision involves sections of the CSSC RNA regulation, the information provided needs to be precise enough to inform the inclusion/exclusion of specific changes to the regulation.

To support such decisions, the most useful information is:

- Expected losses under the current CSSC RNA regulations (i.e., baseline conditions), and,
- For follow-on studies, the change in the expected losses for a proposed set of CSSC RNA regulations (i.e., the difference between the results for a future alternative and the baseline).

To provide this information, the selected risk tool models the transit characteristics of the CSSC RNA and safety zone as well as the key functions associated with safe navigation of the area. The selected risk tool also supports the calculation of the rate of loss events and the associated consequences. Further, the selected tool supports a clear understanding of the drivers of failures to provide the key marine safety functions (e.g., the influence of CSSC RNA regulations on preventing a recreational boater from falling into the water). Finally, the selected tool provides transparency regarding the data used to support frequency, probability and consequence estimates.

The event tree/fault tree tool can compare alternatives on a quantitative risk basis. Event Tree Analysis and Fault Tree Analysis techniques have been used within the USCG for over ten years and have been used in a wide range of industries for over 60 years including aeronautics, nuclear, petrochemical, and others.

While other tools can be useful for quantitative comparisons, the event tree/fault tree tool provides the widest range of features to compare alternatives on a quantitative risk basis. The event tree/fault tree model accounts for transit characteristics; marine safety functions, drivers of failure to provide these functions; and response personnel. The event tree/fault tree tool provides the structure to (1) qualitatively model all scenarios leading to the six risks analyzed; (2) specify the consequences for each scenario; and (3) quantitatively express the expected losses for individual scenarios and across all scenarios.

Advantages of the event tree/fault tree approach:

- **Comprehensive:** While at a very coarse level, the logic structure can include all scenarios leading to the loss events of concern.
- **Comparative:** The models are specific enough to allow consideration and comparison of current and future/alternative CSSC RNA regulations.
- **Transparent:** All input data, whether from a document or a subject matter expert (SME), is clearly source-designated, calculations are based on the input data, and all category limits are clearly defined. Thus, all inputs and the basis for categorization of all outputs are visible for later discussion and adjustment.
- **Usable:** The expected losses per year are expressed in a common currency (\$/year). Thus, results can be used for relative comparisons (e.g., the expected loss for Alternative X is a factor of 20 lower than the expected loss for Alternative Y).

The goal of the event tree/fault tree model is to provide a structure to quantify the risks given the current regulation for the CSSC RNA. To do this, the team developed an electronic risk tool for the event tree using Microsoft Excel spreadsheet software. The event tree has a series of events stated in a success mode, or simply as the occurrence of a phenomenological condition. The event tree begins with the initiating event



of a “transit” (when applicable). As subsequent events occur, there is a branch point, one branch representing success and the other representing failure. In addition, there can be detailed fault trees for each failure branch indicating how the failure branch could occur. Each full path through an event tree represents an event scenario with a quantified frequency based on the frequency of the initiating event and the probabilities of each branch through the tree. Each scenario results in either a “consequence type of interest” or “no loss.” When a particular scenario results in one of the six consequence types analyzed, the frequency and consequence values are combined to obtain the expected loss (risk) associated with the scenario. The expected losses for all scenarios leading to the same loss type are then combined to obtain the total expected loss associated with that loss type for the analyzed situation (e.g., commercial vessel transit of safety zone – non-red flag).

2.3.2 Assumptions for Risk Methodology

This risk methodology and the associated outputs are dependent upon *qualitative* modeling assumptions, *quantitative* modeling assumptions, and consequence-modeling assumptions. Key assumptions in each of these areas are:

Qualitative Modeling Assumption

- The event tree/fault tree structure can adequately describe the relevant loss scenarios associated with CSSC RNA transits and shore activities and the consequence types associated with each scenario.

Quantitative Modeling Assumptions

- Analysts can assign meaningful probabilities to an event occurring during a transit (e.g., the probability that a mariner will fall into the water during a CSSC RNA transit).
- SMEs will be able to reasonably assess conditional failure probabilities (e.g., the probability a person falls into the water after a collision, allision, or sinking)
- Analysts will adequately realize when events occur together and are not independent.
- Analysts can extrapolate nationally-based data from related incidents to the CSSC. *The model requires this because of the limited incident and failure experience within the CSSC RNA.*

Consequence Modeling Assumptions

- The National Maritime Strategic Risk Assessment (NMSRA) equivalency table that aligns various consequence types across a range of severity levels is relevant to this application.
- A human fatality is adequately valued at ~\$7 million; the representative value for the high consequence category can be set to \$7 million because when events in this category occur, they will generally involve one death.

2.3.3 Risk-Informed Process Supporting Regulatory Decisions

2.3.3.1 Process Overview

The risk-informed process for supporting decisions associated with CSSC RNA regulation here applies to this assessment and any follow-on assessments. This assessment establishes a risk baseline associated with key decision factors. Follow-on assessments will be able to compare these risks to the risks associated with any identified alternatives.

The process involves first establishing expected losses for the baseline. The simplified flowchart in Figure 3 describes the main steps in the overall process of informing decisions regarding the effectiveness of 33 C.F.R § 165.923.



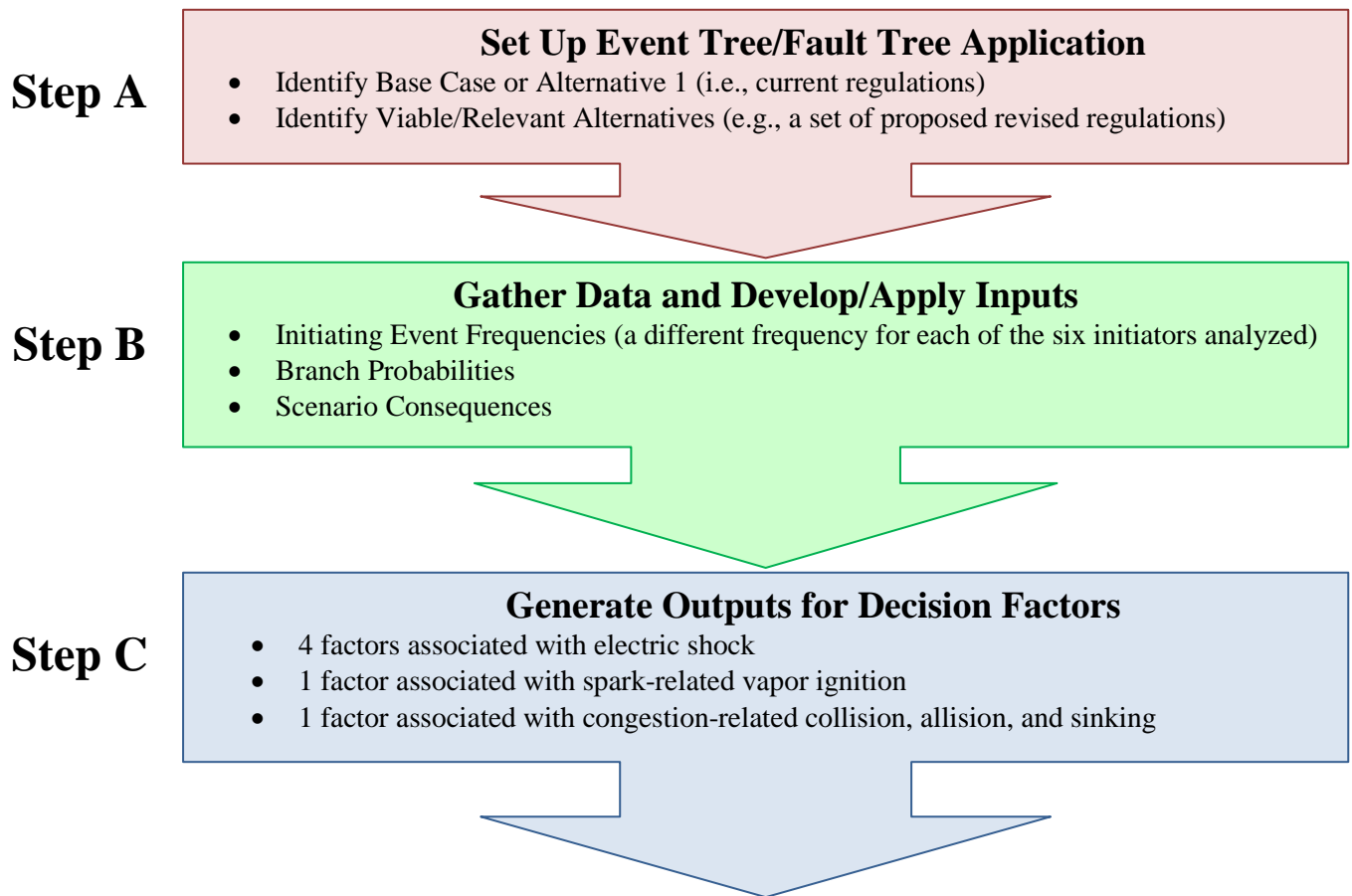


Figure 3. Simplified flowchart of the risk informed process for supporting decisions associated with CSSC RNA Regulation.

The elements generated by each step all interact to create and frame the final risk results. The following paragraphs provide a brief description of each of the steps.

Step A: Set Up Event Tree/Fault Tree Application

This step sets up the event tree/fault tree application using the spreadsheet model. This setup includes the identification of a baseline (e.g., focused on the current regulation) as well as any alternatives to be analyzed (none in this analysis).

Event Trees: Event tree diagrams provide the logic structure for the scenarios leading to the analyzed consequence types for the four situations (i.e., Commercial Vessel Transit of the Safety Zone, Recreational Vessels Transit of the Safety Zone, Vessels Approach of the RNA, and Personnel on the RNA Shore). Each event, depicted horizontally across the top of an event tree, has one or more branches associated with it representing success (upward) or failure (downward) at that point in the event sequence.

Fault Trees: The downward branches in each of the event trees represent the “failure” of the associated event at that point in the event sequence. These downward branches or failure paths are quantified with a probability of failure. In some cases, we can establish these probabilities with no further development of the event. In other cases, we develop a detailed fault tree to explain how this failure path could occur.



Step B: Gather Data and Develop/Apply Inputs

Step B focuses on gathering data and developing all frequency, probability and consequence inputs. There are four elements of Step B:

- *Probability Category Table*: Analysts and SMEs use a table of probability categories to support efficient selection of representative probability values for input to the data selection table.
- *Frequency and Probability Inputs Rationale*: This lists all data sources considered for each event in the event tree/fault tree logic, a summary of the data from the source, the selected or calculated probability for the data source, and the selected probability for the event based on all data sources.
- *Frequency and Probability Inputs*: The input table for the event tree branches showing a listing of events quantified in the event tree/fault tree and their selected value from the data selection table.
- *Consequence Inputs*: The consequence table in the spreadsheet is used to develop representative consequences, given an incident has occurred.

Step C: Generate Outputs for Decision Factors

This step generates the outputs from the event tree for the key decision factors (consequence types).

Summary of Event Tree Results: This summary of results includes the consequence types/decision factors, the frequency of these events [Events/Year], the average consequence [\$/Event], and the expected loss per year [\$/Year]. The expected loss per year [\$/Year] results for each decision factor allow determination of the total risk, or comparison among the different decision factors.

2.3.3.2 Detailed Description of Each Step of the Process Flow

Each step generates elements that all interact to create and frame the final risk results. The following sections provide a detailed description for the three steps.

2.3.3.2.1 STEP A: Set Up Event Tree/Fault Tree Application

The setup of the event trees/fault trees for the CSSC RNA involves identifying the base case (e.g., the current regulation) and any other alternatives of interest (e.g., a differing regulation for the RNA). We begin with development and structure of the event tree and the supporting fault trees.

A.1 Event Trees with Risk Calculations

Section 2.1 described the need for risk results for the six decision factors associated with the regulation for the CSSC fish barrier RNA. The event trees describe specific risk results in dollars per year.

An event tree is an inductive logic tool with a set of events described across the top. These events begin with an initiating event for potential losses of interest, followed by phenomenological conditions or functional successes to avoid the potential losses. The paths through the event tree begin with the initiating event on the left, and progress through one or more branch points for each event defined at the top of the event tree (Figure 4). The standard approach is for each branch point to have an upward branch indicating the success path for the associated event and a downward branch indicating the failure path for that event. A *scenario* consists of a path through the event tree structure. The model bases expected scenario losses on the combination of the scenario frequency and its associated consequences. The model calculates scenario frequency by multiplying initiating event frequency and probability for each branch through the event tree.



CSSC Marine Safety Risk Analysis

Because failure logic for a downward branch in the event tree may be very complex, analysts often model this logic using a *fault tree*, a deductive logic tool. (Fault trees are discussed in subsection A.2). A key assumption in this approach is that all branches of the event tree are independent (e.g., a failure in one branch does not increase the probability of failure in another branch). Thus, analysts must exercise care in developing event tree/fault tree models to verify independence of the events.

The event tree example in Figure 4 has the eight features: (1) Event Tree Title, (2) Events, (3) Event Tree Paths, (4) Scenario Frequency Results, (5) Consequences, (6) Total Risk, (7) Outcome and Notes, and (8) Summary of Results. The following bullets discuss each feature.



8. Summary of Results

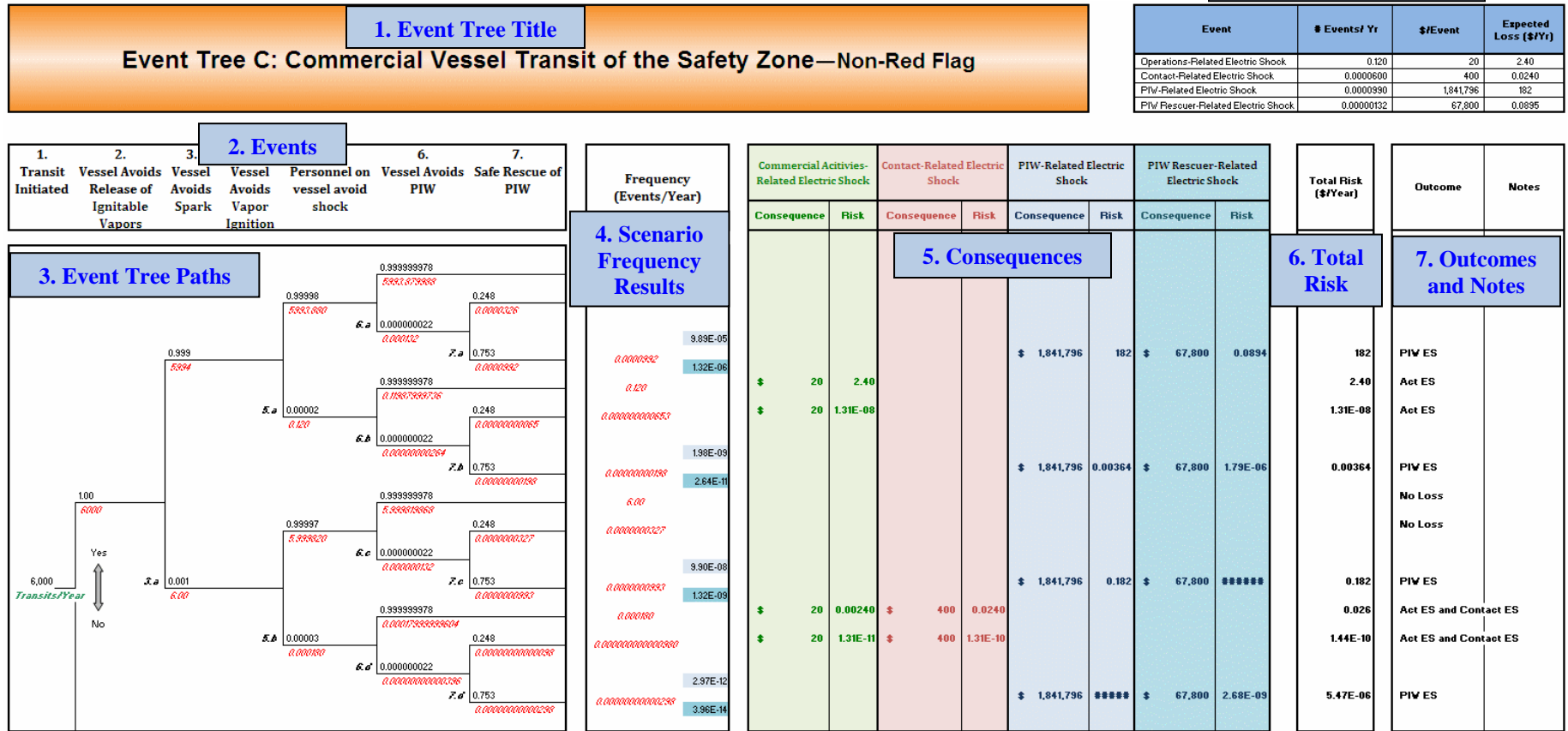


Figure 4. Event tree for non-red flag commercial transit.



- **Event Tree Title:** Describes the situation analyzed and the specific set of vessels addressed by the event tree.
- **Events:** Lists event types analyzed for the different event trees (see list below). For Event Tree C, only five event types apply (in bold) and are analyzed.
 - **Transit initiated**
 - Vessel avoids release of ignitable vapors
 - **Vessel avoids contact-related spark**
 - Vessel avoids spark-related vapor ignition
 - **Personnel on vessel avoid shock**
 - **Avoids PIW**
 - **Safe rescue of PIW**
 - Shore personnel avoid being near the water
 - Removal of PIW before reaching the fish barrier
 - Avoid congestion-related collision, allision, or sinking
- **Event Tree Paths:** Figure 5 shows the paths through Event Tree C (Commercial Vessel Transit of Safety Zone – Non-Red Flag). The initiating event “1. Transit Initiated” is on the left. As you move right, you encounter the first branch point addressing Event 2, “Vessel Avoids Release of Ignitable Vapors.” The upward direction is for the “Yes” or success path and the downward direction is for the “No” or failure path (i.e., vessel has release of ignitable vapors). For this event tree, the vessel is “non-red flag” (with no flammable vapors) and we model success at 100%.

Hence, Event 2 has one branch point, and in this case only the upper portion of the branch is shown because the success or Yes path has a probability of 1.0. Event 3 has one branch point. Event 4 has no branch points (i.e., doesn’t apply) because there is no possibility of an ignition given there was no vapor release. Event 5 has two branch points and Events 6 and 7 each have four branch points (i.e., branches a through d).

- **Scenario Frequency Results:** The frequency column presents the expected number of times per year that the particular scenario or path through the event tree will occur. The model calculates the frequency of a scenario by combining the number of transits/year with the success or failure probability for each branch in the scenario.

For example, in Figure 5 the frequency for the scenario toward the top of the event tree ending in Event 7.a is shown as 0.0000992 (shown in red). The frequency shown in light blue is the portion of the scenario frequency associated with “PIW-Related Electric Shock” and the frequency shown in teal blue is the portion of the scenario frequency associated with “PIW Rescuer-Related Electric Shock.”

- **Consequences:** The scenario paths in Figure 5 lead to an outcome with either a consequence type of interest or “no loss.” An incident can result in one or more of the six consequence types/decision factors addressed by this analysis. Figure 4 includes four consequence types that result from the event tree scenarios occurring. Each consequence type has a consequence value column and a risk value column.

The actual losses for a consequence type depend on the scenario. Step B in this section discusses loss calculation. The value for each consequence type for a scenario is multiplied by the respective scenario frequency to establish the risk or expected loss.



1. Transit Initiated	2. Vessel Avoids Release of Ignitable Vapors	3. Vessel Avoids Spark	4. Vessel Avoids Vapor Ignition	5. Personnel on vessel avoid shock	6. Vessel Avoids PIW	7. Safe Rescue of PIW	Frequency* (Events/Year)	
6,000 Transits/Year	Yes	6,000	0.999	5994	0.99998	5993.880	0.999999978	
							5993.879988	
							0.248	
							0.0000326	
							0.00000022	
							0.000132	
	No	6,000	0.001	6.00	0.00003	0.999997	5.999820	0.999999978
								5.999819868
								0.248
								0.000000327
								0.00000022
								0.00000132
0.999999978								
0.0001799999604								
0.248								
0.0000000000098								
0.000000022								
0.0000000000396								
0.753								
0.0000000000298								
							5,993.880	
							0.0000326	
				6.a			9.89E-05	
					7.a		1.32E-06	
							0.0000992	
				5.a			0.120	
							0.00000000653	
				6.b			1.98E-09	
							0.0000000198	
					7.b		2.64E-11	
							6.00	
							0.000000327	
				6.c			9.90E-08	
							0.000000993	
					7.c		1.32E-09	
							0.000180	
				5.b			0.00000000000980	
							2.97E-12	
				6.d			3.96E-14	

* The frequency shown in red is the frequency for the associated scenario from the event tree. The frequency shown in light blue is the portion of the scenario frequency associated with "PIW electric shock" and the frequency shown in dark blue is the portion of the scenario frequency associated with "PIW rescuer related electric shock".

Figure 5. Event tree paths for Event Tree C.

- **Total Risk:** This column shows the sum of all of the risks for the various consequence types (i.e., PIW-Related Electric Shock, PIW Rescuer-Related Electric Shock) for each event tree scenario.
- **Outcome and Notes:** The scenarios can result in an outcome of "No loss," or a combination of the consequence types/decision factors analyzed.
- **Summary of Results:** The consequence values (\$/event) are multiplied by the associated scenario frequency (# events/yr) to provide an estimated risk result for each consequence type. These scenario risk results for each consequence type are then summed to provide a Total Risk or Expected Loss (\$/Year) for the consequence type. Table 8 shows this loss summary for Event Tree C, "commercial vessel transit of the safety zone-non red flag."



Table 8. Event tree risk results for Event Tree C: Commercial Non-Red Flag Vessels.

Consequence Type/ Decision Factor	Frequency (# Events/ Yr)	Consequence (\$/ Event)	Expected Loss (\$/Yr)
Commercial Activity-Related Electric Shock	0.120	20	2.40
Contact-Related Electric Shock	0.0000600	400	0.0240
PIW-Related Electric Shock	0.0000990	1,841,796	182
PIW Rescuer-Related Electric Shock	0.00000644	67,800	0.436

A.2 Fault Trees

For Event Tree C, the failure paths for Events 3, and 5 through 7 have an associated fault tree to further describe the failure logic. Figure 6 illustrates how fault trees (on the left) are connected to failure events in the event tree. We will further examine one example.

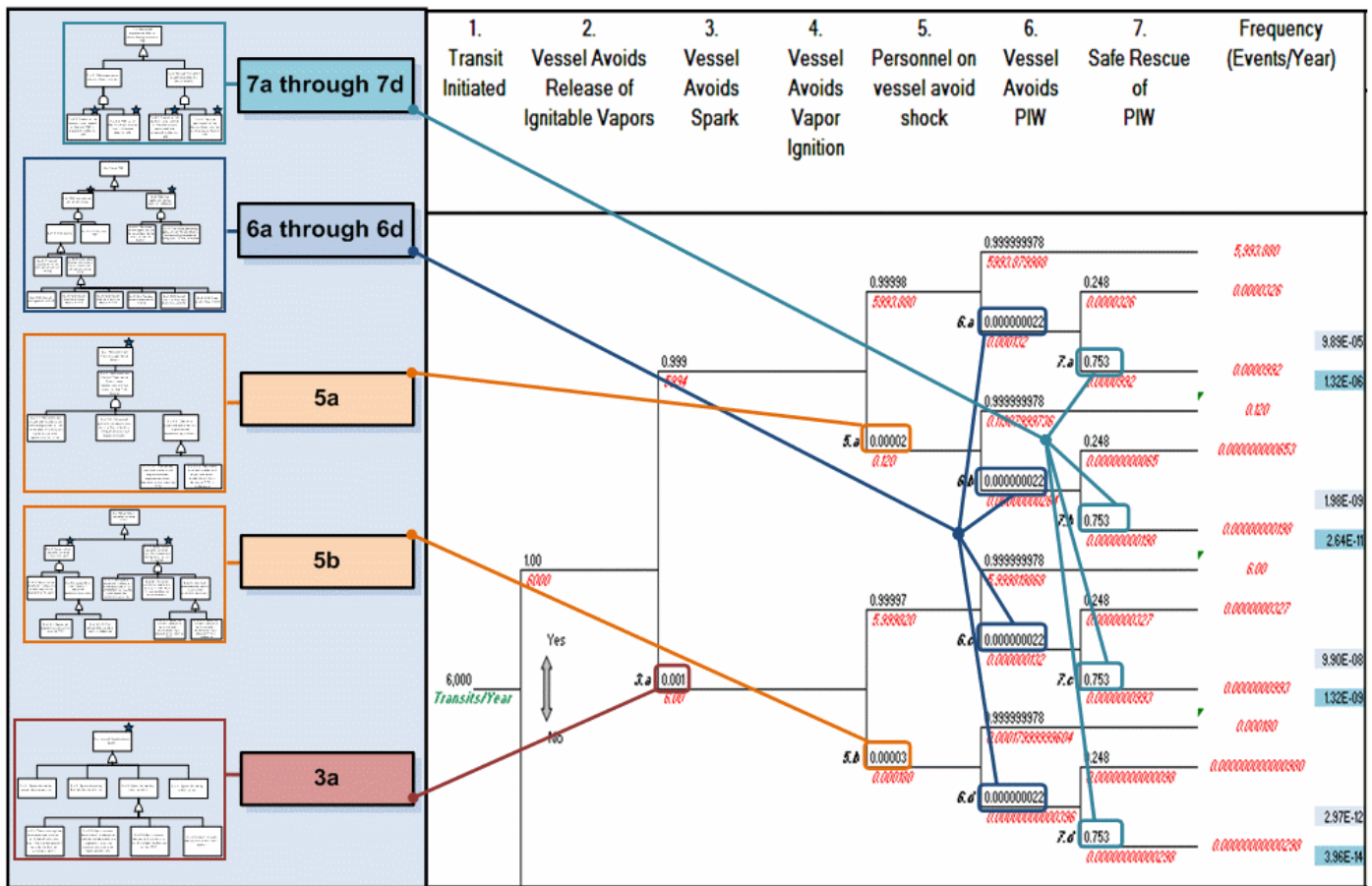


Figure 6. Event tree (on right) with associated fault trees (on left).

Figure 7 shows the fault tree for Path 6.a. The fault tree is relatively simple and involves OR / AND logic. (Note: As a convention, when OR and AND are upper case, they refer to fault tree logic. OR (union or addition) implies that any of the inputs will result in the output. AND (intersection or multiplication) indicates all inputs are required for the output to occur.)

We quantified these fault trees at the first or the second level of the tree. The events quantified at the second level involve AND gates. The probability of the top event for these AND gates is the product of the failure probabilities of the two input events. A key assumption is that all events are independent.

This fault tree has an OR gate at the top, with two inputs to the OR gate indicating that either failure could result in the top event occurring. The input on the left (Event 6.a.1) addresses “PIW from CAS.” This event has an AND gate under it with two inputs indicating that both failures must occur to have Event 6.a.1 occur. The input on the right (Event 6.a.2) addresses “PIW from commercial activities during transit of the safety zone.” This event has an AND gate under it with two inputs, also indicating that both failures must occur to have Event 6.a.2 occur. There is a star placed next to Events 6.a.1 and 6.a.2 indicating that this is the level where the probability is assigned. All events at a level above the stars are based on the starred event values. The events shown below the “star” level are included to (1) portray how non-adherence to regulations can lead to marine safety failures and (2) support discussion and understanding when assigning a probability to the higher level event. A key assumption in the quantification process is that all events are independent.

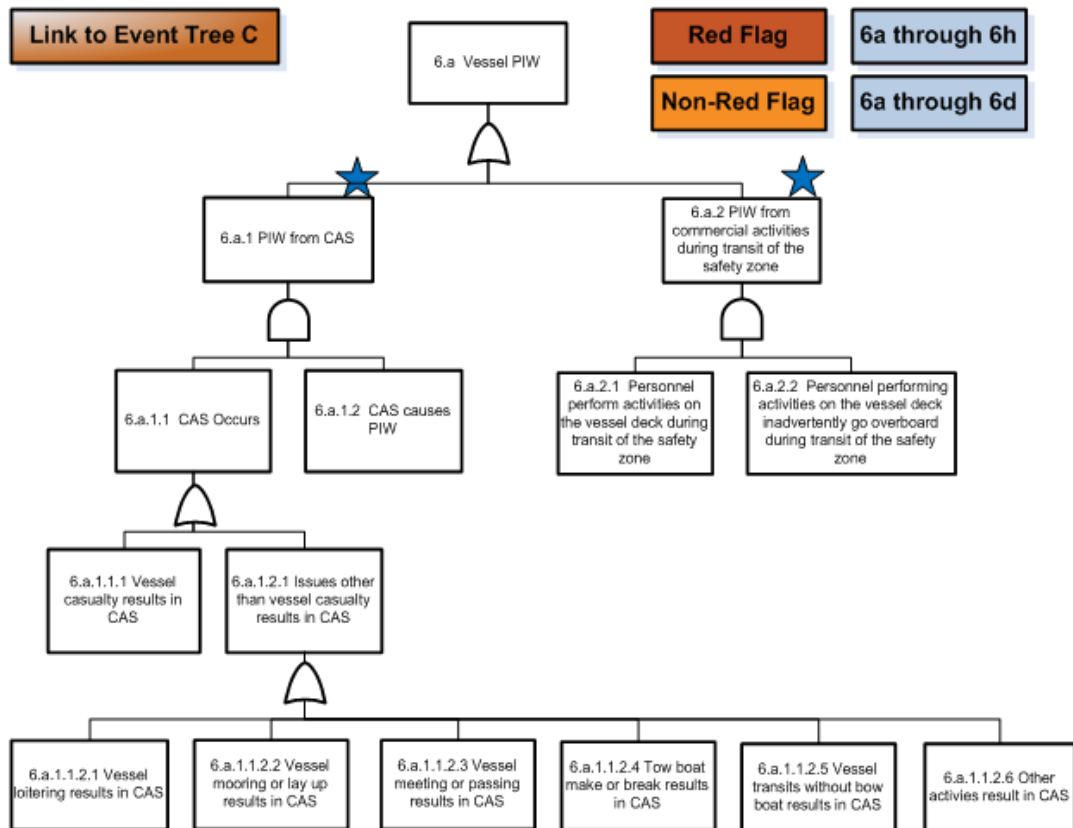


Figure 7. Fault tree for path 6.a to 6.h vessel PIW.

Appendix B provides an overview of each of the remaining fault trees for Event Tree C.



2.3.3.2.2 Detailed Description for STEP B: Develop/Apply Inputs

B.1 Probability Category Table

Each downward (failure) branch in the event tree must have a probability of occurrence value. These probabilities may be either (1) an assigned value (AV) based on calculations or (2) a representative value (RV) for a probability category as described in Table 9. The benefits of using these probability categories and their associated representative value include:

- Efficient—Instead of spending substantial time and resources deriving a probability value, an analyst can simply choose the category with the *probability range* that best represents the event.
- Wide-ranging—The representative value for the category reflects the full range of values within the category. Since the representative value embodies a range of values, it is not sensitive to small changes in information that influenced the analyst to choose the category.
- Relatable—Each probability category has “objective” and “similar situation” benchmarks that can improve the user’s confidence that the most appropriate category is selected.

Table 9 presents 15 categories of probabilities that show the upper and lower bounds and a representative value. These 15 categories range from 1.0 to 0.0000001. This wide range can address events that are almost certain to occur to events that are very rare and are not expected to happen. The breadth of the ranges for categories 6 through 15 are each half of an order of magnitude. Table 9 also provides objective and “similar situation” benchmarks to orient the user to each category. The description column aids in characterizing the expectation of seeing the category occur, given the opportunity.

While probability categories have the benefits described above, none of the representative values was used in this analysis. However, this table can be useful in any future studies of marine safety risk for the CSSC RNA.



Table 9. Probability categories for failure branch modes.

Category	Upper Bound	Lower Bound	Representative Value	Benchmarks		Description
				Objective	Similar Situations	
1	1	0.9	1	Occurs about 10,000 out of 10,000 opportunities	A. Category generally not meaningful when selecting probabilities for failure path; may be useful in describing a success path	Almost certain to happen given the opportunity
2	0.9	0.75	0.85	Occurs about 8500 out of 10,000 opportunities	See "A" above.	Expected to happen given the opportunity
3	0.75	0.5	0.65	Occurs about 6500 out of 10,000 opportunities	B. Category may be meaningful for failure branch where failures have already occurred	Likely to happen given the opportunity
4	0.5	0.3	0.4	Occurs about 4000 out of 10,000 opportunities	See "B" above.	Slightly less than a 50/50 chance of happening given the opportunity
5	0.3	0.1	0.2	Occurs about 2000 out of 10,000 opportunities	See "B" above.	Only slightly surprising to happen given the opportunity
6	0.1	0.05	0.08	Occurs about 800 out of 10,000 opportunities	See "B" above.	Still not too surprising to happen given the opportunity
7	0.05	0.01	0.03	Occurs about 300 out of 10,000 opportunities	C. Category may apply to failure branches preceded by a combination of successes and failures	Somewhat surprising to happen given the opportunity
8	0.01	0.005	0.008	Occurs about 80 out of 10,000 opportunities	See "C" above.	
9	0.005	0.001	0.003	Occurs about 30 out of 10,000 opportunities	See "C" above.	Surprising to see happen given a single opportunity
10	0.001	0.0005	0.0008	Occurs about 8 out of 10,000 opportunities	See "C" above.	
11	0.0005	0.0001	0.0003	Occurs about 3 out of 10,000 opportunities	See "C" above.	
12	0.0001	0.00005	0.00008	80% chance of occurring once in 10,000 opportunities	D. Category may apply to failure branches not preceded by other failures	Extremely surprising to see happen given a single opportunity
13	0.00005	0.00001	0.00003	30% chance of occurring once in 10,000 opportunities	See "D" above.	
14	0.00001	0.000005	0.000008	Has about an 8% chance of occurring once in 10,000 opportunities	See "D" above.	
15	0.000005		0.0000001	1% chance of occurring once in 10,000 opportunities	E. Category may not be realistic for any of the failure branches	



B.2 Frequency and Probability Inputs Rationale

The structure of the *Frequency and Probability Inputs Rationale* (Table 10) is the key to documentation and selection of event frequency and event probabilities used to generate scenario frequency results. The table includes the event and associated input values, reference data, and input value selection.

Table 10. Excerpt from *Frequency and Probability Inputs Rationale* table.

Branch Failure Path Event	Event Description	Input Value*	Reference Data			Input Value Selection
			Value	Source	Data Scoring and Calculations	
6.a	C-N.6.a Vessel PIW (after vessel avoids release or spark)	0.000000022	0.000000022	Calculated value	This event is calculated as either C-N.6.a.1 OR C-N.6.a.2 occurring.	
6.a.1	C-N.6.a.1 PIW from collision, allision or sinking	0.000000002	0.0000002	1, 2	This event requires both a CAS and the CAS resulting in a PIW. The key driver is allisions which occur with varying severities. CAS events that could result in a PIW are very unlikely in the RNA given the current regulations recommending personnel to remain inside during the transit. There have been no reported occurrences of a PIW event to date. The historical record of about 6000 commercial transits per year for 7 years indicates that the cumulative value should be less than 0.00002. Because of the requirements that are in place to minimize the possibility of a CAS in the fish barrier and the practice of commercial vessels to have all personnel inside for the duration of the transit, it is expected that the actual rate of CAS events that cause a PIW will be at least a factor of 10 less than the current experience. Thus, a value of 0.000002 is used. [Note: This value implies one PIW from a CAS in about 83 years under the current rules and practice.]	The data from the AWO report reflects nationally based information on transits in canals for a year. Thus, the AWO based data is used to represent this event.
			0.000000002	3	The calculation for C-N.6.a.2 is based on canal related data and results in a probability of a person falling overboard during a commercial transit of the CSSC of 0.00000002. The data source did not identify any contribution for mariners falling overboard from allisions, collisions or sinkings. It is assumed that this would not be more than a 10% contributor. Thus, the probability of a PIW from a collision, allision, or sinking during a transit of the CSSC is 0.000000002.	

- **Branch Failure Path Event:** This column lists all events used in the quantification of the event scenarios in each event tree (See Section A.1). The event identifiers in the Branch Failure Path Event column include the branch events and starred events in the associated fault trees (see Section A.2).
- **Event Description:** All the events in the “Event Description” column are all used in the scenario quantification process, and include the events at the event tree branch level (e.g., Event 1, Event 2.a, and Event 3.a) as well as any relevant events from an associated fault tree (e.g., Event 6.a.1, Event 6.a.2). For example, Event 6.a is included in the table to address the downward or failure branch representing “Vessel PIW (after vessel avoids release or spark).” However, the table will also include Event 6.a.1 “PIW from CAS” (shown) and Event 6.a.2 “PIW from activities during transit of the safety zone.” The logic in the fault tree for these events is OR logic indicating that if either of the events occurs, then the Event 6.a will occur.
- **Input Value:** This column contains the frequency or probability value that for the event tree quantification. We obtain the value from the conclusion of the data selection column on the right-hand side of the table. Values selected are either a Representative Value [RV] for the category based on the Probability Categories for Branch Points chart (Table 9) or an Assigned Value [AV] based on calculations from the table.



- **Reference Data:** This column identifies all relevant data sources for the specific associated event (e.g., Event 6.a), describes the data from each source and how the data was used to establish a frequency or probability value, and presents the established frequency or probability. This column is subdivided into columns of “Value,” “Source,” and “Data Scoring and Calculations.” The Value column may include multiple input values. If multiple values appear, the input value used in the analysis appears in the Input Value column. The basis for selecting the Input Value appears in the Input Value Selection column. Each event can have as few or as many data sources as are identified by the analysis team. Common data sources include U.S. Army Corps of Engineers, U.S. Coast Guard, and SMEs.

Once analysts specify a data source, they list or describe the relevant data from that source. For example, the data may include the number of hours per year the waterway experiences a certain condition or the failure rates and repair times for critical equipment. The analyst must then describe how this raw data applies as an initiating event frequency or a failure event probability.

Where the event represents a branch in the event tree (e.g., Event 6) with the calculation based on events in an associated fault tree (e.g., Events 6.a.1 and 6.a.2); then the source for the event should reference all supporting events. The data scoring and calculations column should also describe the probability values from those sources, and how values are combined to establish the event tree branch probability (e.g., Event 6.a is calculated as the combination of events 6.a.1 OR 6.a.2).

Input Value Selection: This column provides a review of the data sources and a selection of the value that was used for the associated event. The selected value can be one of the values directly obtained or calculated from one of the sources, or it can be a value based on all of the sources.



B.3 Frequency and Probability Inputs

The event tree model has a table for all of the frequency and probability inputs to the event tree failure branches. Table 11 shows an excerpt from the Frequency/Probability Inputs Table. The table provides the Input Value associated with the Event that corresponds to the values chosen and recorded in Appendix C.

Table 11. Excerpt from frequency/probability inputs table.

Events	Commercial Vessel Events			
	Red Flag		Non-Red Flag	
Initiating Event	1.a	600	1.a	6000
Congestion Related CAS				
Release of Ignitable Vapors	2.a	0.5000020		
	2.a.1.1	0.000020		
	2.a.1.2	0.100000		
	2.a.2	0.500000		
Spark	3.a	0.001000000	3.a	0.001000000
	3.b	0.001000000		
Ignition	4.a	0.0000100000		
	4.a.1	0.0001000000		
	4.a.2	0.100000000		
Person Experiences a Shock	5.a	0.0000200000	5.a	0.0000200000
	5.b	0.0000300000	5.b	0.0000300000
	5.b.1	0.0000100000	5.b.1	0.0000100000
	5.b.2	0.0000200000	5.b.2	0.0000200000
	5.c	0.0000200000		
	5.d	0.0000300000		
	5.d.1	0.0000100000		
	5.d.2	0.0000200000		
	5.e	0.0000300000		
	5.e.1	0.0000100000		
5.e.2	0.0000200000			

B.4 Consequence Inputs

The risk results require combining frequency and consequence results for each loss scenario/incident in the event tree. This section describes consequence results development for the six consequence types in this study:



CSSC Marine Safety Risk Analysis

This risk analysis relies on establishing meaningful average consequences, given an incident occurs. An average consequence value for a particular consequence type (e.g., PIW-Related Electric Shock) provides consideration for the full spectrum of consequence values that might occur during the lifecycle of the fish barrier system.

The Coast Guard Consequence Equivalency Matrix (2009 NMSRA study) addressed a wide range of consequence types (e.g., safety, economic, environmental) and placed these consequence types into categories with equivalent levels of severity. This study uses that basic structure to frame five severity categories with upper and lower bounds and a representative value (Table 12).

Table 12. Severity categories.

Severity Category	Representative Value (\$)	Lower Bound (\$)	Upper Bound (\$)
Very High (VH)	10,000,000,000	3,000,000,000	
High (H)	7,000,000	3,000,000	3,000,000,000
Medium (M)	300,000	10,000	3,000,000
Low (L)	4,000	1,000	10,000
Null	-	-	1,000

Ideally, to establish an average consequence value for a particular loss-event type, we would have a history of thousands of similar systems that cover hundreds of thousands of years of relevant operating history. If such a history existed, we could collate these results into the five severity categories in Table 5. We could then establish a fraction for each severity category for the particular loss type, based on the fraction of the total incidents that actually occurred in that particular severity category.

For example, if there were 1000 total incidents for a particular loss type, and 800 of these incidents were of “Low” severity, then we would assign the Low severity category a fraction of 0.8. In addition, we could sum the losses associated with the 800 incidents in the Low severity category, then divide by 800 to obtain a representative loss value. Similarly, we could establish fractions and representative values for each severity category, and determine an overall average consequence value. This overall average consequence, when multiplied by the expected frequency of occurrence for the associated scenario, establishes an expected loss (risk) for the scenario. Thus, the model would be correct for reflecting what has happened and would be very useful in predicting future losses, given an incident occurs.

For this assessment, there is a limited history of operations for the CSSC RNA with no recorded losses attributable to the fish barrier system. Based on this, we cannot establish a statistically meaningful distribution for severity fractions for each consequence type. Instead, we developed a rationale for these severity fractions based on the best available information, analysis, and subject matter expertise.

To perform this analysis, we need severity category fractions for each consequence type relevant for each initiating event. Table 13 shows all consequence types analyzed marked with an X. To generate a total expected loss or risk, we first need an average consequence for each identified situation (i.e., we calculate the total expected loss or risk by multiplying the frequency for each scenario by the average consequence value for the consequence type). Therefore, each of the identified situations in Table 6 requires a unique set of severity fractions to establish the associated average consequence.



Table 13. Summary of analyzed CSSC loss types.

General Situation Analyzed ¹	Initiator Type ²	Consequence Types Analyzed					
		Electric Shock				Spark-Related Vapor Ignition	Congestion-Related Collision, Allision, or Sinking (CAS)
		Commercial or Recreational-Related Activities	Contact-Related	PIW-Related	PIW Rescuer-Related		
Event Tree C: Commercial Vessel Transit of the Safety Zone	Red Flag	X	X	X	X	X	
	Non-Red Flag	X	X	X	X		
Event Tree R: Recreational Vessels Transit of the Safety Zone	Greater than 20 feet	X		X	X		
	20 feet or Less and PWC	X		X	X		
Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA)	All types			X	X		X
Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore	All types			X	X		

¹ Determines structure of the Event Tree

² Determines Initiating Event frequency and associated branching event probabilities

Appendix D has detailed information on the fractions assigned to each of the severity categories for each consequence type analyzed (i.e., for each situation with an “X” in Table 13). This information includes both the fraction used and the rationale for this fraction. This detailed information allows for a clear understanding of the values used in this report, and provides a basis for adjustments in future applications.

Depending on available information, the analysis team worked the problem using a bottom-up approach, a top-down approach, or both. The bottom-up approach takes available information and estimates a balance of severity category fractions that best reflect the anticipated range of conditions given an incident occurrence involving the consequence type. (Note that severity fractions must always add to 1.0 or 100%). An average consequence is then calculated using these values. On the other hand, the top-down approach estimates an average consequence, and then modifies the severity category fractions to obtain the estimated average consequence.

Table 14 shows the use of severity fractions to calculate an average cost for a consequence type. This example is for PIW-related electric shock for commercial red-flag vessels making a transit of the safety zone. The table has the five severity categories. Each severity category has a representative value shown in parentheses, and an associated severity fraction and average cost. The High severity category has a severity fraction of 0.25, based on the detailed discussion for each severity fraction provided in Appendix D. We multiply this fraction by the associated representative consequence for the severity category of \$7,000,000 (estimated value of a human life) to establish the average cost of \$1,750,000 for the High severity category.



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We repeat this process for each of the severity categories, and sum the results to establish a total average cost of \$1,841,796 for this consequence type.

Table 14. Example of the use of severity fractions to calculate an average cost for a consequence type.

PIW-Related ES		
Category	Severity Fraction	Average Cost (\$)
VH (\$10B)	0	-
H (\$7M)	0.25	1,750,000
M (\$300K)	0.3	90,000
L (\$4K)	0.449	1,796
Null (\$0)	0.001	-
Total	1	1,841,796

Using this approach, we determined an average cost for each of the situations marked with an X in Table 13. As mentioned above, Appendix D provides content similar to Table 14 for each of these situations along with discussion on how each fraction was established.

2.3.3.2.3 Detailed Description for STEP C: Generate Outputs for Key Decision Factors

Figure 4 (see page 18) presented the format for displaying the results for four of the six consequence types/decision factors. In this step, the total marine safety risk includes contributions from each of the six analyzed initiators (where relevant), for each of the six decision factors.

Table 15 gives an example of the risk results for each decision factor (consequence type), showing the risk contribution for each initiator.

Table 15. Risk results example for *one* CSSC RNA decision factor (PIW Electric Shock).

Decision Factor		Event Tree C: Commercial Vessel Transit of the Safety Zone [\$/year]		Event Tree R: Recreational Vessels Transit of the Safety Zone [\$/year]		Event Tree A: Vessels Approach of the RNA [\$/year]	Event Tree S: Personnel on the RNA Shore [\$/year]	Totals [\$/year]
		Red Flag	Non-Red Flag	Greater than 20 feet	20 feet or less and PWCs			
PIW-Related ES	Frequency	0.00001403	0.000099	0.000315	0.0105	0.00788	0.00770	
	Consequence (\$)	1,841,796	1,841,796	1,841,796	1,841,796	7,000,000	7,000,000	
	Expected Loss (\$)	25.8	182	580	19,339	55,125	53,865	129,117



2.4 Risk Analysis Validation and Results

Based on preliminary values for frequency, probability, and consequence, the project team conducted a Validation Session that included CSSC waterway users and facility operators, and federal and state government representatives on June 18-19, 2013 in Romeoville, Illinois.

2.4.1 The Validation Process:

The validation session presented the preliminary values (based solely on data analysis and project team interpretation) to local subject matter experts (SMEs) (Table 16). The goal was to determine whether the frequency and probability of event occurrence and resulting consequence values were in line with the experience and knowledge of those most familiar with CSSC activity.

Table 16. Risk analysis validation session participants.

Tuesday 18 June 2013	Wednesday, 19 June 2013
5 - Industry	4 - Industry
6 – Coast Guard	4 – Coast Guard
1 - USACE	1 - USACE
3 – State (IDNR)	2 – State (IDNR)
1 – Local responder	1 – WI Sea Grant

In the course of the validation session, a risk expert proposed a value from the preliminary analysis, then polled the participants as to their thoughts on a given value. Participants had four voting options:

1. Accept – “Sounds Reasonable; I’m OK with that value.”
2. Mildly Object – “It’s in the ballpark, but I prefer a different value.”
3. Strongly Object – “The value is not in the ballpark; I require a different value.”
4. I Don’t Know – “I don’t have the experience or enough information to answer.”

If any participants indicated objection, the risk expert would try to determine the rationale for the objection, and would suggest that those who objected offer a new value. The risk expert would then re-poll the participants, and through either iteration or consensus, reach a revised value where no one “strongly objected” to the value.

2.4.2 Validation Session Input

As examples of validation input for initiating event frequency, the preliminary data estimated a maximum of 600 red-flag transits per year, but the local SMEs indicated that 850 red-flag transits was more realistic. Another significant change was that preliminary analysis indicated that there are 15,000 times a year when people are on the shore (canal bank) in the RNA. Local SMEs indicated that 30,000 events are more realistic.



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For probability of incident occurrence, preliminary analysis indicated that a commercial red-flag barge collision, allision, or sinking (CAS) would occur once in 50,000 transits. Instead, after discussion, local SMEs proposed and accepted one CAS in 5,000 transits. A second example of a change is with a person in the water (PIW) from a recreational vessel during transit. Preliminary analysis showed that this would occur once in 330,000 transits. Because the analysis based this probability on worst-case, national statistics, the local SMEs felt that due to the regulations, the probability would be less in the CSSC, and accepted one occurrence in 3,300,000 transits.

Consequence analysis also resulted in changes. In these instances, if there was no disagreement with the initial consequence value, SME input addressed the severity fraction for each consequence value.

Appendix E provides specifics of the voting results. The risk results for each of the decision factors/consequence types are shown in Table 17. Appendix F contains detailed risk results.

As indicated, the total “expected annual loss” or total annual risk to marine safety related to the electrified barrier is less than \$137,000 per year. By far, the largest contributor to this risk is person in the water related electric shock. Then, categorized by contributors to the PIW related ES, the largest risks are associated with personnel on the shore in the RNA, followed by personnel entering the water from vessels approaching the RNA, and then persons receiving electric shock due to operation of recreational vessels 20 feet or less (and PWCs).



Table 17. Risk results summary comparison.

Decision Factors		Event Tree C: Commercial Vessel Transit of the Safety Zone				Event Tree R: Recreational Vessels Transit of the Safety Zone				Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA)		Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore	
		Red Flag		Non-Red Flag		Greater than 20 feet		20 feet or less and PWCs		Preliminary Results	Validated Results	Preliminary Results	Validated Results
		Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results				
Activity-Related ES	Frequency (events/yr)	0.01	0.02	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-	-
	Consequence \$/event	20	20	20	20	370	370	370	370	-	-	-	-
	Risk (\$/yr)	0.2	0.3	2	2	50	50	50	50	-	-	-	-
Contact-Related ES	Frequency (events/yr)	0.00001	0.00001	0.0001	0.0001	-	-	-	-	-	-	-	-
	Consequence \$/event	400	400	400	400	-	-	-	-	-	-	-	-
	Risk (\$/yr)	0.002	0.003	0.02	0.02	-	-	-	-	-	-	-	-
PIW-Related ES	Frequency (events/yr)	0.00001	0.00001	0.0001	0.0001	0.003	0.000	0.01	0.01	0.0002	0.0079	0.005	0.008
	Consequence \$/event	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	4,603,196	7,000,000	4,603,196	7,000,000
	Risk (\$/yr)	20	30	200	200	6,000	1,000	20,000	20,000	700	55,100	20,000	50,000
PIW Rescuer-Related ES	Frequency (events/yr)	0.0000001	0.0000009	0.000001	0.000006	0.002	0.00004	0.000014	0.001397	0.000021	0.000520	0.00009	0.00053
	Consequence \$/event	67,800	67,800	67,800	67,800	777,000	1,811,800	67,800	1,811,800	67,800	67,800	67,800	67,800
	Risk (\$/yr)	0.009	0.062	0.09	0.44	2,000	80	1	2531	1	35	6	36
Spark-Related Vapor Ignition	Frequency (events/yr)	0.000003	0.000004	-	-	-	-	-	-	-	-	-	-
	Consequence \$/event	400	400	-	-	-	-	-	-	-	-	-	-
	Risk (\$/yr)	0.001	0.002	-	-	-	-	-	-	-	-	-	-
Congestion-Related CAS	Frequency (events/yr)	-	-	-	-	-	-	-	-	0.1	0.1	-	-
	Consequence \$/event	-	-	-	-	-	-	-	-	39,760	39,760	-	-
	Risk (\$/yr)	-	-	-	-	-	-	-	-	4,000	4,000	-	-

Due to modeling and data uncertainties, the analysis team rounded most results to one significant figure.

3 VIDEO RECORDING REVIEW AND ANALYSIS

While reviewing the first month's CSSC video data, the project team realized that in addition to raw numbers, there was a significant amount of activity-related information in the video record. As this was not the initial purpose of video recording, the project team did a more-detailed review of the second and third month's records. From this comprehensive look, we noted instances where vessel activity did not necessarily comply with provisions of the 33 CFR 165.923, and noted other anomalies that may illustrate possible areas for changes to regulatory, risk mitigation measures.

Figures 8-14 give an example of a situation that caused the project team to consider whether non-compliance with 33 CFR 165.923 is intentional, or due to misunderstanding the rule. Figure 8 shows what appears to be an empty (or partially laden) tank barge as it transits southbound (downstream) under the pipeline arch, approaching barrier 1.



Figure 8. Tank barge transiting southbound (hour 1 minute 25).

Figure 9 shows the tow has reduced speed and is approaching east bank. Figure 10 (hour 1 minute 32) shows the tow alongside CSSC east bank, head end just north of barrier 1 array. (Note: 33 CFR 165.923 (b)(2)(ii)(D) All vessels are prohibited from loitering in the RNA, (E) Vessels may enter the RNA for the sole purpose of transiting to the other side and must maintain headway throughout the transit, and (G): Vessels may not moor or lay up on the right or left descending banks of the RNA.)



Figure 9. Tank barge approached bank (hour 1 minute 31).



Figure 10. Tank barge alongside CSSC east bank.

During the next 15 minutes, the tow keeps station alongside the east bank, never actually mooring, but from video, possibly maintaining “contact” with the bank for more than the next 15 minutes.



Figure 11 shows a hopper barge tow passing the tank barge. (Note: 33 CFR 165.923 (b)(2)(ii)(B): Vessels in commercial service may not pass (meet or overtake) in the RNA...)



Figure 11. Hopper barge passing tank barge.

Figure 12 and Figure 13 show what appears to be a bow boat tying up to the barge. (Note: 33 CFR 165.923 (b)(2)(ii)(H): Towboats may not make or break tows if any portion of the towboat or tow is located in the RNA.) If the tank barge tow was required to take a bow boat, it was prior to entering the RNA at mile 297.2. (Note 33CFR 165.923 (b)(2)(ii)(A): All up-bound and down-bound barge tows that consist of barges carrying flammable liquid cargos (Grade A through C, flashpoint below 140 degrees Fahrenheit, or heated to within 15 degrees Fahrenheit of flash point) must engage the services of a bow boat at all times until the entire tow is clear of the RNA.) The bow boat becomes part of this tow within the RNA at mile 296.7, by making up to the bow of the tank barge. Figure 13 and Figure 14 show people on deck (yellow circles).



Figure 12. “Bow boat” approaches the barge (hour 2 minute 21 (a)).



Figure 13. Person on deck of barge (hour 2 minute 21 (b)).



Figure 14. Two people on deck of barge (hour 2 minute 22).

This series of video-capture images is but one of multiple instances of “anomalous activity” the project team noted during the video review.

4 OXBOW SHORE MEASUREMENTS

In October 2012, RDC and SAIC investigated whether electrical currents associated with the CSSC Dispersal Barrier pose a hazard to workers at the Oxbow Midwest Calcining, LLC barge loading facility (see Figure 15). The team conducted the tests on a not-to-interfere basis, during barge loading and idle periods. Barrier I and Barrier IIB were operating normally during the 23-25 October 2012 measurement period.

Voltage measurements & data analysis showed that during present, routine barge-loading activities (e.g., boarding, mooring/unmooring, shuttle movement, & loading) workers are not normally exposed to hazardous electrical currents. To convert the actual voltage measurements to electrical current, we used a nominal human-body resistance of 500 ohms, a widely accepted value that assumes electrical contact with bare, damp skin. In reality, resistance through a human body varies: lower if electrical contact includes puncturing the skin, higher if the skin is dry. Standard industrial hygiene and personal protective gear (e.g., rubber-soled boots, dry gloves, etc.) provides an even higher degree of electrical safety protection. During 3-1/2 days of set-up, testing, and demobilization, none of the 4-person test team perceived any electrical current, besides the voltage traces indicated on the test equipment video monitor.



Figure 15. Oxbow Facility with shore measurement test points.

At all test points, a distinct 5 Hz signal correlated to the maximum measured voltage. At multiple test points, particularly near the pipeline arch, a 60 Hz signal provided significant electrical “noise.” At the southernmost test points, measurements indicated relatively higher voltages than elsewhere.

Barge movements, particularly multiple-tow transits through Barrier I, appear to impact electrical currents. The highest voltages measured during the experiment were near the southern mooring-shuttle-block during a northbound tow. (Note: the effect of tow-transit on electrical field was not designed as part of this experiment.) The testing did indicate anomalous water-to-ground voltage measurements at the southernmost extent of the Oxbow area (beyond present use-area) during an upbound, 3 x 2 tow transit while the tow was near the vicinity of Barrier I. Table 18 gives a summary of the results and Table 19 Lists the physiological effects of electric current on the body. **Note: The full report appears as Appendix F.**

Table 18. Summary table; maximum voltage and current magnitude.

(with R = 500 Ohms, representative of typical human body impedance).

Test Point	Perpendicular Step (V)	Perpendicular Step (mA)	Parallel Step (V)	Parallel Step (mA)	Touch Point (V)	Touch Point (mA)	Water Touch (V)	Water Touch (mA)	Barge Touch (V)	Barge Touch (mA)
1A	0.451	0.902	3.983	7.966	5.281	10.562	21.09	42.18	--	--
1	0.237	0.474	2.635	5.27	3.547	7.094	20.93	41.86	--	--
2	0.885	1.77	0.979	1.958	2.998	5.996	--	--	--	--
3	0.2	0.4	0.326	0.652	0.857	1.714	4.098	8.196	--	--
4	0.036	0.072	0.101	0.202	0.885	1.77	1.86	3.72	2.366	4.732
5	0.211	0.422	0.098	0.196	0.099	0.198	1.466	2.932	1.388	2.776
6	0.086	0.172	0.27	0.54	1.603	3.206	--	--	--	--
7	0.113	0.226	0.073	0.146	2.077	4.154	--	--	--	--
1 w/tow	0.494	0.988	6.565	13.13	5.696	11.392	47.21	94.42	--	--
3- w/tow	0.129	0.258	0.652	1.304	2.07	4.14	10.000*	20.00*	--	--

*The scale setting used during this test limited the instrument’s maximum voltage measurement capability. The “time-voltage signature during barge pass at test point 3 indicates a higher peak reading may have been present.



Table 19. Physiological effect of electric current on the body.

Current (mA)	Physical Symptoms	Chart Color
0-1	Threshold of Perception (slight tingling sensation)	Blue
1-6	"Let-go" Threshold, Women	Green
1-9	"Let-go" Threshold, Men	Yellow
9-25	Pain, difficult or impossible to release objects, possible loss of muscle control	Orange
60-100	Ventricular fibrillation, stoppage of heart	Red

5 REGULATORY DEVELOPMENT AND RULE CHANGES

The present rule 33 CFR 165.923, Safety Zone and Regulated Navigation Area, Chicago Sanitary and Ship Canal, Romeoville, IL of 1 December 2011, is the latest in a series of regulatory actions to promote safety and to limit the spread of invasive species in the CSSC. (The first rule was issued 1 January 2006.)

Figure 16 is a chart showing the Safety Zone and RNA.

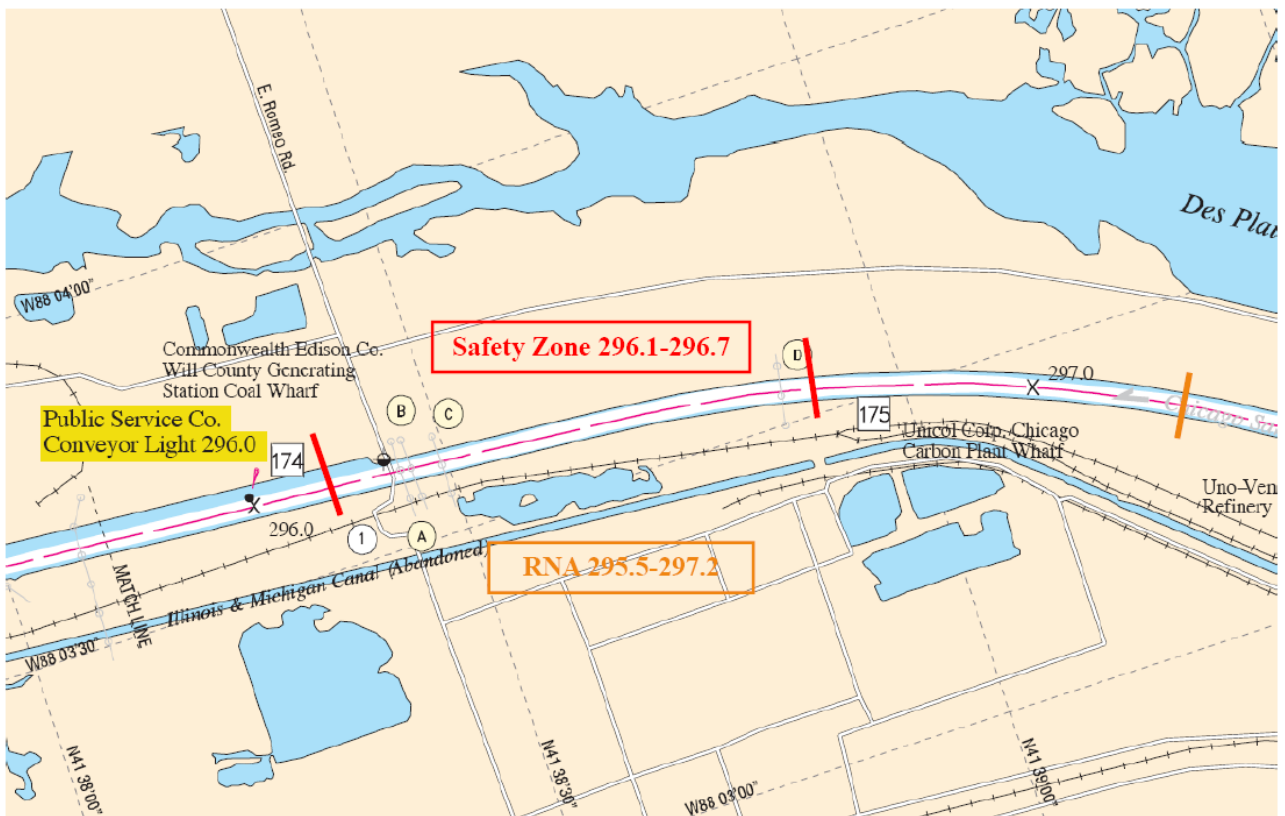


Figure 16. Chart showing Safety Zone and RNA.

5.1 Regulatory Development Background

Throughout the rule history, authors have made various subtle and not so subtle changes to the rule to account for the evolution of understanding risk and modifications to the electric barriers, or to account for special environmental or safety circumstances. On 1 January 2006, the Coast Guard recognized the



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importance of barrier-related marine safety issues by establishing special rules for operating within the barrier and created an RNA. This original RNA differed from today's RNA, in that it was shorter, consisting of the *waters in the CSSC between the Romeo Road Bridge at mile marker 296.1 and the aerial pipeline at marker 296.7*.⁵ These rules were meant to ensure that:

- No vessel within the RNA was permitted to pass another vessel, loiter, lay-up, or break/make-up their tows.
- All vessels were to maintain headway at all times.
- For the safety of crewmembers at risk of falling overboard, anyone on open decks was required to wear a Type 1 personal flotation device (PFD).
- Commercial towing vessels were to use wire rope to build in electrical connectivity between all segments of the tow.

Thirty days following the initial rule, the Coast Guard established a Safety Zone⁶ to coincide with the boundaries of the RNA so that the Captain of the Port had the authority to intermittently control entry into the area. Their purpose for creating this Safety Zone was to preserve marine safety while a second permanent electric dispersal barrier was being constructed and tested. *The Safety Zone was intended as a temporary measure and put into place from 30 January 2006 through 28 February 2006 (§165.T09-142)*. Months later, additional construction and refurbishment of the electric barriers was necessary and the Coast Guard created a second temporary Safety Zone on 10 April 2006. Similarly, the Captain of the Port established this rule to intermittently control entry into the RNA. This regulation was put into place from 10 April 2006 through 30 June 2006 and is identified as §165.T09-018.

On 30 May 2008 the District Commander signed a combined Notice of Proposed Rulemaking and Temporary Final Rule (§165.T09-0470) instituting both a Safety Zone and RNA, *which again covered the same section of the CSSC (mile 296.1 to mile 296.7)*. The unique changes noted here were:

- The Captain of the Port received greater flexibility to close the Safety Zone while repairs to electronic barrier were undertaken.
- The Coast Guard now required a “bow boat” to provide towing assistance for all tows with at least one “red flag” barge.
- The bow boat provided additional towing assistance and was required to be made up to the tow at least one mile before **entering the RNA** from either direction.

The rule was in effect from 30 June through 15 August 2008.

Next, from 3 September 2008 through 1 November 2008, two additional temporary regulations were established to facilitate the closing of the RNA while repairs were being made to the electric barriers. The provision for “red flag” barge tows to take a bow boat at least 1 mile before entering the RNA remained in effect. The primary difference from prior temporary rules was the Safety Zone and RNA rulemakings are numbered separately.

⁵ The Regulated Navigation Area (33CFR165.923) implemented on 1 December 2011 extends from mile 295.5 to mile 297.2. Within the 1 December 2011 RNA is a Safety Zone extending from mile 296.1 to mile 296.7, coinciding with the same boundary as the 1 January 2006 RNA.

⁶ General Safety Zone provisions are contained within 33CFR165.23.



On 16 January 2009 the District Commander signed §165.T09-1247 with two purposes. The first was to establish a Temporary Interim Rule that would give the Captain of the Port the authority to enforce the Safety Zone intermittently from 18 January 2009 through 30 September 2009 while the Army Corps of Engineers was involved with the construction, refurbishment, and testing of the electric barriers. The second purpose was to publish a Notice of Proposed Rulemaking (NPRM) to request comments pertaining to the changes being temporarily implemented and proposed for a future final rule. A subtle change to the earlier versions of the navigation areas was that it slightly redefined the Safety Zone boundary by expanding it from mile 296.1 to mile 296.0 on the down bound end. The rule significantly changed the dimensions of the RNA. The RNA was expanded in size to extend from mile 295 through mile 297.5. By expanding the boundary of the RNA, the bow boat requirement was changed to eliminate the need for it to make up with a “red flag” tow one mile out from the original RNA. With the exception of the bow boat, wire rope, and prohibited passing (meet or overtake) by commercial vessels, all other earlier provisions of the RNA (§165.923) were continued and written so they were enforceable, not along the entire RNA, rather from the Romeo Road Bridge (mile 296.18) to the aerial pipeline (mile 296.7). In addition, this is the first of the rules to explain bow boat in the definitions, that being “the purpose of the bow boat was to provide positive control and prevent the tow of one or more barges from coming in contact with the shore and other moored vessels.” The rule distinguished between commercial vessels and vessels (including recreational).

The next two temporary rules (§165.T09-0767 and §165.T09-0942) suspended the prior Temporary Interim Rule (for the periods 17 August 2009 through 25 August 2009 and 16 October 2009 through 20 November 2009 during testing and evaluation of the increased electric current within the electric barriers. The slight change of the definition “On Scene Representative” made it clear that the Coast Guard’s Representative could be on *shore* and may communicate with vessels via either a VHF radio or loudhailer.

On 16 November 2009 the District Commander established a temporary Safety and Security Zone (§165.T09-1004) to be in effect from 24 November 2009 until 18 December 2009. Entry into the safety and security zones was prohibited for all vessels unless they complied with the provisions established by the Captain of the Port. The purpose of this rule was to restrict access during the application of Rotenone (a piscicide). This Safety and Security Zone differed from earlier temporary zones in two significant ways. First it separated the zones into two parts. The two parts were the Lockport Lock to Electrical Dispersal Safety and Security Zone and the Electrical Dispersal Area Safety and Security Zone. Secondly, after 0800 on 2 December 2009, vessels could not proceed through the Electrical Dispersal Safety and Security Zones except as may be permitted by the Captain of the Port depending on the clean-up efforts with the Rotenone application.

This rulemaking (§165.T09-1004) is the first time that any vessel of 20 feet or less and personal watercraft were forbidden from entering the Electric Dispersal Barrier Safety Zone. For bow boat purposes, the rule redefined a “red flag” barge as a barge carrying Grades A, B, or C with a flashpoint below 140 degrees Fahrenheit, or capable of being heated to within 15 degrees Fahrenheit of the flashpoint.⁷

On both 18 December 2009 and 22 November 2010, the District Commander published Temporary Interim Rules with Request for Comments (§165.T09-1080 and §165.T09-1054). The most noticeable change from earlier rules was the addition of a new requirement to the Safety Zone regulations. This requirement came

⁷ Since Grade “C” Cargoes have a flashpoint of 80 degrees or below, we assumed the bow boat requirement included Grade D cargoes having a flashpoint of up to 140 degrees Fahrenheit.



as a result the need to control the release of non-potable water from one side to the other side of the Safety Zone. If a vessel had non-potable water, it would be required to obtain COTP permission for carrying or discharging the water through the Safety Zone. Potentially confusing is the single exception found in Section (a) (2) (ii) where COTP notice is not mentioned for situations when “steps to prevent the release of non-potable water on board are taken and the discharge could be done in a biologically sound manner.”

These 18 December 2009 and 22 November 2010 Temporary Safety Zones reduced the size of the earlier 16 November 2009 Temporary Safety Zone by 1 mile, reestablishing the former dimensions in effect from 11 January 2006 through 15 November 2009 (mile 296.1 (approx 958 feet south of the Romeo Bridge) to mile 296.7.)

On 1 December 2011, the District Commander signed the Final Rule for Safety Zone and Regulated Navigation Area enforcement (33 CFR 165.923). The Safety Zone portion of the final rule implemented the former temporary provisions for the management of non-potable water. The RNA portion remained relatively unchanged except that it removed the restriction to vessels of 20 feet in length and less and personal watercraft.

5.2 Overview of Regulatory Changes

The fifteen rulemakings demonstrated an evolution of progress, risk awareness, and risk mitigation intent driven by the necessity to accommodate an evolution of learning and identification of risk. Changes to the rules were laborious as each new rule required a separate regulatory process and review for publication in the Federal Register. This process with its sheer number of rules and modifications to individual requirements could challenge the maritime industry and other waterway users to keep up with Federal Register notices. The leading reasons for potential confusion are mentioned below:

- a. The numbering scheme used from rule to rule changed making following the changes much more challenging. It was not uncommon for the same requirement to be identified by 6 different letters and numbers over the history of the changes;
- b. There were 15 rulemakings in 6 years.
- c. The use of Safety Zone, Security Zone, and RNA has specific meaning to the Coast Guard and are used for certain purposes. However, coupling them in some cases and adjoining them in other cases may challenge persons less familiar with the intent of the rules.
- d. “Red flag” barge cargo definition changed three times. The term “red flag” refers to a signal placed on the vessel when moored or at anchor with a bulk cargo regulated by Subchapters D and O. The flag requirements are in 46 CFR 35.30-1 and 151.45-9. Using common terminology but with different definitions could easily confuse everyday vessel operators.
- e. The original RNA was suspended, however was rewritten in its entirety into the new temporary rule.
- f. The RNA southern boundary shifted from miles 296.1 (2006) to 295.0 (Jan 2009) to 295.5 (Dec 2010). Similarly, over the span of 5 years, the northern end of the RNA changed from miles 296.7 to 297.5 to 297.2.
- g. Another significant change was that from 1 January 2006 until 15 November 2009, all personnel on deck were required to wear a “Type I personal flotation device.” As of 16 November 2009, the rule specified personnel on commercial vessels wore Type 1 and personnel on recreation vessels must wear “a Coast Guard approved personal floatation device.” Starting 18 December 2009, all personnel on decks must wear a Coast Guard approved personal flotation device. Potentially



confusing is that a work vest is a Type V PFD and could be (and probably is) worn on the deck of a commercial vessel.

- h. As of 1 December 2010, the rule required that “vessels be greater than 20 feet in length,” and that “vessels must not be a personal watercraft of any kind (e.g. jet-skis, wave runners, kayaks, etc.).” Authors omitted these two classes of vessels in the rule of 1 December 2011.
- i. Non-Potable Water requirements cover non-indigenous species control in the RNA, but are limited to the “Safety Zone.”

Table 20 summarizes the regulatory history by Rule, effective date, and either affected provisions or applicable conditions. It is divided into two parts to illustrate the chronological progression of rulemakings in the Federal Register and the corresponding requirement categories. The top part of the left column identifies each rulemaking in the order in which it came into effect. The bottom part lists the various provisions within the regulations. Differences in color help to distinguish between the effective dates of permanent rules and interim rules. In the upper section, the original rule (165.923) was cancelled from time to time to accommodate a set of revised provisions necessary for the frequency of changes to the barrier.

At any place in the timeline as it progresses to the right, one can draw a vertical line and intersect an assortment of color coded bars. By following the same colored bar to the left, one sees the general provisions in effect during the period of time represented by the shaded area. Note that the provisions listed on the left were not in effect for areas on any bar shown in white, so there were some gaps in the regulatory coverage.

5.3 Regulatory Development Summary

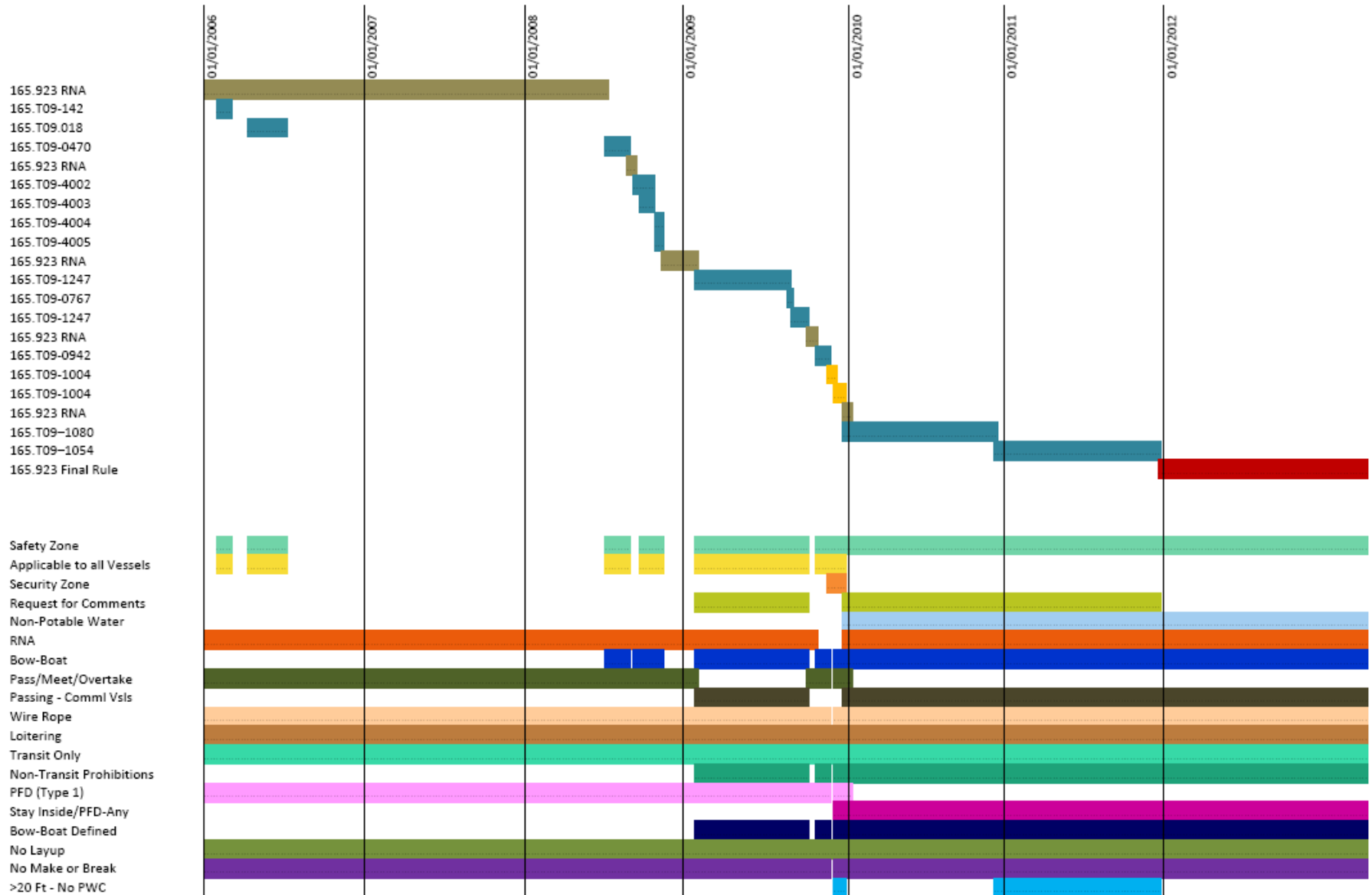
The project team notes there is no regulation of speed in the barrier area. While reviewing the video record, the team documented many instances where smaller watercraft would transit the area at speeds estimated at greater than 15 knots. Though there is a prominent “no wake” sign at the south end of the Oxbow loading area, a mariner sees it after they have exited the barrier.

The regulatory analysis did not review a copy of Oxbow’s waterfront facility permit. The project team assumes that all present activities are permitted, else operations at the Oxbow facility would be prohibited by the Rule. I.e., barges are moored at, tows are made-up and broken, and towboats “loiter” until barge loading operations are complete. In fact, the entire Oxbow facility (and much of the Materials Service Corporation) facility is in the RNA.

Since 2010, various members of RDC project teams have participated in scientific activities on the CSSC. Though we did not log every vessel-operator comment, nor photograph every instance of activity that might be questionable, project team members concur that commercial vessel operator actions indicate honest attempts to comply with provisions of the rule, even though the actual outcome might not necessarily be so.



Table 20. Regulatory history by rule, effective date and provisions.



6 CONCLUSIONS

The risk analysis indicates relatively low consequence values associated with marine activity near the Aquatic Invasive Species Electrified Dispersal Barrier, with an estimated annual, total loss-value of approximately \$137,000. By far, the largest marine safety risk (highest expected loss of approximately \$130,000 per year) is of shock to a person in the water. The risk analysis further associates the largest contributors to the risk as PIW from a vessel approaching the RNA, persons on the shore alongside the RNA, and PIW associated with small recreational vessel transit (vessels $\leq 20'$ and PWCs).

The fall prevention system that Oxbow Midwest Calcining installed is a significant risk-mitigation measure, however access to the canal bank, upstream from the barriers, allows opportunity for PIW incidents, though none has been reported.

The risk analysis shows a negligible consequence value for a spark-related vapor ignition event. The project team reviewed the original Office of Design and Engineering Standards (then CG-521) briefing paper from December 2009, and reviewed circumstances that would both lead to a concentration of ignitable vapors and the opportunity for a spark to occur. The most significant difference between December 2009 and now is that barge loading and fleeting at the Will County Midwest Generating facility ceased in September 2012. This eliminates a significant number of the CG-521 spark-related ignition scenarios.

RDC also investigated whether electrical currents associated with the CSSC Dispersal Barrier pose a hazard to workers at the Oxbow loading facility. In discussions with Oxbow operations staff, an Oxbow representative told the project team that Oxbow limits their barge shuttle operations to the North of the pipeline arch, at a disadvantage to operations. Measurements did not indicate that operators at Oxbow are subject to hazardous electrical currents under present operating procedures. At the extreme southern end of the Oxbow facility (south of the pipeline arch), the investigation team measured higher voltages (and currents), and noted significantly higher measurements when a tow was proceeding northbound, through and adjacent to Barrier 1. USACE has begun preliminary work on construction of a “permanent” Barrier 1, south of the “Demonstration Barrier.” After Demonstration Barrier de-activation, the electric field conditions in vicinity of the southern end of the Oxbow facility may be quite different than as tested during this risk assessment.

The project team noted apparent confusion by stakeholders with the terms “Safety Zone” and “RNA.” During different testing periods, on multiple occasions, project team members saw vessel and crew behavior that led the project team to think that stakeholders obliged with the RNA “safety” provisions in the “Safety Zone,” and readily acted differently once north of the pipeline arch or south of the Romeo Road bridge. Except for the example noted in Section 3 of this report (and one other below), the project team did not specifically seek out nor fully-document the multiple examples that led to this conclusion.

A second example of this potential misunderstanding appears in Figure 17. Just as the tow pictured was clearing the safety zone (note the arch shadow indicated in orange), a crewmember steps out on deck. The video resolution does not allow determination as to whether the individual is wearing a PFD, but again, we think the individual is “trying” to comply with the regulation.

Figure 17 illustrates another concept. While reviewing the video-recording, analysts noted that “long tows” (in excess of 800 feet) occasionally exhibited a less-than “clean” maneuver through the bend north of the



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Safety Zone. Figure 17 shows a 3 x 2 configuration (4 tank barges and two hopper barges), with a bow boat, and the port quarter of the towboat extremely close to the west bank. (Note: video resolution does not allow a determination of whether the tow actually allided with the bank, nor is this report suggesting as much). The “bow boat” requirement of the regulation pertains to this tow as well as the 1 x 1 tow discussed in Section 3 of this report. Some tow configurations (including size/power of towboat) allow much greater maneuverability than others, while adding the bow boat may not actually provide the benefit discussed in the regulation, and even exposes deckhands to the greater risk of PIW electric shock while vessels enter the RNA.



Figure 17. Long tow leaving Safety Zone.

At the risk analysis validation session, one of the participants expressed a concern that the analysis didn't cover a specific initiating event that could lead to a person entering the water, response to a petroleum or hazardous substance spill from the Citgo-Lemont (approx MM 297.5) dock during cargo transfer operations. The ensuing discussion allowed that this special case did not clearly fit within the scope of the risk situations covered by the analysis, but that through its proactive stance, the CSSC Fish Barrier Technical and Safety Working Group did cover this as a “Quick Action Plan” item in the in the CSSC Aquatic Nuisance Species (ANS) Dispersal Barriers Emergency Response plan.



7 RECOMMENDATIONS

Consider the quantitative risk analysis in this report to reflect a “baseline” condition. As barrier operating conditions, waterway activities, incident management procedures and techniques, and other risk drivers change, review the assumptions presented in this work as to their applicability, and how a change to their values affects risks calculated for a specific decision factor, other decision factors, and for the overall risk total.

In considering future regulatory changes, define methods that best manage both the regulatory burden on CSSC RNA users and the associated marine safety risks.

For the next phase in regulatory development, comprehensively study actual waterway and canal-bank activity to note inconsistencies, deviations, and exceptions to the provisions of the present rule, and whether existing or proposed language or provisions address the issues raised in this report.

One specific area that deserves consideration is the blanket requirement for a bow-boat. Specifically, much of the original discussion concerning the need for a bow boat dealt with fleeting operations at the Will County Generating facility. Since September 2012, coal transloading and shipment from this facility has ceased. Also, the blanket provision does not take into account tow configuration and maneuverability.

Consider waterway speed restrictions, especially for recreational vessels that might be susceptible to larger vessel wheel wash, wakes, and bank reflection of vessel wakes.

Consider rewording the present rule to have the term “Safety Zone” apply to marine safety-related provisions associated with the electrified barrier area, within the scope of the term “Regulated Navigation Area,” or the larger Safety Zone provisions that apply to the entire Chicago Area Waterway System.

Once USACE completes Permanent Barrier 1, and during Barrier 1 operational testing, conduct in-canal and shore touch point voltage and current measurements to determine changes in electrical gradients, and whether the northern limits of electrical hazards change appreciably.



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APPENDIX A. CSSC MISLE EVENTS

Table A-1. CSSC MISLE events by year and hazard.

Date	Vessel Type	MM	Incident Type	Description/Consequence	Source
02/04/1997	M/V	295	Collision	M/V pushing single barge "backwards" (stern first) attempted to pass through narrow opening between two other tows; barge struck other tow and received substantial damage to port stern area. Involved low visibility.	MSO CHI Vessel Event & Incident Investigation
08/28/1999	M/V	296	Crew injury	Crewmember was feeding the wire around the post while the M/V was mooring up against a barge. The wire snapped back striking him in the arm and causing a fracture.	MSO CHI Incident Investigation
09/09/1999	M/V	297.6	Collision	Towboat 1 pushing 6 empty barges ahead in bend struck towboat 2, which was tied to two barges doing fleeting ops. Lead port barge of tow 1 struck port bow of towboat 2. Damage to towboat 2 ~\$45K.	MSO CHI Vessel Event & Incident Investigation
09/10/1999	Barge	297	Spill of material	Barge released half gallon of benzene due to leak in packing line of pump shaft.	MSO CHI Vessel Event & Incident Investigation
01/02/2000	Barge	297	Spill of material	Upon commencement of loading decant oil into barge, product began spraying out of #5 starboard tank dome, causing ~1gal of product to enter water.	MSO CHI Vessel Event & Incident Investigation
12/20/2000	[Mystery]	297.4	Spill of material	Received call from NRC regarding a barge. Call indicated a small sheen surrounding the barge located at a canal dock. MSO responded source was not known, did not come from barge in question. No other possible sources were identified.	MSO CHI Incident Investigation
03/30/2001	[Mystery]	297.5	Spill of material	MSO CHI notified of an oily sheen. Responded but could not verify	MSO CHI Incident Investigation
07/09/2001	M/V	297	Spill of material	Discharged ~1 gal of diesel fuel due to engineer turning his back to the connection to check on a potable water line that was leaking.	MSO CHI Incident Investigation
01/16/2002	Facility	297.5	Naphtha spill	A tankerman kicked out a plug from a non-transferring containment area at the dock. ~0.5 gal naphtha spilled into the CSSC and caused a sheen, which dissipated.	MSO CHI Pollution Incidents
09/30/2003	M/V	296.5	Allision	M/V departing fleeting area caught the corner of moored barge, denting the port bow corner of the barge.	MSO CHI Response Cases
06/09/2004	Barge	297.5	Crew injury	Deckhand on a barge tossed a line. He was standing in the loop, the loop caught his heel, he was caught off balance, and he hit the wall resulting in a cut and infection to the right elbow.	MSO CHI Response Cases
08/16/2004	M/V	296	Crew injury	Employee states he was climbing the starboard tow-knee with a 2" pump when he slipped and fell on the tow-knee steps.	MSO CHI Response Cases



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Table A-1. CSSC MISLE events by year and hazard (Cont.).

Date	Vessel Type	MM	Incident Type	Description/Consequence	Source
09/16/2004	Barge	297.5	Mineral Spirits Discharge	Discharge of 5 gal caused by an overflow. The product was contained.	MSO CHI All
12/13/2004	M/V	297	Spill of material	Over filled fuel tank spilling diesel (~15 gal)	MSO CHI All
01/31/2005	M/V	295.5	Allision	Traveling downstream, M/V STBD head of tow landed on what is called the Will County Fleet. When head of tow landed some tie off lines broke and 5 empty barges were loose from fleet. Other M/V assisted in rescuing barges and replacing lines.	MSO CHI Response Cases, Vessel Event & Incident Investigation
05/04/2005	Barge	297	Sinking	Unknown source of water reported in #3 wing-tank of barge. Flooding actually discovered to be in starboard #4 wing tank. Unit inspector attended barge, noting 3" fracture in the starboard No. 4 void forward of the aft bulkhead at the 6" draft.	MSO CHI Response Cases, Vessel Event & Incident Investigation
05/13/2005	M/V	295	Crew injury	M/V deckhand trainee was standing on rake end of loaded barge. He had a seizure causing him to collapse onto the deck of the barge. Tow was tied off in fleet; tow and boat were not moving at time of incident.	MSO CHI Response Cases
06/10/2005	M/V	297.5	Spill of material	M/V was fueling at facility and was running the fuel pump from the dock when fuel started to seep from around the #1 starboard fuel hatch cover. Estimate 25 gallons seeped out and maybe 10 gallons went into the water.	MSO CHI Response Cases, Vessel Event & Incident Investigation
07/01/2005	M/V	296	Equipment Failure	M/V had to shut down center main engine due to mechanical problems. Port starboard main engine still fully operational. (Repair ~\$12,000)	MSO CHI Response Cases, Vessel Event & Incident Investigation
07/06/2005	M/V	297	Spill of material	M/V discharged ~150 gal of #2 Diesel into the water while conducting fueling operations. The crew noticed sheen in the water, then promptly secured operations and finally conducting an initial response. Later the crew checked the port side of the vessel where they found a hole where fuel was leaking from the #1 tank.	MSO CHI Vessel Events
12/08/2005	M/V	296	Fire – initial contained	Fire break out in the engine room while tending barges in fleeting area. A CO ₂ extinguisher was used to put out flames coming from the top of the stbd main engine. Additional ABC extinguishers used along with the fire pump and hose to put out the fire. Engines were shut down and all non essential power was cut.	MSU Vessel Events and Response Cases



CSSC Marine Safety Risk Analysis

Table A-1. CSSC MISLE events by year and hazard (Cont.).

Date	Vessel Type	MM	Incident Type	Description/Consequence	Source
12/22/2005	M/V	297	Injury	Crewmember injured his back while unfacing the vessel from a barge and then putting the face wire back on the boat.	MSU Response Cases
05/05/2006	M/V	296	Pollution	While receiving diesel fuel bunker the #1 starboard fuel tank was overfilled. The person-in-charge of the transfer on the vessel went below deck to close off a valve and during that time the #1 tank overflowed through the tank hatch, across the deck, and into the river. 10 gal. crude oil	MSU Incident Investigations and Response Cases
05/21/2006	M/V	295.5	Injury	Newly hired crewmember was using galley for meals on vessel secured to dock with no crew present. Crewmember's right hand badly swollen and taken to clinic and diagnosed with insect bite.	MSU Response Cases
06/30/2006	M/V	295	Injury	A crewmember burnt the palm of his right hand when he touched a burner and didn't realize that it was on. A burn gel pad was applied, then wrapped in gauze.	MSU Response Cases
01/08/2007	M/V	296/ 297	Oil discharge	~ 10 gal diesel fuel bunker - the #1 starboard fuel tank was overfilled. The person-in-charge of the transfer on the vessel went below deck to close off a valve. No on-scene response was conducted as the spill was adequately cleaned up by the responsible party.	MSU Response Cases
01/10/2007	M/V	297.4	Oil discharge	M/V was taking on 20,000 gallons of diesel fuel. The fuel level gauge spiked from 1/2 full to overflow within 3 minutes. The product then flowed from the sounding tubes to the main deck and over the side into the CSSC causing a visible sheen on the waterway. Contractors came on site to remove all possible product..	MSU Vessel Events
02/22/2007	M/V	296	Material Failure/Fire	Oil leaked out between the dipstick and tube and dropped onto the STBD main engine manifold igniting into a small fire. The 6' flames were put out with a nearby extinguisher with no damage done to the engine or room.	MSU Vessel Events
06/11/2007	M/V	297.5	Pollution - Enforcement	M/V spilled 100 gallons of red-dyed diesel fuel into the CSSC mile marker 297.5. The spill occurred while the vessel was taking on fuel. An improperly secured fuel cap on the opposite side of the vessel (starboard fueling station) was the primary cause of the spill. Cleanup was properly conducted by vessel personnel, facility equipment and personnel, and contractors hired by the responsible party. The CSSC was closed for approx 22 hours during the cleanup efforts. Minimal traffic was delayed during this time.	MSU Pollution Incidents



CSSC Marine Safety Risk Analysis

Table A-1. CSSC MISLE events by year and hazard (Cont.).

Date	Vessel Type	MM	Incident Type	Description/ Consequence	Source
08/17/2007	M/V	296	Material Failure/Vessel Maneuverability-Partial Reduction	Loss of oil pressure resulted in the starboard main shutting down. Vessel was able to transit to dock on port main without incident.	MSU Vessel Events
01/24/2008	M/V	297	Material Failure/Vessel Maneuverability-Partial Reduction	Lost propulsion on the STBD side. They were currently at their destination in Lemont	MSU Vessel Events
02/29/2008	M/V	296	Allision	SLM received call from M/V. They stated that another M/V allided with one of their empty grain barges	Sector Response Cases and MSU Vessel Events
05/15/2008	M/V	296	Collision	M/V was northbound pushing three barges in a row loaded with cement. The wire tie that head all the barges together came undone and the barges hit some barges that were moored up along the wall. There were four hopper barges loaded with coal along the wall. MSU CHI personnel responded and they could not find any damage except for some scraped paint.	MSU Vessel Events
08/05/2008	M/V	297.7	Oil discharge	~ 400 gallons of paving asphalt spilled into the CSSC due to a blown gasket at the connection point.	MSU Vessel Events and Response Cases and MSU Pollution



APPENDIX B. EVENT TREE/FAULT TREE (QUALITATIVE)

This appendix presents the qualitative structure that describes how CSSC RNA loss events can occur. The appendix shows each of the four event tree structures that were developed and the fault trees that were needed to explain how failure paths for selected event tree branches occurred. This structure is used to identify all needed frequency, probability and consequence inputs.

Section 2.3.3 Risk Informed Process Supporting Regulatory Decisions includes an overview and detailed descriptions of the event tree/fault tree process. Building the event tree/fault tree logic corresponds with STEP A in the simplified flowchart in Figure 3. This appendix provides the specific qualitative logic structure used to describe the loss scenarios. To model the scenarios leading to the loss events and the associated consequence types, event tree/fault tree diagrams were developed for the following four transits, access or user group situations:

- Commercial Vessel Transit of the Safety Zone
 - a. Red Flag
 - b. Non-Red Flag
- Recreational Vessels Transit of the Safety Zone
 - a. Greater than 20 Feet
 - b. 20 Feet or Less and Personal Water Craft (PWC)
- Vessels Approach of the Regulated Navigation Area (RNA)
- Personnel on the Regulated Navigation Area (RNA) Shore

A master or generic event tree structure was developed for the four situations listed above. Separate event trees were developed for red flag and non-red flag transits; and for transits by each of the two categories of recreational vessels. Thus, a total of six separate event trees (one for each of these six initiating events) were quantitatively analyzed.

An event tree is an inductive logic tool with a set of events described across the top of the page. These events begin with the initiating event for the potential losses of interest followed by functional successes that are important to avoiding the potential loss events. The paths through the event tree begin with the initiating event on the left hand side and progress from left to right through one or more branch points for each event defined at the top of the page. Moving from the left hand side of the event tree, each of the success events will be encountered one or more times with a branch point shown at each encounter. The standard approach is for each branch point to have an upward branch indicating the success path for the associated event and a downward branch indicating the branch failure path event. The branch point failure paths for the event are labeled with lower case letters (i.e., a, b, c, etc.).

The failure logic for a downward branch in the event tree may be somewhat complex; therefore, this logic is often modeled using a fault tree, which is a deductive logic tool, for many of these branch failure path events. The fault trees involve either OR or AND logic. In addition, the fault trees are all quantified at either the first or the second level of events in the tree with a STAR indicating the events quantified. The events shown below the STAR level are included to support discussion and understanding when assigning a probability to the higher-level event. A key assumption in the quantification process is that all the events are independent.



Each path continuation through the event tree structure is an event scenario. Each path through the branches of the event tree can occur in a variety of ways based on all of the failure logic for each associated fault tree. The full set of detailed paths that can occur (e.g., the initiating event followed by Event 1.1 failing etc.; OR initiating event followed by Event 1.2 failing etc.; OR etc.) represent the detailed qualitative description for the event tree scenario. The analysis generates the frequency for a scenario by first calculating the branch failure and success probabilities, and then taking the product of the initiating event frequency and the probability for each branch (success for upward paths and failure for downward paths) through the event tree.

Rather than combining the failure logic for all branch points for each scenario, this analysis first calculates the branch point probabilities based on the fault tree logic for that branch and then uses those probabilities to develop the scenario frequency. This means that there could be dependencies among the events in the event sequence that are not properly addressed. However, a key assumption in this analysis is that all branches of the event tree are independent (e.g., a failure in one branch would not increase the probability of failure in another branch). Thus, care must be exercised in the development and quantification of the event tree/fault tree models to verify independence of the events and to compensate when independence is questionable.

The following four sections of this appendix present the Event Trees/Fault Trees for each of the four situations listed above. Each section begins with a brief introduction of the event tree for the situation and all associated fault trees.

B.1 Commercial Vessel Transit of the Safety Zone

This situation addresses a commercial vessel transiting the safety zone. Commercial vessels include red flag and non-red flag vessels. Figure B-1 presents the master event tree for this situation showing an initiating event followed by six additional events. The corresponding faults trees for the event tree are provided in Figures B-2 through B-9. The events across the top of the event tree include the following:

- Transit Initiated
- Vessel Avoids Release of Ignitable Vapors
- Vessel Avoids Spark
- Vessel Avoids Vapor Ignition
- Personnel on Vessel Avoid Shock
- Vessel Avoids PIW
- Safe Rescue of PIW

Table B-1 identifies the fault trees developed for red flag and non-red flag vessel transits of the safety zone.

Table B-1. Fault trees that describe how failure paths occur for Event Tree C: Commercial Vessel Transit of the Safety Zone.

Event (Across Top of Event Tree)	Branch Failure Path Event Addressed		Applicable Fault Tree Figure
	Red Flag	Non-Red Flag	
2. Vessel avoids release of ignitable vapors	2a	N/A	Figure B-2
3. Vessel avoids spark	3a and 3b	3a	Figure B-3
4. Vessel avoids vapor ignition	4a	N/A	Figure B-4
5. Personnel on vessel avoid shock	5a and 5c	5a	Figure B-5
	5b, 5d, and 5e	5b	Figure B-6
6. Vessel avoids PIW	6a through 6h	6a through 6d	Figure B-7
	6i and 6j	N/A	Figure B-8
7. Safe rescue of PIW	7a through 7j	7a through 7d	Figure B-9



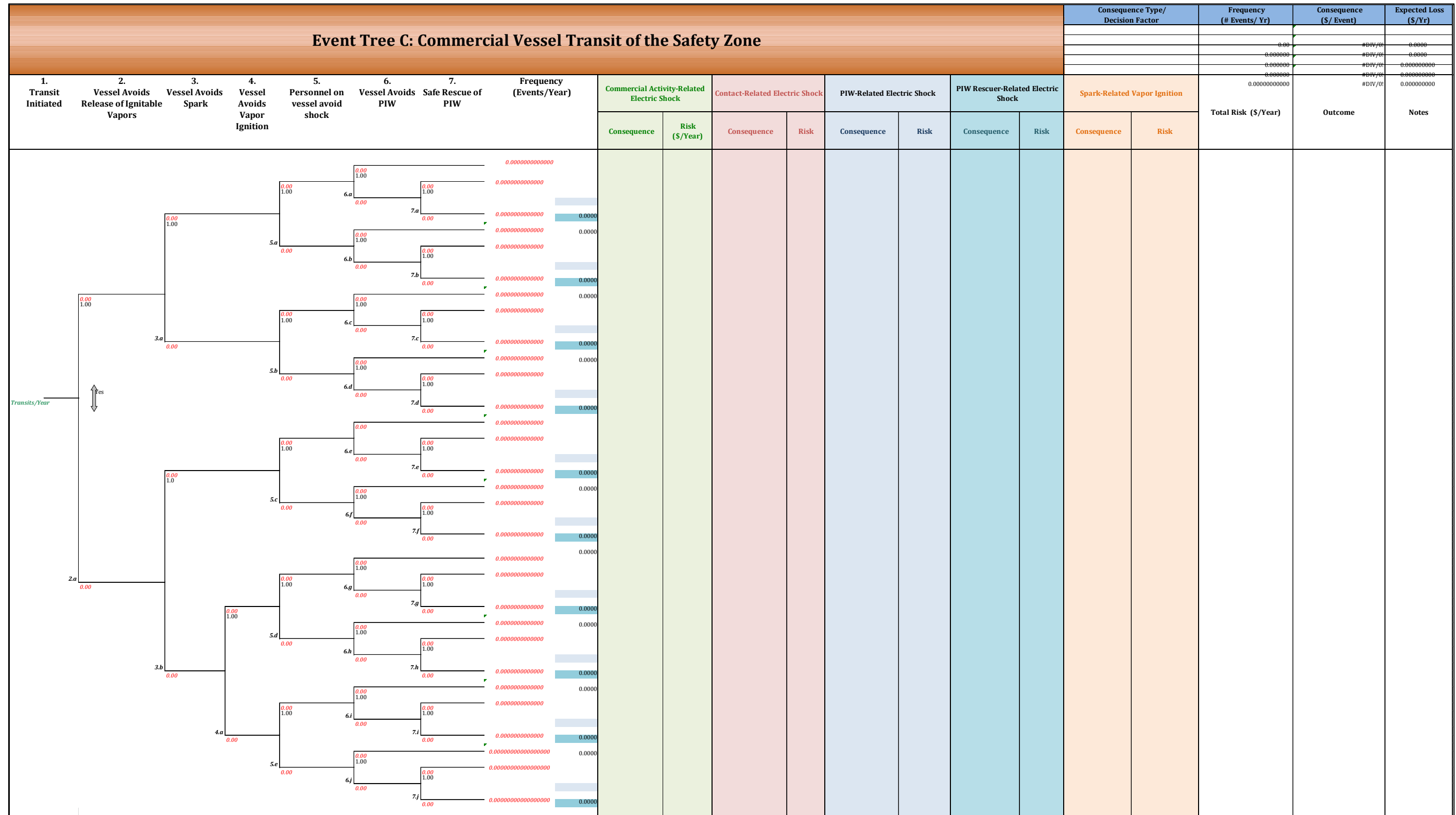
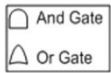



Figure B-1. Event Tree C: Commercial Vessel Transit of the Safety Zone.

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Legend



 Shows the level where the probability is to be assigned.

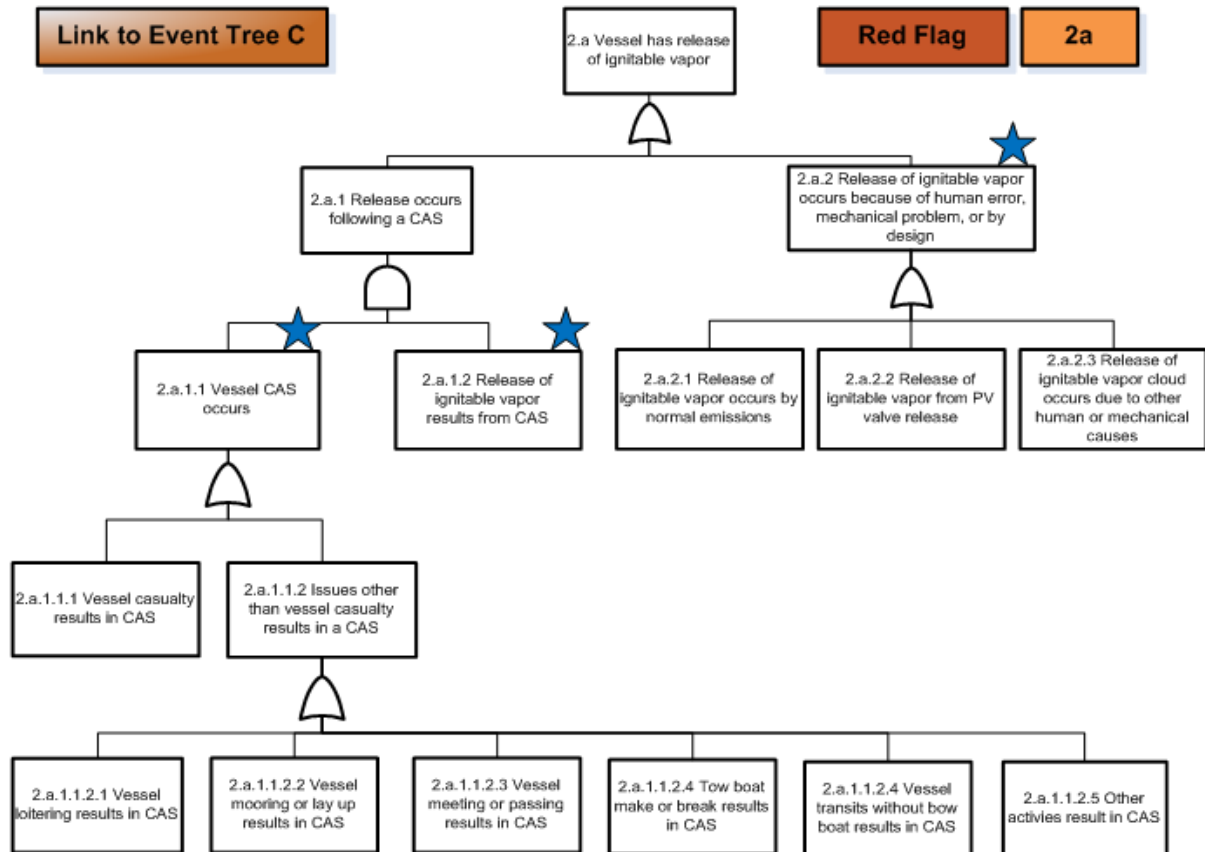


Figure B-2. Event Tree C: Branch Failure Path Event 2a.



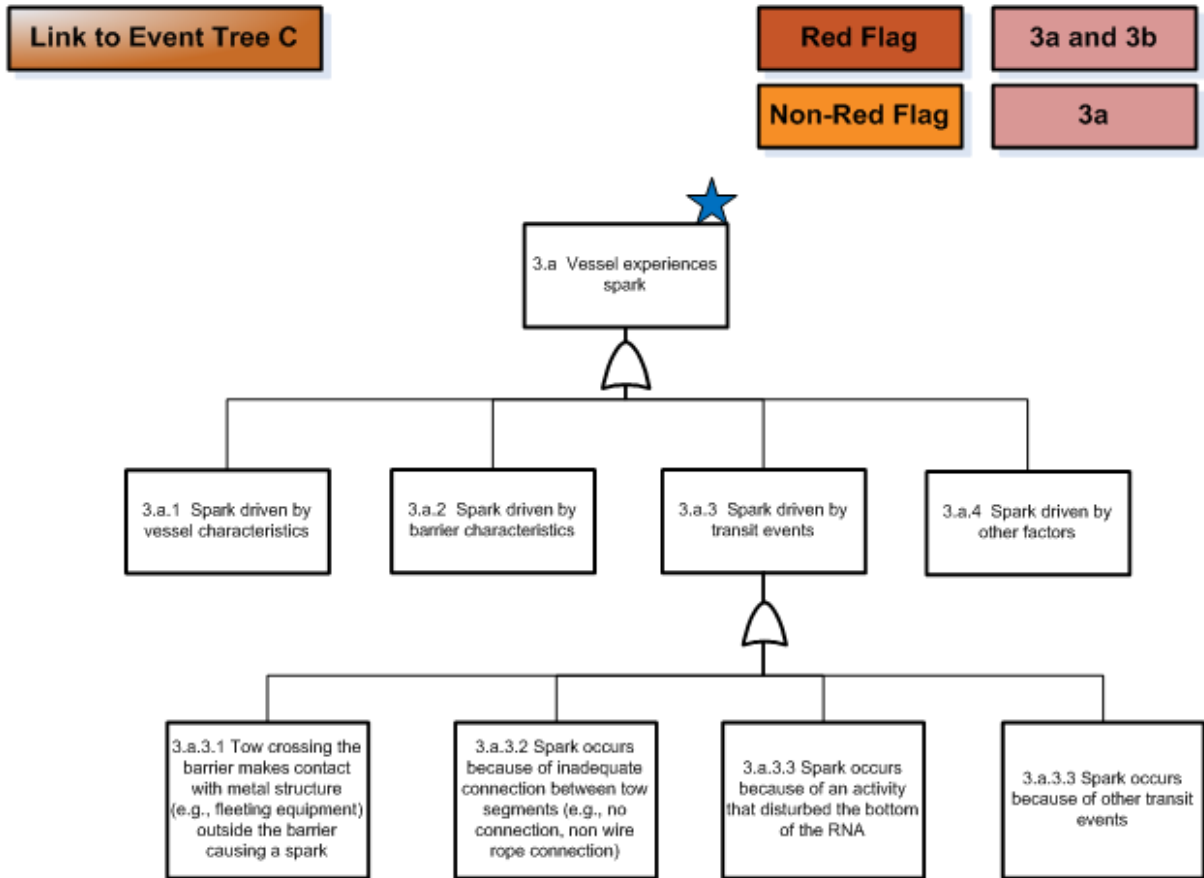


Figure B-3. Event Tree C: Branch Failure Path Events 3a and 3b.

[Link to Event Tree C](#)

Red Flag

4a

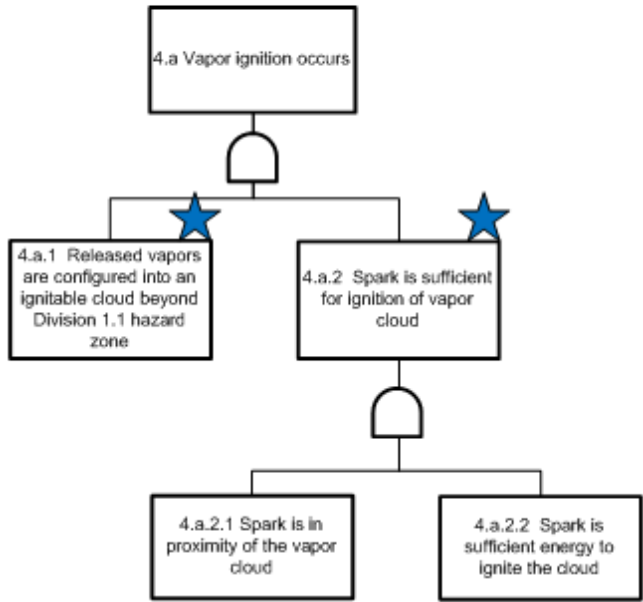


Figure B-4. Event Tree C: Branch Failure Path Event 4a.



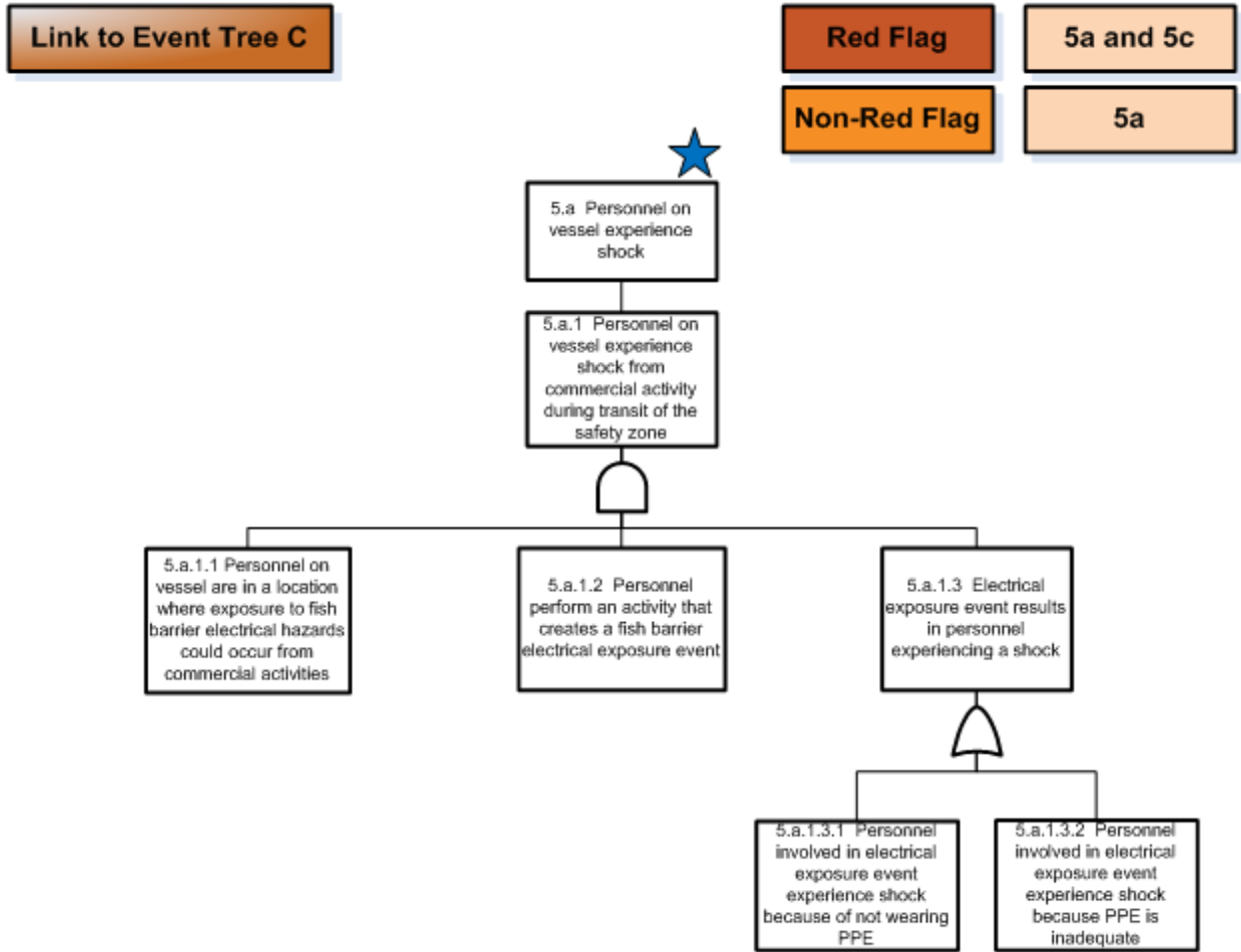


Figure B-5. Event Tree C: Branch Failure Path Events 5a and 5c.



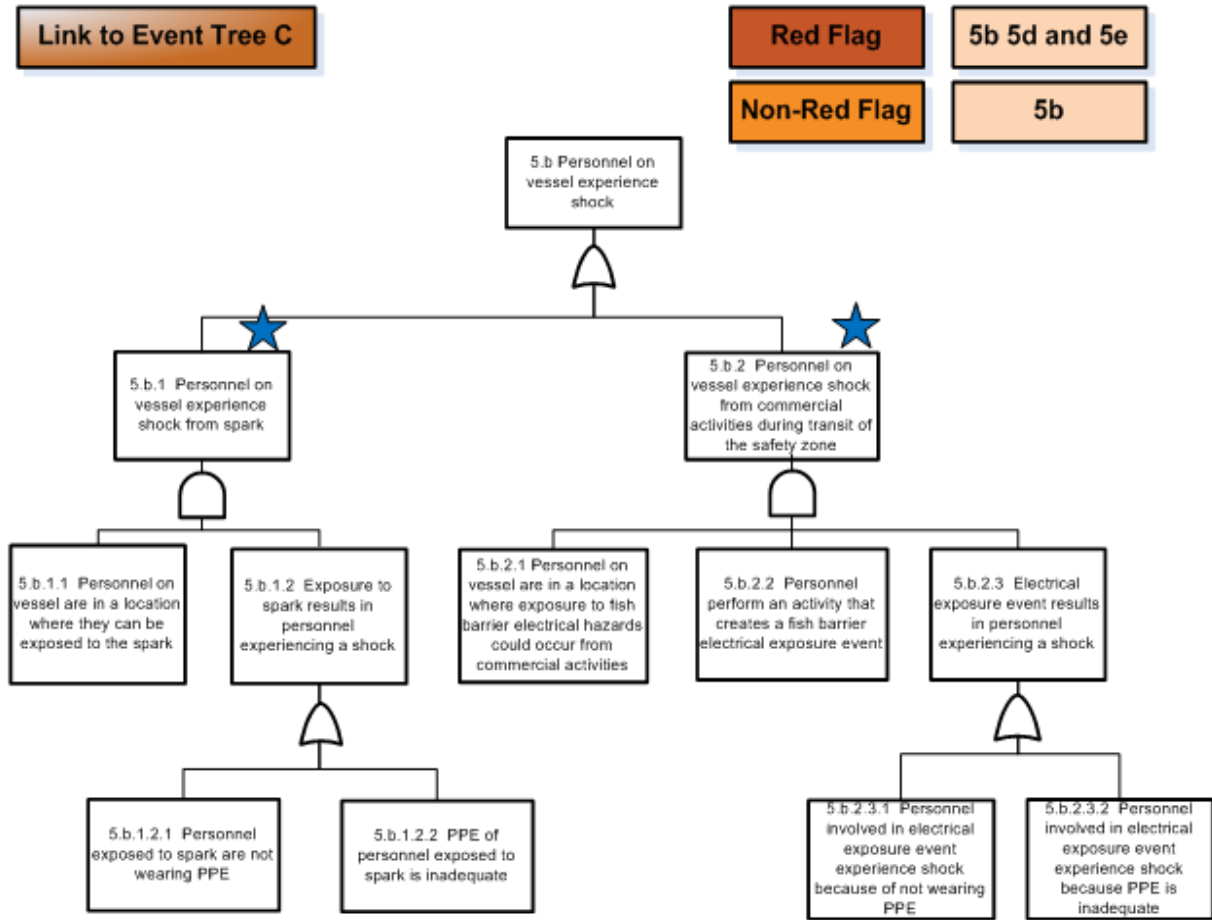


Figure B-6. Event Tree C: Branch Failure Path Events 5b 5d and 5e.



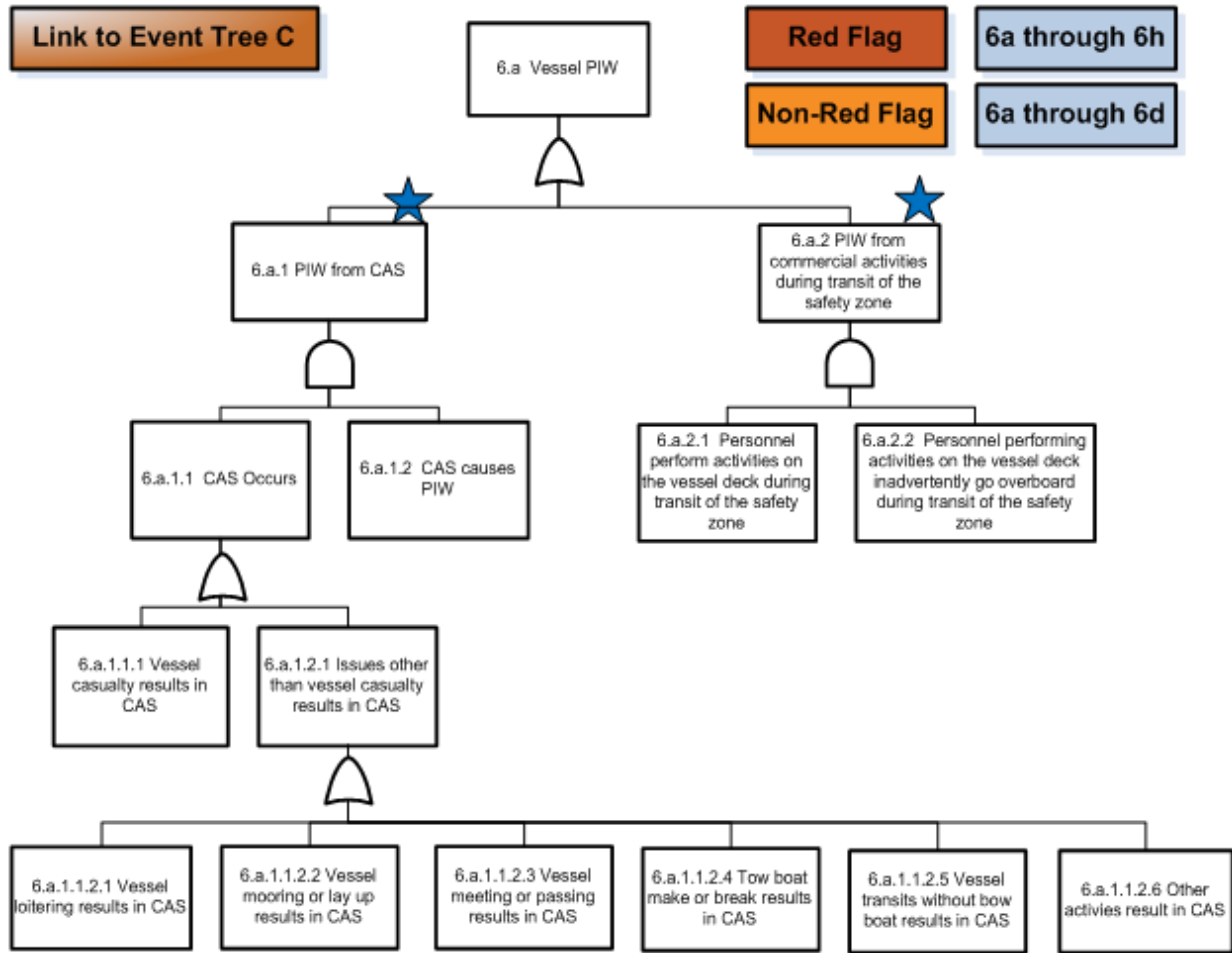


Figure B-7. Event Tree C: Branch Failure Path Events 6a through 6h.



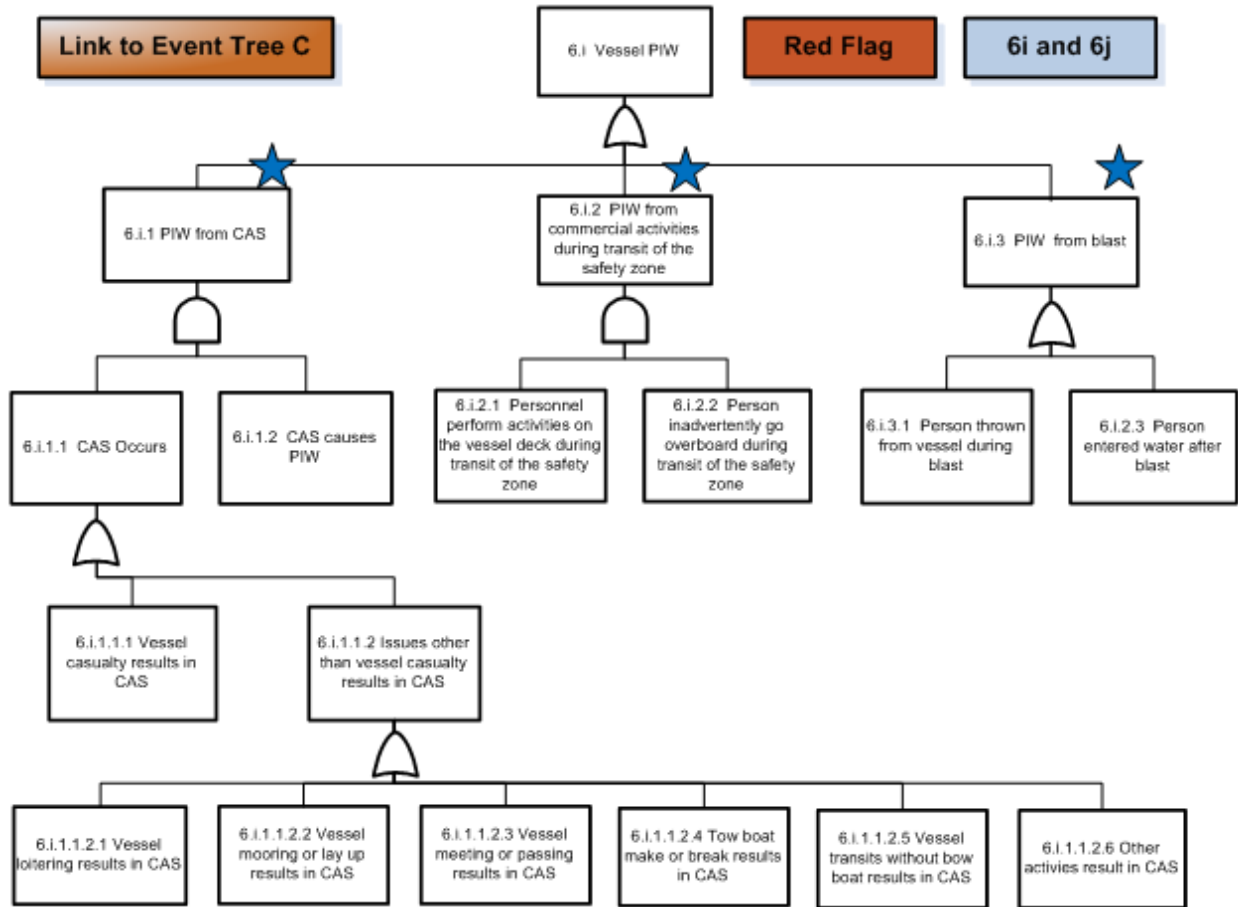


Figure B-8. Event Tree C: Branch Failure Path Events 6i and 6j.



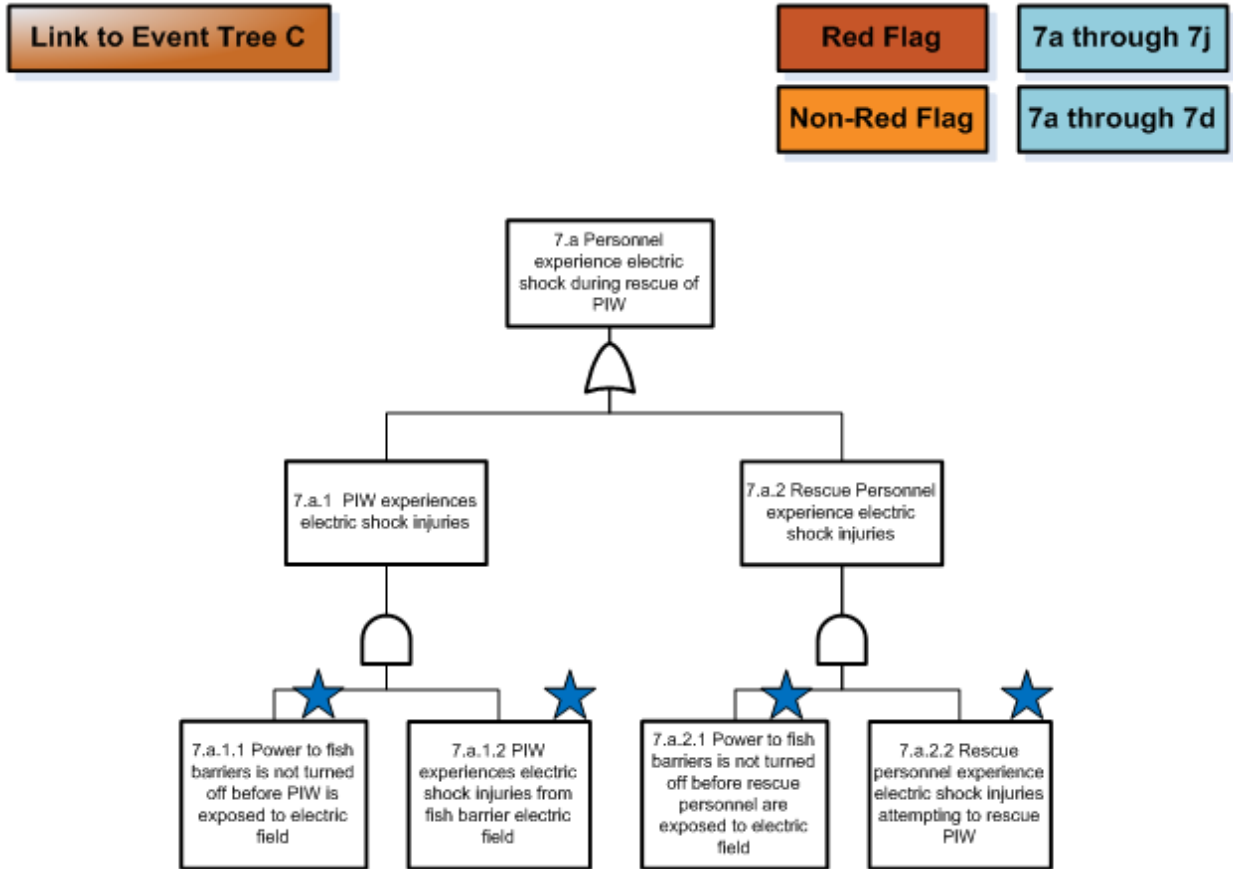


Figure B-9. Event Tree C: Branch Failure Path Events 7a through 7j.

B.2 Recreational Vessels Transit of the Safety Zone

This situation addresses recreational vessels transiting the safety zone. Recreational vessels include vessels “Greater Than 20 Feet” and “20 Feet or Less and PWCs”. Figure B-10 presents the master event tree for this situation showing an initiating event followed by three additional events. The corresponding fault trees for Event Tree R are provided in Figures B-11 through B-13.

Specifically, the events across the top of the event tree include the following:

- Transit Initiated
- Personnel on Vessel Avoids Shock
- Vessel Avoids PIW
- Safe Rescue of PIW

Table B-2 identifies the fault trees developed for the recreational vessels transit of the safety zone for vessels “Greater than 20 Feet” and “20 Feet or Less and PWCs”.



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Table B-2. Fault trees that describe how failure paths occur for Event Tree R: Recreational Vessels Transit of the Safety Zone.

Event (Across Top of Event Tree)	Branch Failure Path Event Addressed		Applicable Fault Tree Figure
	Greater Than 20 Feet	20 Feet or Less and PWCs	
2. Personnel on vessel avoids shock	2a	2a	Figure B-11
3. Vessel avoids PIW	3a and 3b	3a and 3b	Figure B-12
4. Safe rescue of PIW	4a and 4b	4a and 4b	Figure B-13



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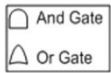



Event Tree R: Recreational Vessels Transit of the Safety Zone						Consequence Type/ Decision Factor		Frequency (# Events/ Yr)	Consequence (\$/ Event)	Expected Loss (\$/Yr)		
1. Transit Initiated	2. Personnel on Vessel Avoids Shock	3. Vessel Avoids PIW	4. Safe Rescue of PIW	Frequency (Events/Year)	Recreational Activities-Related Electric Shock		PIW-Related Electric Shock		Total Risk (\$/Year)	Outcome	Notes	
					Consequence	Risk	Consequence	Risk				Consequence
				0.0000					0.000000	#DIV/0!	\$ -	
				0.0000					0.000000	#DIV/0!	\$ -	
				0.0000					0.000000	#DIV/0!	\$ -	
				0.0000					0.000000	#DIV/0!	\$ -	
				0.0000					0.000000	#DIV/0!	\$ -	

Figure B-10. Event Tree R: Recreational Vessels Transit of the Safety Zone.

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Legend



 Shows the level where the probability is to be assigned.

[Link to Event Tree R](#)

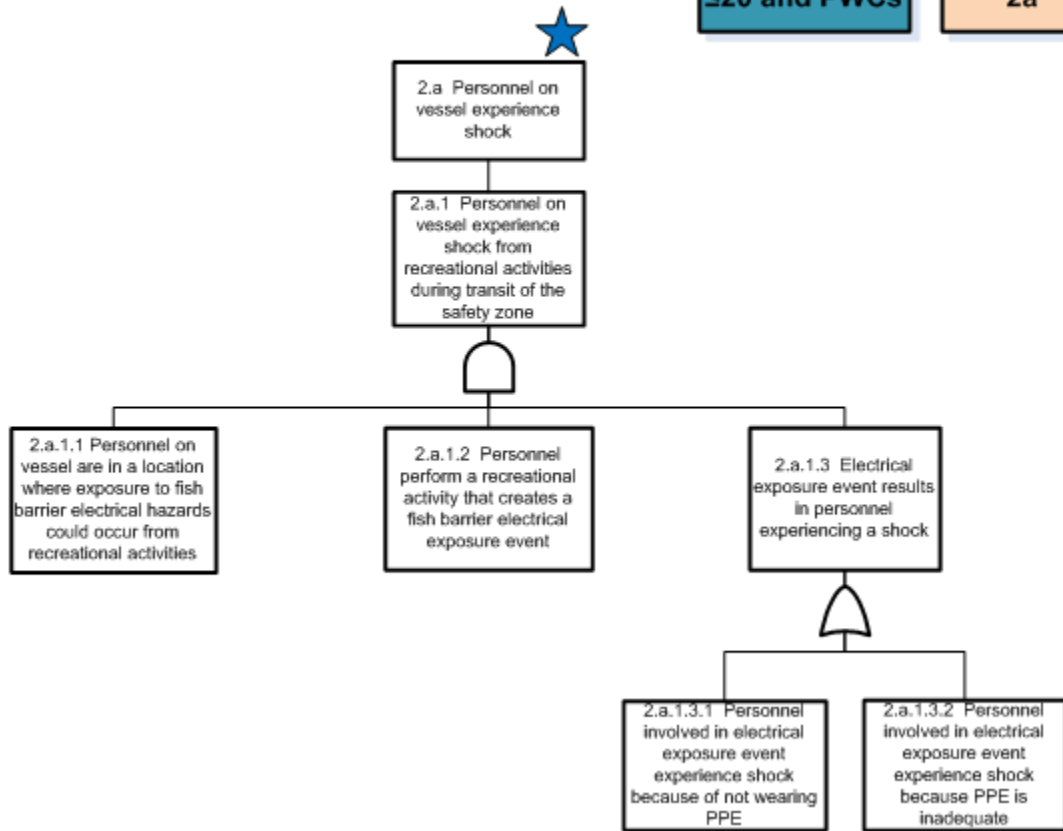


Figure B-11. Event Tree R: Branch Failure Path Event 2a.



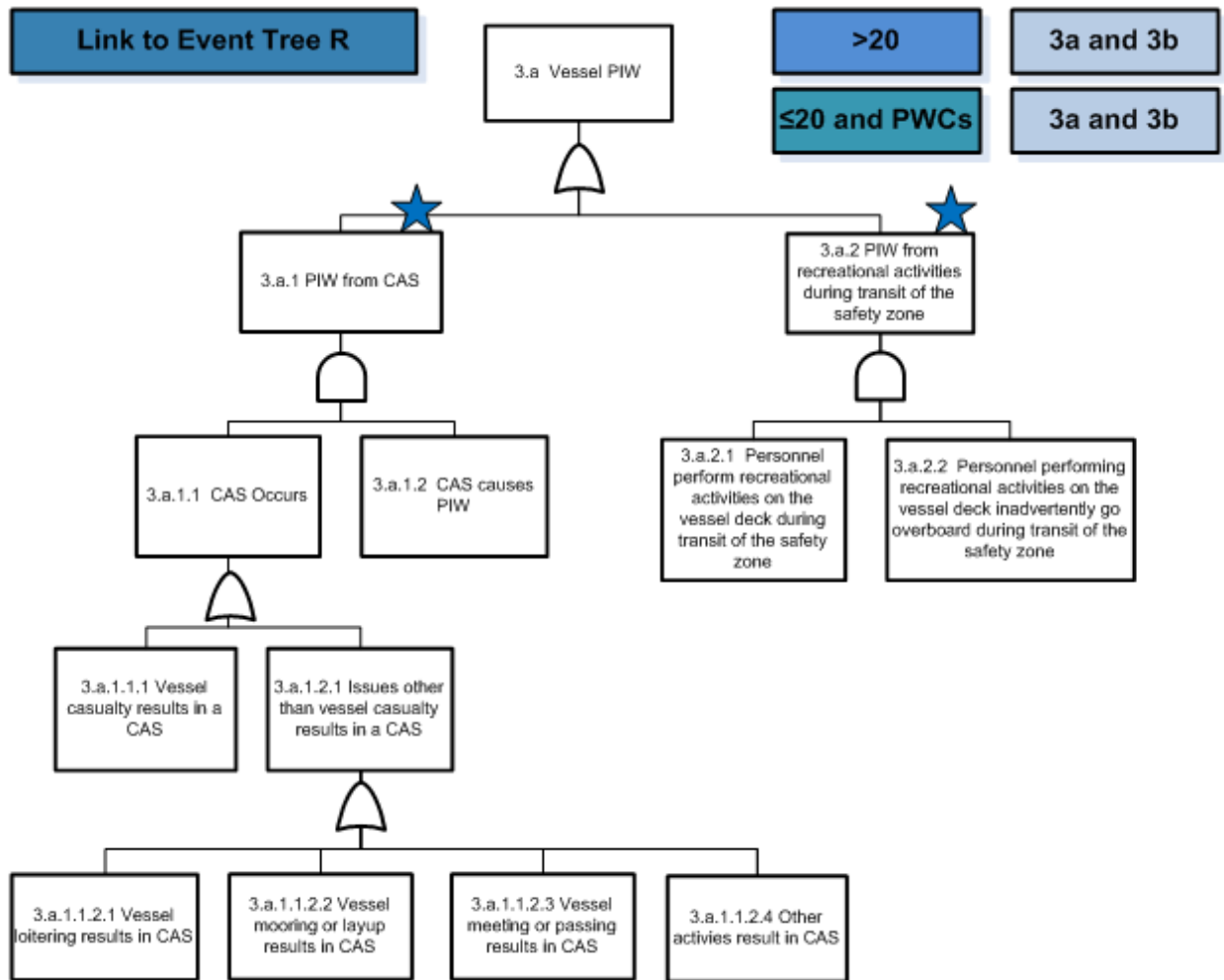


Figure B-12. Event Tree R: Branch Failure Path Events 3a and 3b.



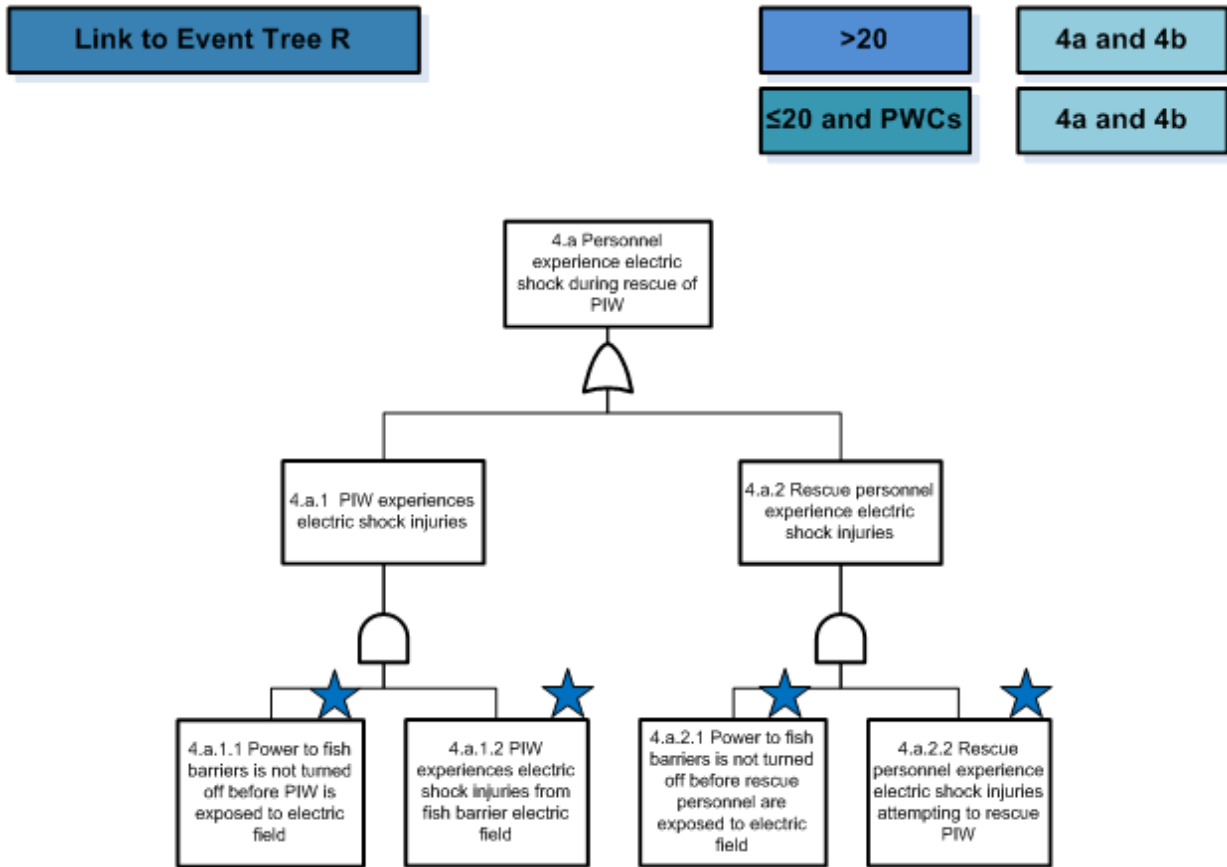


Figure B-13. Event Tree R: Branch Failure Path Events 4a and 4b.

B.3 Vessels Approach of the Regulated Navigation Area (RNA)

This situation addresses vessels approaching the RNA up to the safety zone. This includes all commercial and recreational vessels. Figure B-14 presents the master event tree for this situation showing an initiating event followed by four additional events. Specifically, the events across the top of the event tree include the following:

- Approach Initiated
- Vessel Avoids Congestion-Related CAS
- Vessel Avoids PIW
- Personnel are Safely Removed from Water Before Reaching the Safety Zone
- Safe Rescue of PIW

Table B-3 identifies the fault trees developed for all vessels approaching the RNA up to the safety zone. The corresponding faults trees for Event Tree A are provided in Figures B-15 through B-17.



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Table B-3. Fault trees that describe how failure paths occur for Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA).

Event (Across Top of Event Tree)	Branch Failure Path Event Addressed	Applicable Fault Tree Figure
2. Vessel avoids congestion-related CAS	2a	None
3. Vessel avoids PIW	3a	Figure B-15
	3b	Figure B-16
4. Personnel are safely removed from water before reaching the safety zone	4a and 4b	None
5. Safe rescue of PIW	5a and 5b	Figure B-17

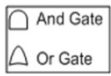



Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA)						Consequence Type/ Decision Factor	Frequency (# Events/ Yr)	Consequence (\$/ Event)	Expected Loss (\$/Yr)					
						Congestion-Related CAS		PIW-Related Electric Shock		PIW Rescuer-Related Electric Shock		Total Risk (\$/Year)	Outcome	Notes
1. Approach Initiated	2. Vessel Avoids Congestion Related CAS	3. Vessel Avoids PIW	4. PIW is Safely Removed Before Reaching the Safety Zone	5. Safe Rescue of PIW	Frequency (Events/Year)	Consequence	Risk	Consequence	Risk	Consequence	Risk			

Figure B-14. Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA).

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Legend



 Shows the level where the probability is to be assigned.

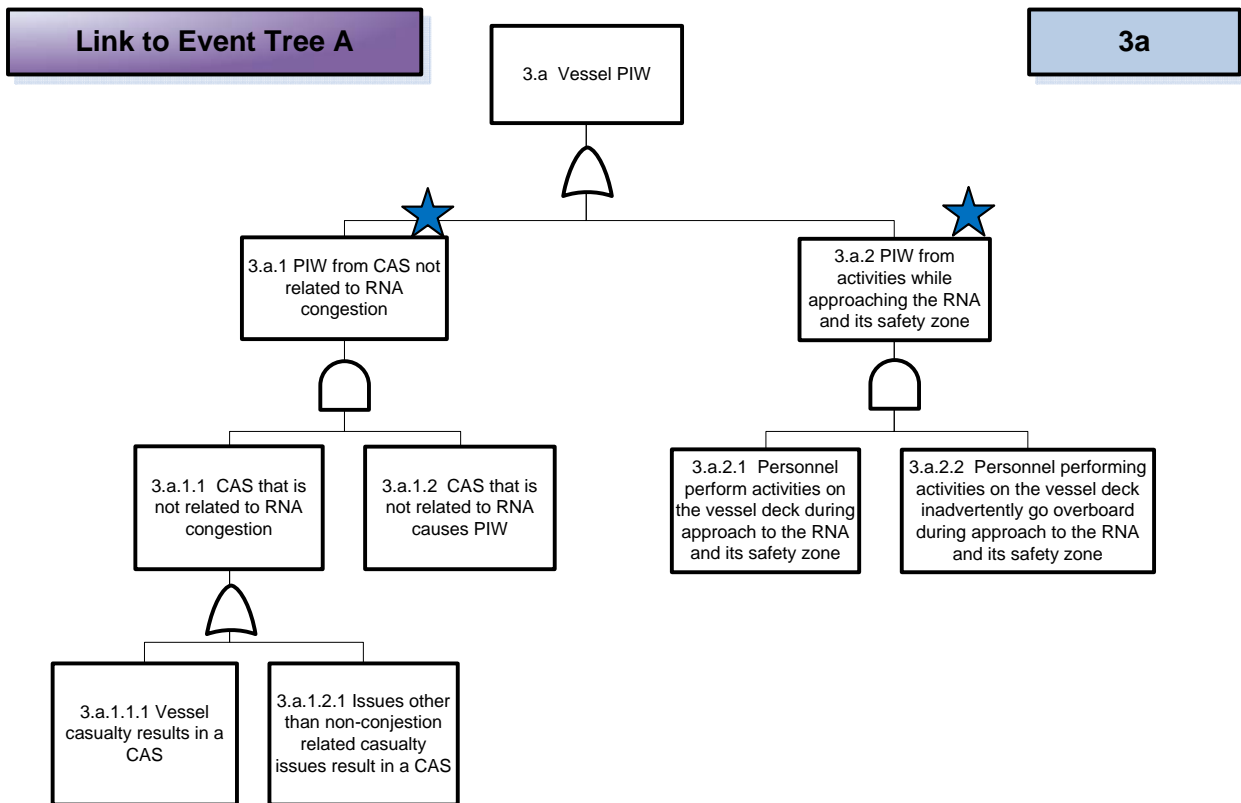


Figure B-15. Event Tree A: Branch Failure Path Event 3a.



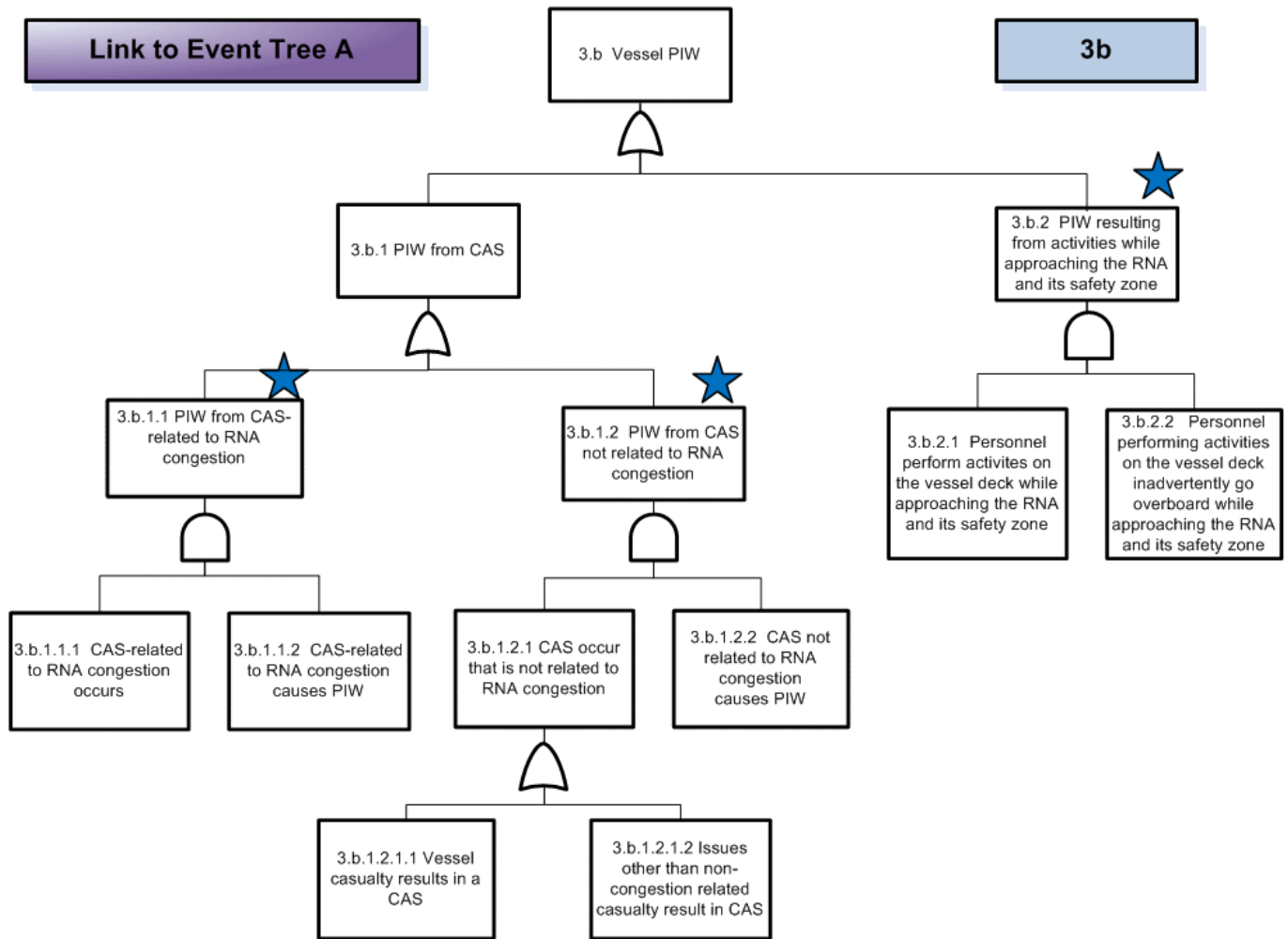


Figure B-16. Event Tree A: Branch Failure Path Event 3b.



[Link to Event Tree A](#)

5a and 5b

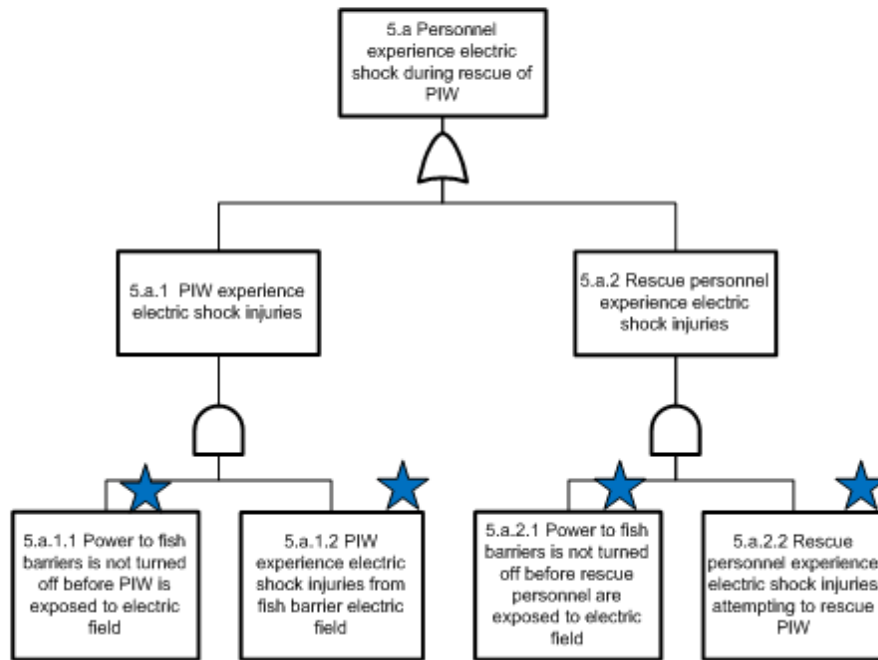


Figure B-17. Event Tree A: Branch Failure Path Events 5a and 5b.

B.4 Personnel on the Regulated Navigation Area (RNA) Shore

This situation addresses personnel on the RNA shore. This includes all government and non-government personnel. Figure B-18 presents the master event tree for this situation showing an initiating event followed by four additional events. Specifically, the events across the top of the event tree include the following:

- Shore Personnel Enter the RNA Shore Area
- Shore Personnel Avoid Being Near the Water
- Shore Personnel Avoid Entering the Water
- Shore Personnel are Safely Removed Before Reaching the Safety Zone
- Safe Rescue of PIW

Table B-4 identifies the fault trees developed for personnel on the RNA shore. The corresponding fault tree for Event Tree S is provided in Figure B-19.



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Table B-4. Fault trees that describe how failure paths occur for Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore.

Event (Across Top of Event Tree)	Branch Failure Path Event Addressed	Applicable Fault Tree Figure
2. Shore personnel avoid being near the water	2a	None
3. Shore personnel avoid entering the water	3a	None
4. Shore personnel are safely removed from water before reaching the safety zone	4a	None
5. Safe rescue of PIW	5a	Figure B-18

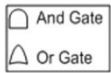



Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore						Consequence Type/ Decision Factor		Frequency (# Events / Yr)	Consequence (\$ / Event)	Expected Loss (\$/Yr)		
1. Shore Personnel Enter the RNA Shore Area	2. Shore Personnel Avoid Being Near the Water	3. Shore Personnel Avoid Entering the Water	4. PIW is Safely Removed Before Reaching the Safety Zone	5. Safe Rescue of PIW	Frequency (Events/Year)	PIW-Related Electric Shock		0.000000	#DIV/0!	\$ -		
					Consequence	Risk	PIW Rescuer-Related Electric Shock					
								Consequence	Risk	Total Risk (\$/Year)	Outcome	Notes

Figure B-18. Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore.

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Legend



 Shows the level where the probability is to be assigned.

[Link to Event Tree S](#)

5a

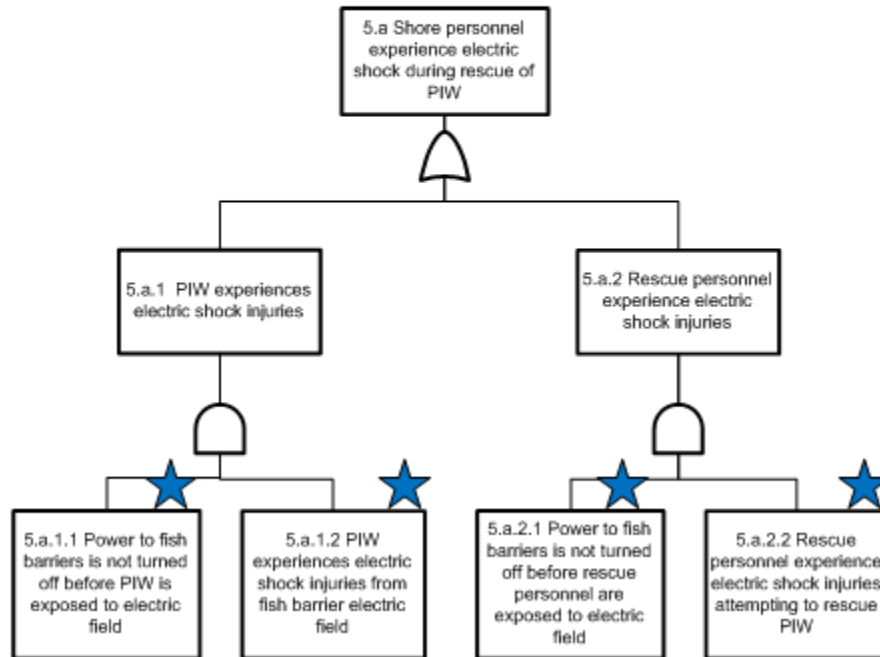


Figure B-19. Shore Personnel in the RNA.



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APPENDIX C. EVENT FREQUENCY/PROBABILITIES

Section 2.3.3 also introduces the development of frequency and probability inputs and a detailed description of the data selection table included in this appendix. Developing the event frequency and probability values corresponds with STEP B in the simplified flowchart in Figure 3.

Table C-1 presents a summary of all frequencies and probabilities for the six analyzed event trees described in Appendix B. An input value is provided for all failure branches in each of the analyzed event trees. In addition, an input value is provided for all events marked with a “STAR” in all relevant fault trees. In the Microsoft Excel® spreadsheet, the values used in the event trees are taken directly from this summary table.

Table C-2 presents the data selection table, and the values in the “Input Value” column are the source of the respective event values in Table C-1. The yellow highlighted rows represent values that were adjusted during the Validation Session (with the second/bolded value being the one chosen). Table C-1 addresses all quantified events shown, and is designed to help ensure complete transparency in the frequency/probability data collected and used in this analysis. Also provided is the detailed data collection and description of the evaluation process used to develop all input event frequencies and probabilities for all failure branches in each of the six analyzed event trees described in Appendix B. An input value is described for all events marked with a “STAR” in all relevant fault trees, and text is provided describing how these fault tree event probabilities are combined to establish the associated branch point failure probability. Where more than one event frequency/probability is considered for an analyzed input event, each value is described and text is provided regarding the basis for the value selected for application in this analysis.



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Table C-1. Frequency/probability inputs.

Events	Commercial Vessel Events				Recreational Vessel Events				Approaching Vessel Events	Shore Personnel Events		
	Red Flag		Non-Red Flag		Vessels Greater Than 20 feet		Vessels 20 Feet or Less and PWCs					
Initiating Event	1.a	850	1.a	6,000	1.a	700	1.a	7	1.a	10,000	1.a	30,000
Congestion-Related CAS									2.a	0.00001		
Release of Ignitable Vapors	2.a	0.50002										
	2.a.1.1	0.0002										
	2.a.1.2	0.1										
	2.a.2	0.5										
Spark	3.a	0.001	3.a	0.001								
	3.b	0.001										
Ignition	4.a	0.00001										
	4.a.1	0.0001										
	4.a.2	0.1										
Person Experiences a Shock	5.a	0.00002	5.a	0.00002	2.a	0.0002	2.a	0.02				
	5.b	0.00003	5.b	0.00003								
	5.b.1	0.00001	5.b.1	0.00001								
	5.b.2	0.00002	5.b.2	0.00002								
	5.c	0.00002										
	5.d	0.00003										
	5.d.1	0.00001										
	5.d.2	0.00002										
	5.e	0.00003										
	5.e.1	0.00001										
5.e.2	0.00002											
Persons on RNA Shore Approach the Water											2.a	0.3

Table C-1. Frequency/probability inputs (Cont.).

Person Enters the Water	6.a	0.00000022	6.a	0.00000022	3.a	3.a	0.0000006	3.a	0.002	3.a	3.a	0.00002	3.a	3.a	0.000006
	6.a.1	0.000000002	6.a.1	0.000000002		3.a.1	0.0000003	3.a.1	0.001		3.a.1	0.00001		3.a.1	0.00001
	6.a.2	0.00000002	6.a.2	0.00000002		3.a.2	0.0000003	3.a.2	0.001		3.a.2	0.00001		3.a.2	0.00001
	6.b	0.00000022	6.b	0.00000022		3.b	0.0000006	3.b	0.002		3.b	0.10002		3.b	0.10002
	6.b.1	0.000000002	6.b.1	0.000000002		3.b.1	0.0000003	3.b.1	0.001		3.b.1.1	0.1		3.b.1.1	0.1
	6.b.2	0.00000002	6.b.2	0.00000002		3.b.2	0.0000003	3.b.2	0.001		3.b.1.2	0.00001		3.b.1.2	0.00001
	6.c	0.00000022	6.c	0.00000022							3.b.2	0.00001		3.b.2	0.00001
	6.c.1	0.000000002	6.c.1	0.000000002											
	6.c.2	0.00000002	6.c.2	0.00000002											
	6.d	0.00000022	6.d	0.00000022											
	6.d.1	0.000000002	6.d.1	0.000000002											
	6.d.2	0.00000002	6.d.2	0.00000002											
	6.e	0.00000022													
	6.e.1	0.000000002													
	6.e.2	0.00000002													
	6.f	0.00000022													
	6.f.1	0.000000002													
	6.f.2	0.00000002													
	6.g	0.00000022													
	6.g.1	0.000000002													
6.g.2	0.00000002														
6.h	0.00000022														
6.h.1	0.000000002														
6.h.2	0.00000002														
6.i	0.000100022														
6.i.1	0.000000002														
6.i.2	0.00000002														
6.i.3	0.0001														
6.j	0.000100022														
6.j.1	0.000000002														
6.j.2	0.00000002														
6.j.3	0.0001														
Person in the Water drifts into the Fish Barrier									4.a	0.1			4.a	0.2	
									4.b	0.1					
Personnel Injured during Rescue of PIW	7.a	0.762	7.a	0.762	4.a	4.a	0.775	4.a	0.775	5.a	5.a	0.76238	5.a	5.a	0.727
	7.a.1.1	1	7.a.1.1	1		4.a.1.1	1	4.a.1.1	1		5.a.1.1	1		5.a.1.1	0.95
	7.a.1.2	0.75	7.a.1.2	0.75		4.a.1.2	0.75	4.a.1.2	0.75		5.a.1.2	0.75		5.a.1.2	0.75
	7.a.2.1	0.975	7.a.2.1	0.975		4.a.2.1	1.00	4.a.2.1	0.998		5.a.2.1	0.99		5.a.2.1	0.975
	7.a.2.2	0.05	7.a.2.2	0.05		4.a.2.2	0.1	4.a.2.2	0.10		5.a.2.2	0.05		5.a.2.2	0.05
	7.b	0.762	7.b	0.762		4.b	0.775	4.b	0.775		5.b	0.76238			

Table C-1. Frequency/probability inputs (Cont.).

Personnel Injured during Rescue of PIW	7.b.1.1	1	7.b.1.1	1	4.b.1.1	1	4.b.1.1	1	5.b.1.1	1
	7.b.1.2	0.75	7.b.1.2	0.75	4.b.1.2	0.75	4.b.1.2	0.75	5.b.1.2	0.75
	7.b.2.1	0.975	7.b.2.1	0.975	4.b.2.1	1	4.b.2.1	0.998	5.b.2.1	0.99
	7.b.2.2	0.05	7.b.2.2	0.05	4.b.2.2	0.1	4.b.2.2	0.1	5.b.2.2	0.05
	7.c	0.762	7.c	0.762						
	7.c.1.1	1	7.c.1.1	1						
	7.c.1.2	0.75	7.c.1.2	0.75						
	7.c.2.1	0.975	7.c.2.1	0.975						
	7.c.2.2	0.05	7.c.2.2	0.05						
	7.d	0.762	7.d	0.762						
	7.d.1.1	1	7.d.1.1	1						
	7.d.1.2	0.75	7.d.1.2	0.75						
	7.d.2.1	0.975	7.d.2.1	0.975						
	7.d.2.2	0.05	7.d.2.2	0.05						
	7.e	0.762								
	7.e.1.1	1								
	7.e.1.2	0.75								
	7.e.2.1	0.975								
	7.e.2.2	0.05								
	7.f	0.762								
	7.f.1.1	1								
	7.f.1.2	0.75								
	7.f.2.1	0.975								
	7.f.2.2	0.05								
	7.g	0.762								
	7.g.1.1	1								
	7.g.1.2	0.75								
	7.g.2.1	0.975								
	7.g.2.2	0.05								
	7.h	0.762								
	7.h.1.1	1								
	7.h.1.2	0.75								
	7.h.2.1	0.975								
	7.h.2.2	0.05								
	7.i	0.762								
	7.i.1.1	1								
	7.i.1.2	0.75								
	7.i.2.1	0.975								
	7.i.2.2	0.05								
	7.j	0.762								
7.j.1.1	1									
7.j.1.2	0.75									
7.j.2.1	0.975									
7.j.2.2	0.05									

Table C-2. Frequency and probability inputs rationale.

Failure Branch	Event Type	ARP Number	Event Description	Value	Data Scoring and Calculations Rationale
A.1.a	Initiating Event	F1	Vessels Approaching the RNA	10,000	Total vessel traffic through the barrier is less than 10,000 transits per year.
C-R.1.a		F2	Red Flag Transits	600	Based on camera log
				850	A local commercial operator identified vessel transits for his facility as about 80%-90% of the 600 transits (e.g., ~425/year). Due to an increase in waterway usage for red-flag barge transits, he expects the actual number of vessels to be about twice that of the red-flag vessel traffic through the CSSC RNA (e.g., 425 * 2). Thus, it is expected that the number of transits for all operators is about 850/year.
C-N.1.a		F3	Non-Red Flag Transits	6,000	For Initiator B (Commercial Non-Red Flag vessel (CN)): About 15 per day for about 400 days/yr Includes all commercial non-Red Flag vessels (e.g., all barge tows or independent towboats and fleeting activity at the RNA boundary)
R-G.1.a		F4	Recreational Vessels Greater than 20 feet Initiate Transit the Safety Zone	700	There are about 90 powered recreational vessel transits (greater than 20 feet (R-G)) of the safety zone during each summer month. Loop transits increase in the fall. It is expected that other seasons will have substantially fewer transits. Thus, it is expected that the number of transits will be about 700/year.
R-L.1.a		F5	Recreational Vessels (20 feet or Less & PWC)	7	Presume that there are approximately 1% of the total recreational that are in this category.
S.1.a		F6	Personnel on the RNA Shore	15000	Based on the potential for 40 people per day to enter the area for 365 days per year for a total of about 15,000 entrances per year.
				30,000	Based on the presence of material handlers, USACE, USCG, deck operators and commercial operations in the RNA, and residential and private citizens, the average number of persons entering the RNA shore is about 80 people per day and given 365 days per year, the total number of persons entering the RNA shore is expected to be no more than about 30,000 per year.
C-R.2.a.1.1	Vessel experiences A Release of Ignitable Vapors	P1	P1: Commercial Red Flag Barge Collision, Allision or Sinking (CAS) Occurs	0.00002	The rate of reported CAS in the CSSC RNA has been less than one per year. Because of the geometry of the CSSC RNA, and the current rules and regulations, it would be very difficult to have a CAS with sufficient energy to possibly allow a release. There has been about 7 years without a CAS of a Red Flag vessel of significant energy. Assuming that CAS of significant energy occur at about a factor of 10 less than this for a population of about 600 Red Flag vessels per year results in a probability of about 1/600 transits * 1/7 years * 1/10 = 0.000023 or about 0.00002 per transit.
				0.0002	The rate of reported CAS in the CSSC RNA has been less than one per year. Because of the geometry of the CSSC RNA, and the current rules and regulations, it would be very difficult to have a CAS with sufficient energy to possibly allow a release. There has been about 7 years without a CAS of a Red Flag vessel of significant energy. Given the population of about 850 Red Flag vessels per year results in a probability of about 1/850 transits * 1/7 years= 0.000168 or about 0.0002 per transit.
C-R.2.a.1.2		P2	Release of Ignitable Vapor Results from a Red Flag CAS	0.1	Assume that one in ten of the CAS events with Red Flag vessels results in a release.

Table C-2. Frequency and probability inputs rationale (Cont.).

C-R.2.a.2		P3	Release of ignitable Vapor occurs in Red Flag Barges Because of Human Error, Mechanical Problem, or by Design	0.5	Because it is a common characteristic of the Red Flag vessels to have fugitive emissions, it is assumed that this condition will exist half of the time as the vessel transits the safety zone.
C-R.3.a	Vessel experiences a Spark	P4	Commercial Vessel Experiences Spark	0.001	The current regulations are designed to prevent the conditions that would support a spark. While sparks have been reported prior to the current regulations, there have been no sparks reported for over 7 years under the revised regulations. During the last 7 years there have been about 42,000 commercial transits. This implies a rate of sparking under the current rules and regulations of less than 0.000023/transit. Because the crew might not know that a spark occurred from a minor allision, a spark could have occurred that was not reported. Thus, an assumed probability of 0.001 or once in 1000 transits is used.
C-R.3.b					
C-N.3.a					
C-R.4.a.1	Vapor ignition occurs	P5	Released Vapors on Red Flag Barge are Configured into an Ignitable Cloud Beyond the Division 1.1 Hazard Zone	0.0001	Because of the required movement of the vessel, it is extremely unlikely for an ignitable cloud to form beyond 5 feet from the source (i.e., the Class 1, Division 1 designated hazard zone). The vents are located to ensure that they are not near spaces where a confinement could occur. Thus, it is assumed that this would occur with a probability of less than one in ten-thousand transits.
C-R.4.a.2		P6	Spark on Red Flag Barge is Sufficient for Ignition of Vapor Cloud	0.1	For this to happen, the spark must be in the proximity of the cloud and be of sufficient energy to cause ignition. Because of the location of the release points, it is unlikely for the ignitable cloud to be in close proximity of the spark which is most likely to occur between the hull of the vessel and a metal structure. The current requirement of having a bow boat further helps to ensure that any spark would be a significant distance from any ignitable cloud. Thus, it is assumed that the probability of an ignitable cloud moving to the proximity of the spark and the spark being of sufficient energy to ignite the cloud is less than one in one hundred thousand or 0.00001. However, the very conservative value of 0.1 will be used based on the potential for unaddressed dependency issues.
C-R.5.a	Person Experiences a Shock from activities during transit of the safety zone	P7	Personnel on Commercial Vessel Experience Shock from Activities	0.00002	Personnel on the vessel could experience shock from activities. The most severe shock is expected to be a relatively small shock that might cause a person to jerk away. To experience such a shock, however, they would have to be performing activities on deck while transiting the safety zone, which is highly unlikely. There have been no reported occurrences of this event to date. The historical record of about 6000 transits per year for 7 years indicates that the value should be less than 0.00002. This value applies to 5.a and 5.c because both of these situations involve a shock occurring even though there has been no spark, and these events are not dependent on whether a release has occurred.
C-R.5.c					
C-N.5.a					
C-R.5.b.2					
C-R.5.d.2					
C-R.5.e.2					
C-N.5.b.2					
R-G.2.a	P8	Personnel on Recreational Vessel > 20 Feet Experience Shock from Activities	0.0002	The key drivers for experiencing a shock on vessels over 20 feet vessel personnel complete the circuit by touching two metal items on a non-metal boat that both have contact with the surface of the water. While there have been no reported incidents during a seven year period, studies have demonstrated that this is a possibility. Equipment or systems that are improperly grounded could cause a circuit that is open and which would be closed by the recreational boater. Seven years of 700 transits per year implies a probability of less than 0.0002 shocks per transit.	

Table C-2. Frequency and probability inputs rationale (Cont.).

R-L.2.a		P9	Personnel on Recreational Vessel 20 Feet or Less and PWC Experience Shock from Activities	0.02	The key drivers for experiencing a shock on smaller vessels and PWC (nonmetal small fishing boats, kayaks, and other small metal boats) include insertion of hand in the water, hand on conductive shaft of paddle in the water, Over seven years there have been no reported incidents of personnel on smaller vessels and PWC in the fish barrier experiencing a shock. This implies a probability of less than 0.02 shocks per transit.
C-R.5.b.1		P10	Personnel on Commercial Vessel Experience Shock from Spark	0.00001	Even though the spark has occurred, it is very unlikely that personnel would be at a location where they could be shocked by the spark because the spark would occur between the barge and another metal structure. A value of 0.00001 is used as the probability of a person on the vessel being in a vulnerable location and the spark shocking them.
C-R.5.d.1					
C-R.5.e.1					
C-N.5.b.1					
C-R.6.a.2	Person Enters the Water from Activities	P11	PIW from Activities During Commercial Vessel Transit of the Safety Zone	0.00000002	About 3 mariner overboard events occur per year in canals. Further, of the 25,000 miles of waterways in the United States, it is assumed that about 10% of these miles are canals based on canal related man-hours of about 5 million out of a total of about 75 million man-hours. From this, the probability of a mariner overboard in a canal mile during a year can be calculated as: (3 mariners overboard in canals per year)/(25000 waterway miles * 1 Canal waterway mile/10 waterway miles) = 0.001 mariners overboard/canal mile year. Thus, the probability of a mariner falling overboard during a transit of the CSSC can be estimated as: the probability of a mariner overboard in one mile of canal transit divided by the number of commercial transits of the CSSC in a year or (0.001 mariners overboard/canal mile year)/ (6600 commercial transits of the CSSC/year) = 0.00000015 or ~0.0000002. Because the regulations require the vessel personnel to be as inboard as possible, it is expected that the actual probability will be at least a factor of 10 less than the value developed based on general commercial traffic in a canal. Thus, a value of 0.00000002 is used for the probability of a mariner falling overboard during a otherwise normal transit of the CSSC.
C-R.6.b.2					
C-R.6.c.2					
C-R.6.d.2					
C-R.6.e.2					
C-R.6.f.2					
C-R.6.g.2					
C-R.6.h.2					
C-R.6.i.2					
C-R.6.j.2					
C-N.6.a.2					
C-N.6.b.2					
C-N.6.c.2					
C-N.6.d.2					
R-G.3.a.2		P12	PIW from Activities During Transit of Safety Zone for a Recreational Vessel > 20 Feet	0.000003	The Recreational Boating Statistics 2011 report (COMDTPUB P16754.25) reported that 359 falls overboard occurred for about 12 million registered boats. Assuming that each boat travels about 10 miles per year, the probability of a recreational boater falling overboard in a transit of a mile = (359 recreational boater falls overboard/year)/(12,000,000 registered boats * 10 miles/registered boat –year) = 3 X 10 ⁻⁶ recreational boater falls overboard/ registered boat-mile. While it could be argued that the recreational boater will be more careful given the posted warnings, no credit is currently assigned for this factor. Thus, a probability of 0.000003 is used.
R-G.3.b.2				0.0000003	The Recreational Boating Statistics 2011 report (COMDTPUB P16754.25) reported that 359 falls overboard occurred for about 12 million registered boats. Assuming that each boat travels about 100 miles per year, the probability of a recreational boater falling overboard in a transit of a mile = (359 recreational boater falls overboard/year)/(12,000,000 registered boats * 100 miles/registered boat –year) = 3 X 10 ⁻⁷ recreational boater falls overboard/ registered boat-mile. While it could be argued that the recreational boater will be more careful given the posted warnings, no credit is currently assigned for this factor. Thus, a probability of 0.0000003 is used.

Table C-2. Frequency and probability inputs rationale (Cont.).

R-L.3.a.2	Person Enters the Water from Activities	P13	PIW from Activities During Transit of the Safety Zone for a Recreational Vessel 20 Feet or Less & PWC	0.001	Because no relevant data has been located for transits involving "Recreational Vessels 20 Feet and Less and PWCs", this event probability will be based on data used to assess the "Greater than 20 Feet" transits. The Recreational Boating Statistics 2011 report (COMDTPUB P16754.25) reported that 359 falls overboard occurred for about 12 million registered boats. Assuming that each boat travels about 10 miles per year, the probability of a recreational boater falling overboard in a transit of a mile = (359 recreational boater falls overboard/year)/(12,000,000 registered boats * 10 miles/registered boat-year) = 3 X 10 ⁻⁶ recreational boater falls overboard/ registered boat-mile. While it could be argued that the recreational boater will be more careful given the posted warnings, no credit is currently assigned for this factor. A probability of 0.000003 was used for this event for "Recreational Vessels Greater than 20 Feet." It is expected that the probability of this event for "Recreational Vessels 20 Feet or Less and PWCs" will be much more likely than for "Recreational Vessels Greater than 20 Feet," perhaps by as much as several orders of magnitude. This is because it is expected that many of these events go unreported. Thus, a value of 0.001 will be used for this event.
R-L.3.b.2					
A.3.a.2	Person Enters the Water from Activities	P14	PIW from Activities While Approaching the RNA and the Safety Zone	0.00001	There have been no recorded cases in seven years of records of a PIW as a vessel approached the RNA during seven years of recorded activity with about 10,000 vessels approaching the RNA and its safety zone per year. Thus, the probability of a congestion related CAS is expected to be less than about 0.00001.
A.3.b.2					
C-R.6.a.1	Person Enters the Water from a CAS	P15	PIW from CAS for Commercial Vessel	0.000000002	The calculation for C-R.6.a.2 is based on canal related data and results in a probability of a person falling overboard during a commercial transit of the CSSC of 0.00000002. The data source did not identify any contribution for mariners falling overboard from allisions, collisions or sinkings. It is assumed that this would not be more than a 10% contributor. Thus, the probability of a PIW from a CAS during a transit of the CSSC is 0.000000002.
C-R.6.b.1					
C-R.6.c.1					
C-R.6.d.1					
C-R.6.e.1					
C-R.6.f.1					
C-R.6.g.1					
C-R.6.h.1					
C-R.6.i.1					
C-R.6.j.1					
C-N.6.a.1					
C-N.6.b.1					
C-N.6.c.1					
C-N.6.d.1					

Table C-2. Frequency and probability inputs rationale (Cont.).

R-G.3.a.1	Person Enters the Water from a CAS	P16	PIW from a CAS for Recreational Vessel > 20 Feet	0.000003	The Recreational Boating Statistics 2011 report (COMDTPUB P16754.25) reported that 222 ejected from vessel, 115 departed vessel and 0 sinking events occurred for about 12 million registered boats. These events are interpreted as events that results in a recreational boater forced into the water. Assuming that each boat travels about 10 miles per year, the probability of a recreational boater falling overboard in a transit of a mile = (337 recreational boater forced into the water/year)/(12,000,000 registered boats * 10 miles/registered boat –year) = 3 X 10 ⁻⁶ recreational boater forced into the water/ registered boat-mile. While it could be argued that the recreational boater will be more careful given the posted warnings, no credit is currently assigned for this factor. Thus, a probability of 0.000003 is used for this event.
R-G.3.b.1				0.0000003	The Recreational Boating Statistics 2011 report (COMDTPUB P16754.25) reported that 222 ejected from vessel, 115 departed vessel and 0 sinking events occurred for about 12 million registered boats. These events are interpreted as events that results in a recreational boater forced into the water. Assuming that each boat travels about 100 miles per year, the probability of a recreational boater falling overboard in a transit of a mile = (337 recreational boater forced into the water/year)/(12,000,000 registered boats * 100 miles/registered boat –year) = 3 X 10 ⁻⁶ recreational boater forced into the water/ registered boat-mile. While it could be argued that the recreational boater will be more careful given the posted warnings, no credit is currently assigned for this factor. Thus, a probability of 0.000003 is used for this event.
R-L.3.a.1		P17	PIW from CAS for Recreational Vessel 20 Feet or Less & PWC	0.001	Because no relevant data has been located for transits involving "Recreational Vessels 20 Feet and Less and PWCs," this event probability will be based on data used to assess the "Greater than 20 Feet" transits. The Recreational Boating Statistics 2011 report (COMDTPUB P16754.25) reported that 222 ejected from vessel, 115 departed vessel and 0 sinking events occurred for about 12 million registered boats. These events are interpreted as events that result in a recreational boater forced into the water. Assuming that each boat travels about 10 miles per year, the probability of a recreational boater falling overboard in a transit of a mile = (337 recreational boater entering the water/year)/(12,000,000 registered boats * 10 miles/registered boat–year) = 3 X 10 ⁻⁶ recreational boater entering the water/ registered boat-mile. While it could be argued that the recreational boater will be more careful given the posted warnings, no credit is currently assigned for this factor. Thus, a probability of 0.000003 is used for this event. It is expected that the probability of this event for "Recreational Vessels 20 Feet or Less and PWCs" will be much more likely than for "Recreational Vessels Greater than 20 Feet", perhaps by as much as several orders of magnitude. This is because it is expected that many of these events go unreported. Thus, a value of 0.001 will be used for this event.
R-L.3.b.1					
A.3.a.1		P18	PIW from a CAS Not Related to Congestion for a Vessel Approaching the RNA	0.00001	There have been no recorded CAS that were attributed to congestion created by the RNA or from other causes during seven years of recorded activity with about 10,000 vessels approaching the RNA and its safety zone per year. Thus, the probability of a CAS that is not related to RNA congestion causing a PIW is expected to be less than about 0.00001.
A.3.b.1.2					
A.3.b.1.1	P19				

Table C-2. Frequency and probability inputs rationale (Cont.).

C-R.6.i.3	Person Enters the Water from a blast	P20	PIW from Blast on Red Flag Barge	0.0001	It is expected that the largest ignition event will be a minor deflagration. Thus, unless the event scares the person into losing their balance and falling overboard (when they are expected to be inboard), it is very unlikely that the ignition would cause a PIW. Thus, it is expected that the probability of a PIW is less than 0.0001 given an ignition has occurred.
C-R.6.j.3					
C-R.7.a.1.1	Personnel Experience Electric Shock: Power to Fish Barrier is not turned off before PIW exposed to electric field	P21	Power to Fish Barriers is Not Turned Off Before PIW from Vessel Transiting Safety Zone is Exposed to Electric Field	1.0	This probability for this event is dependent on many factors regarding personnel recognizing that a person has entered the water and responding promptly before the person is exposed to the electric field. At least a third of the incidents will involve a person falling directly into the barriers. In addition entering the water in the safety zone creates an immediate exposure to at least some electric field.
C-R.7.b.1.1					
C-R.7.c.1.1					
C-R.7.d.1.1					
C-R.7.e.1.1					
C-R.7.f.1.1					
C-R.7.g.1.1					
C-R.7.h.1.1					
C-R.7.i.1.1					
C-R.7.j.1.1					
C-N.7.a.1.1					
C-N.7.b.1.1					
C-N.7.c.1.1					
C-N.7.d.1.1					
R-G.4.a.1.1					
R-G.4.b.1.1					
R-L.4.a.1.1					
R-L.4.b.1.1					
A.5.a.1.1	Personnel Experience Electric Shock: Power to Fish Barrier is not turned off before PIW exposed to electric field	P22	Power to Fish Barriers is Not Turned Off Before PIW from Approaching Vessel is Exposed to Electric Field	0.01	Because of the number of personnel who could be aware of the person entering the water, and the variety of communication tools available to the vessel personnel, it is expected that the probability of not turning off the fish barrier power before PIW is exposed to the electric field is less than 0.01.
A.5.b.1.1				1	It is not expected that the personnel who could be aware of the person entering the water would affect the rescue of the PIW before the power to the fish barrier is turned off. Currently, there is no phone number publicly posted or available to most of the operators in the RNA area for a direct point of contact for turning off the barriers. The current notification procedures for turning the barriers off are not expected to permit a timely enough response to turn the power off before a PIW is exposed to the electric field. Additionally, while persons are always present at the barriers and authorized to turn off the power to preserve a life, the barrier area is not actively monitored for a PIW and there is no centralized control point for terminating the power to all barriers. Therefore, it is expected that the probability of not turning off the fish barrier power before PIW is exposed to the electric field is 1.0.

Table C-2. Frequency and probability inputs rationale (Cont.).

S.5.a.1.1		P23	Power to Fish Barriers is Not Turned Off Before PIW from the RNA Shore is Exposed to Electric Field	0.75	For the 50% (i.e., half of the 20%) who enter the water in the safety zone, there is almost no chance of securing the power before they are exposed to the electric field. For the 50% that drift into the fish barrier, it is expected that the power would be turned off half of the time before they enter the safety zone. Thus, the probability of the power not being turned off before the PIW is exposed to the electric field is about 0.75%.
				0.95	For the 50% who enter the water in the safety zone, there is no chance of securing the power before they are exposed to the electric field. For the 50% that drift into the fish barrier, it is expected that the power would be turned off 10% of the time before they enter the safety zone. Thus, the probability of the power not being turned off before the PIW is exposed to the electric field is about 0.95%.
C-R.7.a.1.2	Personnel Experience Electric Shock: PIW Experience Electric Shock Injuries	P24	PIW from Safety Zone Transit or Shore Experience Electric Shock Injuries from Fish Barrier Electric Field	0.75	<p>There are portions of the safety zone where the PIW would not experience electric shock injuries above the null consequence category before their rescue. Rescue could occur by personnel on the vessel or by other emergency personnel.</p> <p>Because the person has about a 50% chance of falling into an area that would be immediately above the null consequence category and because there could be another 50% chance of the person entering those areas before rescue, a 75% chance of the event occurring is used.</p>
C-R.7.b.1.2					
C-R.7.c.1.2					
C-R.7.d.1.2					
C-R.7.e.1.2					
C-R.7.f.1.2					
C-R.7.g.1.2					
C-R.7.h.1.2					
C-R.7.i.1.2					
C-R.7.j.1.2					
C-N.7.a.1.2					
C-N.7.b.1.2					
C-N.7.c.1.2					
C-N.7.d.1.2					
R-G.4.a.1.2					
R-G.4.b.1.2					
R-L.4.a.1.2					
R-L.4.b.1.2					
S.5.a.1.2					
A.5.a.1.2		P25	PIW from Approaching Vessel Experience Electric Shock Injuries from the Fish Barrier Electric Field	0.75	Given that the fish barrier power has not been turned off, it is expected that the PIW is very likely to suffer electric shock injuries entering the fish barrier. Thus, a probability of 0.75 is used.
A.5.b.1.2					

Table C-2. Frequency and probability inputs rationale (Cont.).

C-R.7.a.2.1	Personnel Experience Electric Shock: Power to Fish Barrier is not turned off before PIW Rescuer exposed to electric field	P26	Power to Fish Barriers Not Turned Off Before Rescuer Personnel for a Commercial Vessel or Shore Personnel are Exposed to Electric Fish Barriers	0.1	In general personnel are trained to avoid electric shock injuries and would work to ensure that the power is turned off before being exposed to the electric field (see the response plan). However, rescue might be attempted by a person on the vessel or other unofficial rescue personnel. Thus, a 10% chance of exposure is used.
C-R.7.b.2.1					
C-R.7.c.2.1					
C-R.7.d.2.1					
C-R.7.e.2.1					
C-R.7.f.2.1					
C-R.7.g.2.1					
C-R.7.h.2.1					
C-R.7.i.2.1					
C-R.7.j.2.1					
C-N.7.a.2.1					
C-N.7.b.2.1					
C-N.7.c.2.1					
C-N.7.d.2.1					
S.5.a.2.1				0.975	It is expected that personnel affecting a rescue will be attempted by a person on the vessel or other unofficial rescue personnel. Due to the expected high severity of injury to the PIW, personnel with initial awareness of the PIW are expected to initiate immediate response rather than wait on professional responders to affect first response. Thus, a 97.5% chance of exposure is used.
R-G.4.a.2.1	P27	Power to Fish Barriers is Not Turned Off Before Rescue Personnel for a Recreational Vessel > 20 feet are Exposed to Electric Field	1.0	Recreational boaters on larger boats are very likely to immediately attempt a rescue. Thus, it is expected that the fish barrier power will not be turned off before other personnel on the recreational boat attempt a rescue which will expose them to the electric field.	
R-G.4.b.2.1					
R-L.4.a.2.1	P28	Power to Fish Barriers is Not Turned Off Before Rescue Personnel for a Rec Vessel 20 feet or Less & PWC are Exposed to Electric Field	0.01	0.998	Recreational boaters on boats that are 20 feet or less and PWC are likely to be alone. When these recreational boaters enter the water, rescue is more likely to come from trained rescue personnel. These rescue personnel are trained to have the power turned off prior to attempting rescue.
R-L.4.b.2.1					Recreational boaters on boats that are 20 feet or less and PWC are likely to be accompanied by another person on the boat or another PWC. Very rarely does a Recreational boater or PWC traverse the CSSC alone. When these recreational boaters enter the water, rescue is likely to come from the companion PWC or fellow boater rather than wait on professional responders to affect first response. Thus, a 99.8% chance of exposure is used given the off occasion that a boater transits alone and rescue is affected by professionally trained responders.
A.5.a.2.1	P29	Power to Fish Barriers is Not Turned Off Before Rescue Personnel for a Vessel Approaching the RNA are Exposed to Electric Field	0.01	0.99	Because of the number of personnel who could be aware of the person entering the water, and the variety of communication tools available to the vessel personnel, it is expected that the probability of not turning off the fish barrier power before PIW is exposed to the electric field is less than 0.01.
A.5.b.2.1					Vessels approaching the RNA and Safety Zone are likely to have more than 1 person on the vessel or be watercrafts that travel in pairs. When a person enters the water while approaching the RNA and Safety Zone, the rescue attempt is likely to come from another person aboard the vessel or a fellow boater rather than notifying the Coast Guard of the PIW and waiting for the electric field to be turned off. Thus, a 99% chance of exposure is used given the off occasion that there is enough time to provide notice to the barrier engineer to turn off the electric field for a responder to affect a rescue.

Table C-2. Frequency and probability inputs rationale (Cont.).

C-R.7.a.2.2	Personnel Experience Electric Shock: PIW Rescuer Experience Electric Shock Injuries	P30	Rescue Personnel Experience Electric Shock Injuries Attempting a PIW Rescue (Excluding Recreational Vessels)	0.1	Official rescue personnel are trained to not attempt a rescue before the power is turned off. However rescue may be attempted by other personnel. Even in this case the rescuer may be adequately protected by training and equipment. Thus, a 10% chance of shock above the null consequence is used.										
C-R.7.b.2.2															
C-R.7.c.2.2															
C-R.7.d.2.2															
C-R.7.e.2.2															
C-R.7.f.2.2															
C-R.7.g.2.2															
C-R.7.h.2.2															
C-R.7.i.2.2															
C-R.7.j.2.2															
C-N.7.a.2.2															
C-N.7.b.2.2															
C-N.7.c.2.2															
C-N.7.d.2.2															
A.5.a.2.2	Personnel Experience Electric Shock: PIW Rescuer Experience Electric Shock Injuries	P30	Rescue Personnel Experience Electric Shock Injuries Attempting a PIW Rescue (Excluding Recreational Vessels)	0.05	Official rescue personnel are trained to not attempt a rescue before the power is turned off. However rescue may be attempted by other personnel. Even in this case, the rescuer may be able to attempt rescue from a distance that would not expose the rescuer to the electric field or the rescuer may be adequately trained and properly equipped with PPE to avoid direct exposure to the electric field. Thus, a 5% chance of shock above the null consequence is used.										
A.5.b.2.2															
S.5.a.2.2															
R-L.4.a.2.2															
R-L.4.b.2.2															
R-G.4.a.2.2															
R-G.4.b.2.2															
A.2.a						Congestion-Related CAS	P32	Approaching Vessel Experiences a Congestion Related CAS	0.00001	There have been no recorded CAS that were attributed to congestion created by the RNA. Thus, the probability of a congestion related CAS is expected to be less than about 0.00001.					
R-L.4.a.2.2						Personnel Experience Electric Shock: PIW Rescuer Experience Electric Shock Injuries	P31	Rescue Personnel Experience Electric Shock Injuries Attempting a PIW Rescue for Recreational Vessels	0.5	Rescue by other recreational boaters is expected to be attempted for powered vessels greater than 20 feet. Thus, because in many instances the rescuer will not be adequately trained regarding the electric shock issues, the probability of the rescue personnel suffering electric shock is expected to be about 0.5.					
R-L.4.b.2.2															
R-G.4.a.2.2															
R-G.4.b.2.2															
A.2.a											Congestion-Related CAS	P32	Approaching Vessel Experiences a Congestion Related CAS	0.1	Rescue by other recreational boaters is expected to be attempted for powered vessels greater than 20 feet. It is assumed that in many instances the rescuer will not have PPE or be adequately trained regarding the electric shock issues and could intentionally enter the water to rescue the PIW. The probability of the rescue personnel suffering electric shock is expected to be about 0.1.

Table C-2. Frequency and probability inputs rationale (Cont.).

A.4.a	Person in the Water drifts into the Fish Barrier	P33	PIW Approaching RNA and its Safety Zone are Not Safely Removed Before Reaching Safety Zone	0.1	Because this event occurs approaching the RNA and its safety zone, those who fall in are expected to attempt to swim away from the safety zone. In addition, in most cases other personnel will be aware of their situation, and will initiate rescue actions. Thus, it is expected that less than 10% of these personnel will not be safely rescued before reaching the safety zone. The results for A.4.a and A.4.b are expected to be about the same because the safe rescue is not expected to be very dependent on whether the PIW was from normal activities or a CAS.
A.4.b				0.05	Because this event occurs approaching the RNA and its safety zone, those who fall in may not be aware of the location of the Barriers. The average flow rate for the waters in the CSSC is about 1 to 5 feet per second and those who enter the water may not be able to swim away from the safety zone. Additionally, those who fall in North of the Demonstration Barrier will float towards the safety zone. Notwithstanding, in most cases other personnel will be aware of their situation, and will initiate rescue actions. Thus, it is expected that about 1 in 20 or 5% of these personnel will not be safely rescued before reaching the safety zone. The results for A.4.a and A.4.b are expected to be about the same because the safe rescue is not expected to be very dependent on whether the PIW was from normal activities or a CAS.
S.2.a	Persons on RNA Shore Approach the Water	P34	Shore Personnel are Near the Water	0.3	It is expected that about 30% of the personnel entering the shore area will be close enough to the water to have the potential to inadvertently fall in.
S.3.a	Person Enters the Water from the Shore	P35	Shore Personnel Enter the Water (Falls in) After Getting Close to the Shore	0.00001	There is only one recorded incident of a person working in this area inadvertently falling into the canal. Over the 20 year period there would have been approximately 180,000 (i.e., 15,000 * 0.3 * 4,500) personnel in a position to possibly fall in with one incident occurring. This indicates a probability of about 0.00001 for a person working near the shore to fall into the canal.
				0.000006	There is only one reported incident of a person working in this area inadvertently falling into the canal. Over the 20 year period there would have been approximately 180,000 (i.e., 30,000 persons/year * 20 years * 30% of persons are close to the water) personnel in a position to possibly fall in with one reported incident occurring. This indicates a probability of about 0.000006 (i.e., 1/180,000) for a person working near the shore to fall into the canal.
S.4.a	Person in the Water drifts into the Fish Barrier	P36	Shore Personnel Not Safely Removed Before Reaching the Safety Zone	0.2	A 0.2 probability is based on the assumptions that (1) only 10% of the personnel that fall in are already in the safety zone, and (2) another 10% contribution comes from personnel who enter the water outside the safety zone not being safely removed before they enter the safety zone (i.e., of the 90 percent who fall in away from the safety zone, only about 10% are not safely removed before they enter the safety zone). Those who fall in outside of the safety zone are expected to attempt to swim away from the safety zone. In addition, in most cases other personnel will be aware of their situation, and will initiate rescue actions.

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APPENDIX D. SCENARIO CONSEQUENCES

Section 2.3.3 provides an introduction to the development of average consequence input values for each consequence type associated with each analyzed scenario. Specifically, Table 13 identifies (with an “X”) all “Initiator Type” and “Consequence Type” pairings requiring an average consequence value for the risk calculations. Developing the average consequence values corresponds with STEP B in the simplified flowchart in Figure 3.

Table D-1 presents a summary of average consequence values in dollars for each relevant consequence type for the six analyzed situations. The six analyzed consequence types are shown across the top of the table, and the six analyzed initiator types are shown on the left hand side of the page. The cells with average consequence values shown in Table D-1 correspond to the cells containing an “X” in Table 13. In addition, the basis for each average consequence value is shown in two columns; with one column showing the identified severity fractions for the five severity categories and the second column showing the associated cost for that severity category. The cost for a severity category is calculated by multiplying the severity fraction by the representative value for that severity fraction. The representative values for each severity category along with the category lower and upper bounds are shown on the bottom of the table.

Table D-2 presents the consequence input discussion and rationale. This table provides a detailed description of all the rationale for each severity fraction used to develop each of the average consequence values in Table D-1. This table has five major column headings designed to help ensure complete transparency in the average consequence values used in this analysis. The first heading is “General Description of Consequence Types”. Under this heading, the events are structured around the three generic types of consequences of (1) Electric Shock, (2) Spark-Related Vapor Ignition, and (3) Congestion-Related Collision, Allision, and Sinking (CAS). Electric Shock is further divided into the four subtypes of consequences of (1) PIW-Related Electric Shock, (2) PIW Rescuer-Related Electric Shock, (3) Commercial or Recreational-Activity-Related Electric Shock, and (4) Contact-Related Electric Shock. Each cell identifies the consequence type in bold letters followed by a paragraph describing the consequence type.

The second heading in Table D-2 is “Description of the Consequence for Each Relevant Initiator Type.” Table 13 identifies all relevant average consequence values needed for this analysis. Each “X” in the table corresponds to an average consequence value that is needed for the “Consequence Type” and “Initiator Type” pairing. Each cell in this column identifies the Consequence Type/Initiator Type pairing in bold letters followed by a paragraph describing the average consequences expected from all associated loss scenarios.

The third heading in Table D-2 is “Average Cost”. This cost represents the expected average cost for a population of future loss events that result in the consequence type for the relevant initiator type (e.g., PIW-related electric shock for red-flag commercial vessel transits of the safety zone). The average cost is calculated by summing the average costs associated with each of the five severity categories.

The fourth heading in Table D-2 is “Severity Category.” The first column under this heading is “Severity Fraction.” This fraction for a severity category is the expected fraction of future loss events for the consequence type/initiator type pairing that will occur in the respective severity category. The severity fractions for the five severity categories associated with the consequence type/initiator type pairing must sum to 1.0 representing the full set of future loss events considered for the pairing. The second column under



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this heading is “Category Cost.” This cost is the expected average cost for the category, which is calculated by multiplying the category severity fraction, by the category representative cost (See Table D-1).

The final heading on the right hand side of Table D-2 is “Description of the Severity Fraction”. This column provides a detailed rationale for each severity fraction. Because no incidents have occurred within the RNA resulting in the assessed consequences, the rationale for the fractions is based on analysis team discussions.



Table D-1. Summary of average consequence values and associated severity fractions for relevant combinations of initiators and decision factors.

Event Tree	Vessel Category	Severity Scale	Congestion-Related CAS		Commercial Activities-Related ES		Contact-Related ES		PIW-Related ES		PIW Rescuer-Related ES		Spark-Related Vapor Ignition		
			Severity Fraction	Avg Cost	Severity Fraction	Avg Cost	Severity Fraction	Avg Cost	Severity Fraction	Avg Cost	Severity Fraction	Avg Cost	Severity Fraction	Avg Cost	
Event Tree C: Commercial Vessel Transit of the Safety Zone	Red Flag Vessels	VH (\$10B)			0	\$ -	0	\$ -	0	\$ -	0	\$ -	0	\$ -	
		H (\$7MM)			0	\$ -	0	\$ -	0.25	\$ 1,750,000	0.005	\$ 35,000	0	\$ -	
		M (\$300K)			0	\$ -	0	\$ -	0.3	\$ 90,000	0.1	\$ 30,000	0	\$ -	
		L (\$4K)			0.005	\$ 20	0.1	\$ 400	0.449	\$ 1,796	0.7	\$ 2,800	0.1	\$ 400	
		Null (\$0)			0.995	\$ -	0.9	\$ -	0.001	\$ -	0.195	\$ -	0.9	\$ -	
		TOTALS			1	\$ 20	1	\$ 400	1.00000	\$ 1,841,796	1	\$ 67,800	1.000000	\$ 400	
		Non-Red Flag Vessels	VH (\$10B)			0	\$ -	0	\$ -	0	\$ -	0	\$ -		
	H (\$7MM)				0	\$ -	0	\$ -	0.25	\$ 1,750,000	0.005	\$ 35,000			
	M (\$300K)				0	\$ -	0	\$ -	0.3	\$ 90,000	0.1	\$ 30,000			
	L (\$4K)				0.005	\$ 20	0.1	\$ 400	0.449	\$ 1,796	0.7	\$ 2,800			
Null (\$0)				0.995	\$ -	0.9	\$ -	0.001	\$ -	0.195	\$ -				
	TOTALS			1	\$ 20	1	\$ 400	1	\$ 1,841,796	1	\$ 67,800				
Event Tree R: Recreational Vessels Transit of the Safety Zone	Vessels Greater Than 20 Feet	VH (\$10B)			0	\$ -			0	\$ -	0	\$ -			
		H (\$7MM)			0.00005	\$ 350			0.25	\$ 1,750,000	0.25	\$ 1,750,000			
		M (\$300K)			0	\$ -			0.3	\$ 90,000	0.2	\$ 60,000			
		L (\$4K)			0.005	\$ 20			0.449	\$ 1,796	0.45	\$ 1,800			
		Null (\$0)			0.99495	\$ -			0.001	\$ -	0.1	\$ -			
		TOTALS			1	\$ 370			1	\$ 1,841,796	1	\$ 1,811,800			
		Vessels 20 Feet or Less and PWCs	VH (\$10B)			0	\$ -			0	\$ -	0	\$ -		
	H (\$7MM)				0.00005	\$ 350			0.25	\$ 1,750,000	0.25	\$ 1,750,000			
	M (\$300K)				0	\$ -			0.3	\$ 90,000	0.20	\$ 60,000			
	L (\$4K)				0.005	\$ 20			0.449	\$ 1,796	0.45	\$ 1,800			
Null (\$0)				0.99495	\$ -			0.001	\$ -	0.10	\$ -				
	TOTALS			1	\$ 370			1	\$ 1,841,796	1	\$ 1,811,800				
Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA)		VH (\$10B)			0	\$ -			0.0	\$ -	0	\$ -			
		H (\$7MM)			0.005	\$ 35,000			1.0	\$ 7,000,000	0.005	\$ 35,000			
		M (\$300K)			0.01	\$ 3,000			0.0	\$ -	0.1	\$ 30,000			
		L (\$4K)			0.44	\$ 1,760			0.0	\$ -	0.7	\$ 2,800			
		Null (\$0)			0.545	\$ -			0.0	\$ -	0.195	\$ -			
		TOTALS			1	\$ 39,760			1	\$ 7,000,000	1	\$ 67,800			
Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore		VH (\$10B)							0.0	\$ -	0	\$ -			
		H (\$7MM)							1.0	\$ 7,000,000	0.005	\$ 35,000			
		M (\$300K)							0.0	\$ -	0.1	\$ 30,000			
		L (\$4K)							0.0	\$ -	0.7	\$ 2,800			
		Null (\$0)							0.0	\$ -	0.195	\$ -			
		TOTALS							1	\$ 7,000,000	1	\$ 67,800			
		Severity Scale	Category	Representative Value	Lower Bound	Upper Bound									
		VH (\$10B)	Very High	\$ 10,000,000,000	\$ 3,000,000,000										
		H (\$7MM)	High	\$ 7,000,000	\$ 3,000,000	\$ 3,000,000,000									
		M (\$300K)	Medium	\$ 300,000	\$ 10,000	\$ 3,000,000									
		L (\$4K)	Low	\$ 4,000	\$ 1,000	\$ 10,000									
		Null (\$0)	Null	\$ -	\$ -	\$ 1,000									

Table D-2. Detailed descriptions of average consequence values and associated severity fractions for relevant combinations of initiators and decision factors.

General Description of Consequence Types	Description of Specific Consequence Types	Event Tree Applicable	Preliminary Average Cost	Validated Average Cost	ARP NUMBER	Severity Fraction Input Value	Severity Category		Description of the Severity Fraction				
							Fraction	Cost					
						0	0	\$ -	It is not expected that there will ever be any PIW incidents that would need a representative value of \$10 Billion.				
<p>Electric Shock (ES): This event focuses on a person receiving an electric shock while (1) performing an commercial or recreational activity during the transit of the safety zone; (2) complete the circuit by touching two metal items that both have contact with the surface of the water; (3) entering the water exposed to the electrified field; or (4) responding to a person in the water (PIW) exposed to the electrified field. These incidents can range in severity from only a recognition of a minor feeling to severe injury or death.</p>	<p>PIW-Related Electric Shock: This event addresses the potential loss that can be experienced when a person has inadvertently entered the water somewhere in the RNA and its safety zone. If the person enters the water over one of the barriers, then there is a high likelihood of severe injury or death. If the person enters the water adjacent to the fish barriers, but not directly over them, then the severity of the shock ranges from a relatively minor feeling to severe injury or death depending on the strength of the electrified field and the medical condition of the PIW (e.g., a person with a pacemaker may experience defibrillation).</p>	<p>This event involves a mariner inadvertently being in the water in the safety zone and experiencing shock from the barrier before the barrier can be turned off. Because of the chance that this incident could result in a death with an equivalent cost of about \$7 Million, it is expected that these incidents will have an average cost between \$1.5 and \$2 Million.</p>	1,841,796	1,841,796		0.25	0.25	\$ 1,750,000	The mariners involved in PIW incidents in the safety zone will enter the water very near or directly over a barrier in about 25% the PIW of these incidents. In these situations, the shock a person would receive is expected to cause serious injury or death. The representative value for this consequence category is \$7,000,000 F26 This will result in an average loss per incident of about \$1,750,000 from this severity category.				
										0.3	0.3	\$ 90,000	About 75% of the safety zone is not directly over the fish barrier system. In these areas between the barriers, the shock that a person would receive will vary substantially. It is expected that about 40% of the time when a mariner falls into the areas not directly over the fish barrier system that the person will experience a shock that is severe enough to cause extended hospitalization. For the entire area this means that about 30% of the PIW incidents will result in this category (Low) of loss. This will result in an average loss per incident of about \$90,000 (i.e., 0.3 *\$300,000) from this severity category.
										0.449	0.449	\$ 1,796	About 75% of the safety zone is not directly over a specific barrier. In these zones between the barriers, the shock that a person would receive will vary substantially. It is expected that about 60% of time when a mariner falls into the areas not directly over the fish barrier system that the shock will result in only minor injury with a hospital visit to verify that the person is not severely injured. For the entire area this means that about 45% of the PIW incidents will result in this category (Very Low) of loss. This will result in an average loss per incident of about \$2,800 (i.e., 0.45 * \$4,000). Note: The actual number used is 0.449 to allow for a very small fraction to result in the Null severity category.
										0.001	0.001	\$ -	There is a very small chance that the person falls into the water in such a location that would result in no meaningful impact or injury.

Table D-2. Detailed descriptions of average consequence values and associated severity fractions for relevant combinations of initiators and decision factors (Cont.).

	If the person enters the water in an area with very little electric field, there should be little effect on the person other than perhaps needing to be medically examined.	This event involves both personnel floating into the safety zone and personnel falling into the safety zone. Further, it is expected that these individuals will experience severe injury or death that will have an average cost of between \$4 to \$5 Million.	PIW-Related ES for Vessels Approach of the RNA	4,603,196	7,000,000	C2.1	1	0.65	\$ 4,550,000	In about 65% of the incidents (100% of the 50% from personnel entering from outside the safety zone and 30% of the 50% entering from within the safety zone), the mariner is expected to enter the water very near or directly over the fish barrier system. In these situations, the shock a person would receive is expected to cause serious injury or death. The representative value for this consequence category is \$7,000,000 based on an equivalent average death penalty of about \$7,000,000 and the expectation that only one person will be involved per incident. This will result in an average loss per incident of about \$4,550,000 (e.g., 0.65 * \$7,000,000) from this severity category.	
								1.00	\$ 7,000,000	It is expected that in 100% of these situations the shock a person would receive is expected to cause serious injury or death. The representative value for this consequence category is \$7,000,000 based on an equivalent average death penalty of about \$7,000,000 and the expectation that only one person will be involved per incident. This will result in an average loss per incident of about \$7,000,000 (e.g., 1.0 * \$7,000,000) from this severity category.	
							C2.2	0	0.175	\$ 52,500	About 70% of the safety zone is not directly over the specific barriers. In these zones between the barriers, the shock that a person would receive will vary substantially. Of the 35% of personnel that fall into the safety zone portion not directly over the fish barrier system, about half are expected to experience a shock that is severe enough to cause extended hospitalization with a representative cost of \$300,000. This will result in an average loss per incident of about \$52,500 (e.g., 0.175 * \$300,000) from this severity category.
									0.000	\$ -	It is not expected that there will ever be any incidents that would need a representative value of \$300,000.
			C2.3			0	0.174	\$ 696	About 70% of the safety zone is not directly over the specific barriers. In these zones between the barriers, the shock that a person would receive will vary substantially. Of the 35% of personnel fall into the safety zone portion not directly over the fish barriers, about half are expected to experience a shock that will only require an exam to verify that they are not seriously injured with a representative cost of \$4,000. This will result in an average loss per incident of about \$696 (e.g., 0.175 * \$4,000) from this severity category.		
							0.000	\$ -	It is not expected that there will ever be any incidents that would need a representative value of \$4,000.		
			C2.4			0	0.001	\$ -	There is a very small chance that the person falls into the water in such a location that would result in no meaningful impact or injury. There is a very small chance that the person falls into the water in such a location that would result in no meaningful impact or injury.		
							0.000	\$ -	It is not expected that there will ever be any incidents that would result in no measurable or recordable loss.		

Table D-2. Detailed descriptions of average consequence values and associated severity fractions for relevant combinations of initiators and decision factors (Cont.).

<p>PIW Rescuer-Related ES: This event could involve a rescue attempt by personnel ranging from a recreational boater with little experience in rescue to the professional local response personnel and USCG personnel. The recreational boater is expected to have minimal awareness of the situation including lack of understanding of (1) the need for ensuring that the fish barrier is turned off and (2) the need for PPE to protect against any potential electric shock (e.g., nylon rope, insulated shoes). The professional rescue personnel are trained to get the fish barrier turned off prior to attempting rescue and are equipped with proper PPE.</p>	<p>While the rescuer is expected to be trained and should be wearing proper PPE, this incident involves the rescuer suffering an electric shock during rescue. It is expected that the majority of these cases will result in only minor injuries, but it is possible that more serious injuries could occur. The average cost of these incidents is expected to be between \$50,000 and \$100,000.</p>	<p>PIW Rescuer-Related ES for Red Flag Commercial Vessel Transit of the Safety Zone</p>	67,800	67,800	C3.1	0.005	0.005	\$ 35,000	It is expected that there is some possibility that a rescuer would suffer serious injury or death from the electric shock experienced during a rescue. A 0.5% chance is used to represent this possibility.		
		<p>PIW Rescuer-Related ES for Non-Red Flag Commercial Vessel Transit of the Safety Zone</p>				C3.2	0.1	0.1	\$ 30,000	There is about a 10% chance that a rescuer would suffer an injury requiring extended hospitalization due to an electric shock.	
		<p>PIW Rescuer-Related ES for Vessels Approach of the RNA</p>					C3.3	0.7	0.7	\$ 2,800	It is expected that there is about a 70% chance that a rescuer would experience a shock that would require a medical examination/ minor medical attention.
		<p>PIW Rescuer-Related ES for Personnel on the RNA Shore</p>						C3.4	0.195	0.195	\$ -
	<p>Because the initial rescue will likely be by another person on the recreational vessel, it is expected that the rescuers will be more likely to experience more serious injuries than if a professional rescuer were involved. The average cost of these incidents is expected to be between \$500,000 and \$1,000,000.</p>	<p>PIW Rescuer Related ES Recreational Vessels Greater than 20 feet Transit of the Safety Zone:</p>	C4.1	0.25	0.1				\$ 700,000	Recreational vessels may affect self-rescue of a PIW and be unaware of the dangers of the electrified waters or act upon emotion. A rescuer may even go in the water which could result in a death. It is estimated that this could occur once in every 10 incidents or in about 10% of the incidents.	
				0.25	0.25	\$ 1,750,000			Recreational vessels may affect self-rescue of a PIW and be unaware of the dangers of the electrified waters or act upon emotion. A rescuer may even go in the water which could result in a death. It is estimated that this could occur once in every four incidents or in about 25% of the incidents.		
		<p>PIW Rescuer-Related ES for Recreational Vessels 20 feet or less and PWCs Transit of the Safety Zone</p>	777,000	1,811,800	C4.2	0.2	0.25		\$ 75,000	It is expected that in about 25% of the incidents that a PIW Rescuer will suffer serious injury requiring extended hospitalization.	
						0.2	0.2	\$ 60,000	It is expected that in about 20% of the incidents that a PIW Rescuer will suffer serious injury requiring extended hospitalization.		
					C4.3	0.45	0.5	\$ 2,000	In about 50% of the incidents the rescuer will require a medical examination or minor medical treatment.		
							0.45	\$ 1,800	In about 45% of the incidents the rescuer will require a medical examination or minor medical treatment.		
					C4.4	0.1	0.15	\$ -	In about 15% of the incidents the PIW is rescued and the rescuer suffers no meaningful impact or injury.		
							0.1	\$ -	In about 10% of the incidents the PIW is rescued and the rescuer suffers no meaningful impact or injury.		

Table D-2. Detailed descriptions of average consequence values and associated severity fractions for relevant combinations of initiators and decision factors (Cont.).

<p>Activity-Related ES: Electric shock incidents that occur during commercial or recreational activities are generally expected to involve relatively mild electric shocks that will at most result in minor injury. Activity-related electric shock incidents will generally involve the mariner inadvertently completing the circuit between two metal objects on the vessel. Most of these incidents will occur inboard. The material of which the vessel is constructed, size of the vessel, ability to remain inboard, health condition of the mariner (e.g., significant shocks with the potential for serious injury for personnel with pacemakers), and whether or not the vessel is human powered are factors that influence the severity of the electric shock.</p>	<p>These incidents are expected to involve the mariner inadvertently completing a circuit while performing an activity during a transit through the safety zone. However, such incidents are expected to only result in a minor shock to the mariner. The average cost of these incidents is expected to be less than \$50.</p>	<p>Activities-Related ES for Red Flag Commercial Vessel Transit of the Safety Zone:</p>	20	20	C5.1	0	0	\$ -	It is not expected that there will ever be any incidents that would need a representative value of \$7 Million.
		<p>Activities-Related ES for Non-Red Flag Commercial Vessel Transit of the Safety Zone</p>			C5.2	0	0	\$ -	It is not expected that there will ever be any incidents that would need a representative value of \$300,000.
					C5.3	0.005	0.005	\$ 20	1 in 200 incidents someone will receive an electric shock that may require medical examination or minor medical attention.
					C5.4	0.995	0.995	\$ -	About 99.5% of the incidents will involve an electric shock that will have no little or no impact on personnel.
	<p>These incidents are expected to involve the mariner inadvertently completing a circuit while performing an activity on the vessel. The vast majority of these incidents are expected to have only minor impacts. However, there is the remote possibility of the mariner experiencing more serious consequences. The average cost of these incidents is expected to be between \$100 and \$500.</p>	<p>Recreational Activity-Related ES for Recreational Vessels Greater than 20 feet Transit of the Safety Zone:</p>	370	370	C6.1	0.00005	0.00005	\$ 350	There is some possibility of a person would die from the shock because of other medical issues (e.g., pacemaker malfunction).
		<p>Recreational Activity-Related ES for Recreational Vessels 20 feet or less and PWCs Transit of the Safety Zone</p>			C6.2	0	0	\$ -	It is not expected that there will ever be any contact-related electric shock incidents that would need a representative value of \$300,000.
					C6.3	0.005	0.005	\$ 20	About 1 in 200 incidents someone will receive an electric shock that may require medical examination or minor medical attention.
					C6.4	0.99495	0.99495	\$ -	About 99.5% of the incidents will involve an electric spark that will have no little or no impact on personnel.

Table D-2. Detailed descriptions of average consequence values and associated severity fractions for relevant combinations of initiators and decision factors (Cont.).

<p>Contact-Related ES: Contact-Related electric shock incidents will most often occur when the commercial vessel allides with a metal object outside of the safety zone while a portion of the vessel is still inside the safety zone. The spark that is generated when this contact occurs will usually be near the point of contact with only minor impact to any personnel. It is expected that these incidents will have an average cost of about \$400 and that these losses will be independent of whether the incident occurs with a red flag or a non-red flag vessel.</p>	<p>Contact-Related ES for Red Flag Commercial Vessel Transit of the Safety Zone</p>	400	400	C7.1	0	0	\$ -	It is not expected that there will ever be any contact-related electric shock incidents that would need a representative value of \$7 Million.
				C7.2	0	0	\$ -	It is not expected that there will ever be any contact-related electric shock incidents that would need a representative value of \$300,000.
				C7.3	0.1	0.1	\$ 400	About 10% of the incidents will involve a person being impacted by the spark. However, it is expected that this will involve only minor injuries that may require being examined to verify that there is no serious injury. This will result in an average loss per incident of about \$400 (e.g., 0.1 *\$4,000) for this severity category.
				C7.4	0.9	0.9	\$ -	About 90% of the incidents will involve a spark that occurs only at the point of contact with no impact on personnel and will create no measurable loss.
<p>Spark-Related Vapor Ignition for Red Flag Commercial Vessel Transit of the Safety Zone: The spark-related vapor ignition that can occur during transit of the safety zone for a red flag vessel is expected to be a very small deflagration type event involving a small quantity of ignitable vapor. This is because of (1) the small quantities of ignitable vapors that would be released in the designated release area and (2) the quick dispersion of these vapors as the vessel transits the safety zone. It is expected that these incidents will have an average cost of about \$400.</p>	<p>Spark-Related Vapor Ignition for Red Flag Commercial Vessel Transit of the Safety Zone:</p>	400	400	C8.1	0	0	\$ -	It is not expected that there will ever be any vapor ignition incidents that would need a representative value of \$7 Million.
				C8.2	0	0	\$ -	It is not expected that there will ever be any vapor ignition incidents that would need a representative value of \$300,000.
				C8.3	0.1	0.1	\$ 400	About 10% of the incidents will involve a quick burning of a small volume of ignitable vapor that could possibly cause some minor paint damage which would require repainting. This will result in an average loss per incident of about \$400 (e.g., 0.1 *\$4,000) from this severity category.
				C8.4	0.9	0.9	\$ -	About 90% of the incidents will involve a quick burning of a very small volume of ignitable vapor and will create no measurable loss.
<p>Congestion-Related Collision, Allision, Sinking (CAS) for Vessels Approach of the RNA: CAS incidents can occur upon approaching the RNA because of the increased congestion in these areas. It is expected that most of these incidents will involve losses with an average cost of about \$40,000.</p>	<p>Congestion-Related Collision, Allision, Sinking (CAS) for Vessels Approach of the RNA:</p>	39,760	39,760	C9.1	0.005	0.005	\$ 35,000	It is expected that about 0.5% of the CAS incidents result in a loss that is between \$3 Million and \$3 Billion. This will result in an average loss per incident of about \$35,000 (e.g., 0.005 * \$7,000,000).
				C9.2	0.01	0.01	\$ 3,000	It is expected that about 1% of the CAS incidents result in a loss that is between \$10,000 and \$3,000,000. This will result in an average loss per incident of about \$3,000 (e.g., 0.01 * \$300,000).
				C9.3	0.44	0.44	\$ 1,760	It is expected that about 44% of the CAS incidents result in a loss that is between \$1000 and \$10,000. This will result in an average loss per incident of about \$1,760 (e.g., 0.44 * \$4,000).
				C9.4	0.545	0.545	\$ -	It is expected that about 55% of the incidents result in no measurable or recordable loss.

APPENDIX E. DETAILED CUMULATIVE RISK BY INITIATOR

Developing the event tree/fault tree detailed risk results corresponds with STEP C in the simplified flowchart in Figure 3. Section 2.3.3 introduced the development of the detailed risk results using event trees/fault trees. In particular, Figure 4 provides an example of the event tree structure used in the quantification process with the structure divided into eight parts. The approach for each part is then described in detail. An event tree was analyzed for each of the six Initiator Types evaluated listed below.

- Event Tree C: Commercial Vessel Transit of the Safety Zone–Red Flag
- Event Tree C: Commercial Vessel Transit of the Safety Zone–Non-Red Flag
- Event Tree R: Recreational Vessels Transit of the Safety Zone–Greater than 20 Feet
- Event Tree R: Recreational Vessels Transit of the Safety Zone–20 Feet or Less and PWC
- Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA)
- Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore

Table E-1 presents a summary of the risk results from these six event trees. The results include Frequency (# Events/Yr), Consequence (\$/Event) and Expected Loss (\$/Yr) for each of the decision factors. Table E-2 summarizes the risk results from the six event trees even further by including only the expected losses for each decision factor.

Figures E-3 through E-8 present snapshots of each of the six event trees in the order listed above.



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Table E-1. Summary of the risk results from the six initiators.

Decision Factors		Event Tree C: Commercial Vessel Transit of the Safety Zone				Event Tree R: Recreational Vessels Transit of the Safety Zone				Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA)		Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore		Totals [\$ /year]	
		Red Flag		Non-Red Flag		Greater than 20 feet		20 feet or less and PWCs		Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results
		Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results	Preliminary Results	Validated Results
<i>Activity-Related ES</i>	Frequency (events/yr)	0.01	0.02	0.1	0.1	0.1	0.1	0.1	0.1	-	-	-	-	0.4	0.4
	Consequence \$/event	20	20	20	20	370	370	370	370	-	-	-	-	258	255
	Risk (\$/yr)	0.2	0.3	2	2	50	50	50	50	-	-	-	-	100	100
<i>Contact-Related ES</i>	Frequency (events/yr)	0.00001	0.00001	0.0001	0.0001	-	-	-	-	-	-	-	-	0.00007	0.00007
	Consequence \$/event	400	400	400	400	-	-	-	-	-	-	-	-	400	400
	Risk (\$/yr)	0.002	0.003	0.02	0.02	-	-	-	-	-	-	-	-	0.03	0.03
<i>PIW-Related ES</i>	Frequency (events/yr)	0.00001	0.00001	0.0001	0.0001	0.003	0.000	0.01	0.01	0.0002	0.0079	0.005	0.008	0.02	0.03
	Consequence \$/event	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	1,841,796	4,603,196	7,000,000	4,603,196	7,000,000	2,601,298	4,872,710
	Risk (\$/yr)	20	30	200	200	6,000	1,000	20,000	20,000	700	55,100	20,000	50,000	50,000	130,000
<i>PIW Rescuer-Related ES</i>	Frequency (events/yr)	0.0000001	0.0000009	0.000001	0.000006	0.002	0.00004	0.000014	0.001397	0.000021	0.000520	0.00009	0.00053	0.002	0.002
	Consequence \$/event	67,800	67,800	67,800	67,800	777,000	1,811,800	67,800	1,811,800	67,800	67,800	67,800	67,800	736721	1074687
	Risk (\$/yr)	0.009	0.062	0.09	0.44	2,000	80	1	2531	1	35	6	36	2000	2700
<i>Spark-Related Vapor Ignition</i>	Frequency (events/yr)	0.000003	0.000004	-	-	-	-	-	-	-	-	-	-	0.000003	0.000004
	Consequence \$/event	400	400	-	-	-	-	-	-	-	-	-	-	400	400
	Risk (\$/yr)	0.001	0.002	-	-	-	-	-	-	-	-	-	-	0.001	0.002
<i>Congestion-Related CAS</i>	Frequency (events/yr)	-	-	-	-	-	-	-	-	0.1	0.1	-	-	0.1	0.1
	Consequence \$/event	-	-	-	-	-	-	-	-	39,760	39,760	-	-	39,760	39,760
	Risk (\$/yr)	-	-	-	-	-	-	-	-	4,000	4,000	-	-	4,000	4,000

Table E-2. Risk results – expected losses.

Validated Risk Results Summary							
Decision Factors	Event Tree C: Commercial Vessel Transit of the Safety Zone [\$/year]		Event Tree R: Recreational Vessels Transit of the Safety Zone [\$/year]		Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA) [\$/year]	Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore [\$/year]	Totals [\$/year]
	Red Flag	Non-Red Flag	Greater than 20 feet	20 feet or less and PWCs			
<i>Activity-Related ES</i>	0.3	2	50	50	–	–	100
<i>Contact-Related ES</i>	0.003	0.02	–	–	–	–	0.03
<i>PIW-Related ES</i>	30	200	1000	20000	55100	50000	130,000
<i>PIW Rescuer-Related ES</i>	0.062	0.44	80	2531	35	36	2,700
<i>Spark-Related Vapor Ignition</i>	0.002	–	–	–	–	–	0.002
<i>Congestion-Related CAS</i>	–	–	–	–	4000	–	4,000

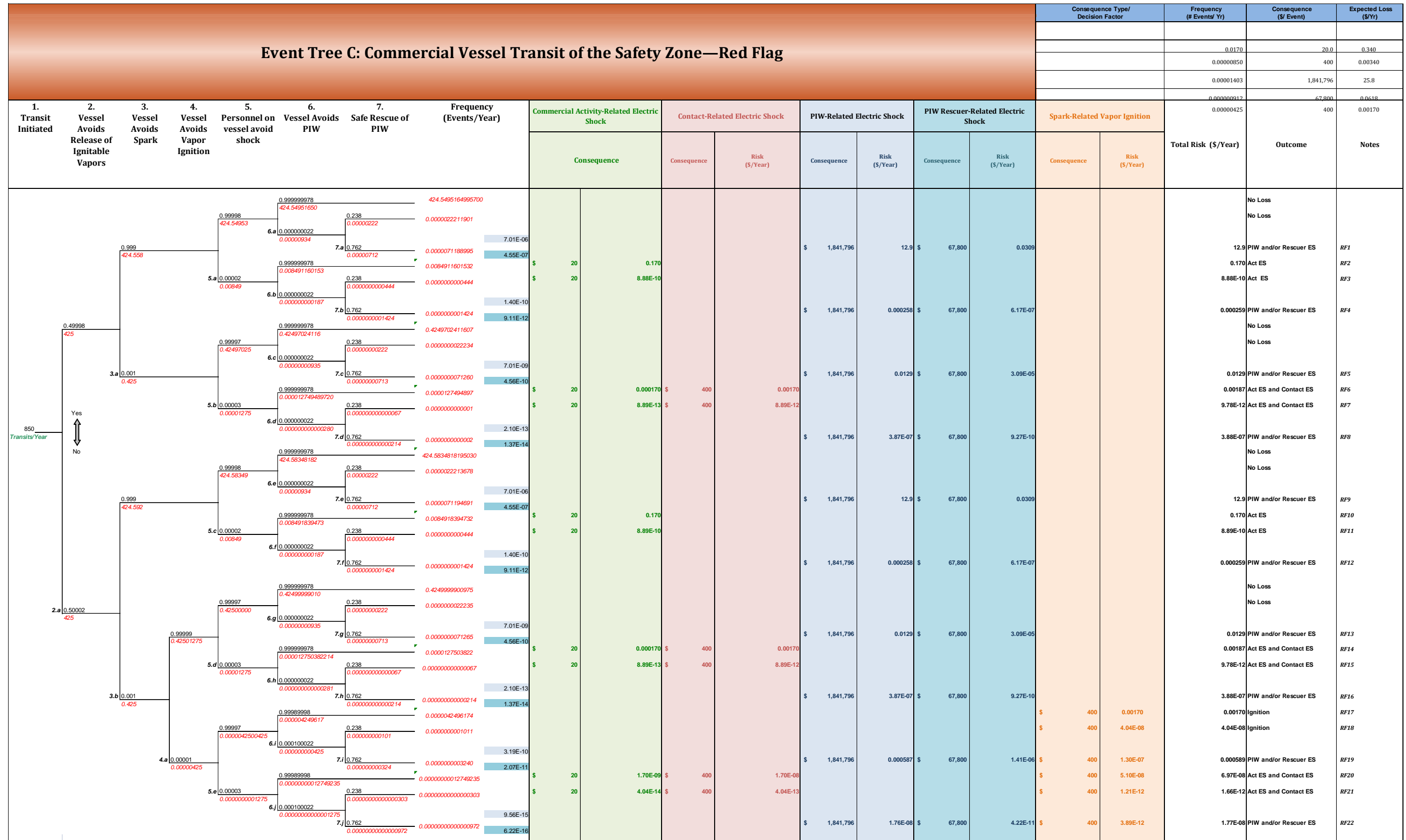


Figure E-1. Event Tree C: Commercial Vessel Transit of the Safety Zone—Red Flag.

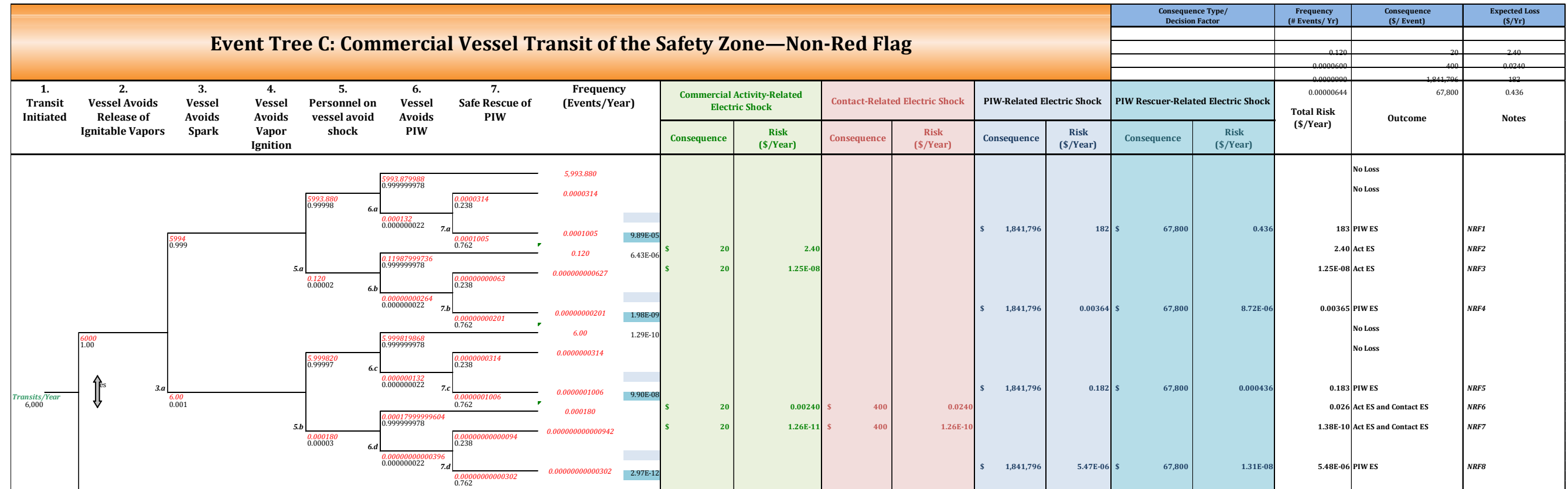


Figure E-2. Event Tree C: Commercial Vessel Transit of the Safety Zone–Non-Red Flag.

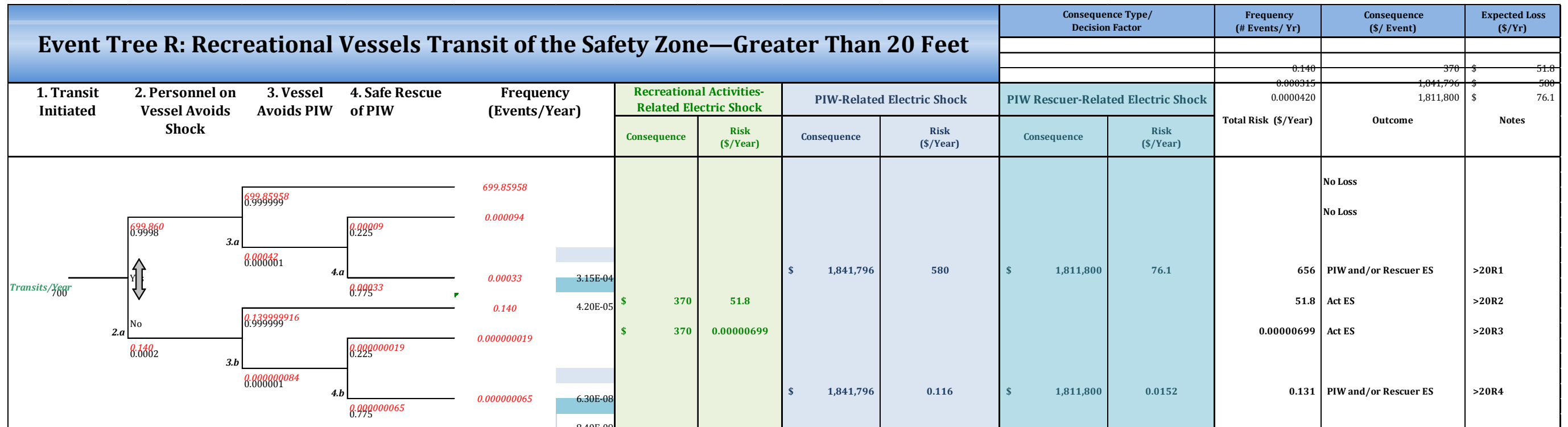


Figure E-3. Event Tree R: Recreational Vessels Transit of the Safety Zone—Greater than 20 Feet.

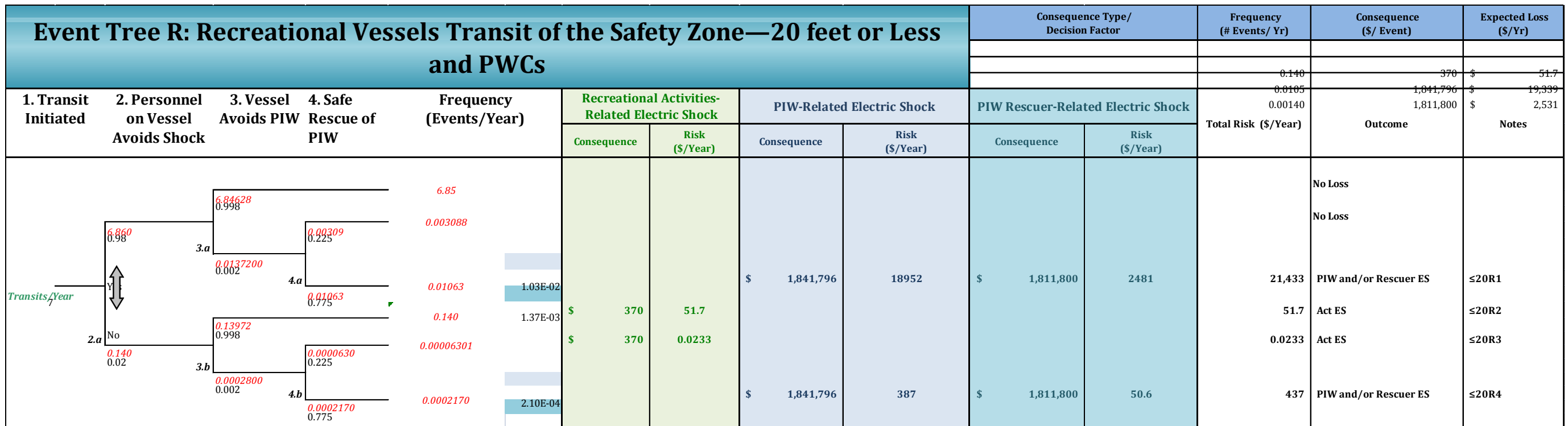


Figure E-4. Event Tree R: Recreational Vessels Transit of the Safety Zone—20 Feet or Less and PWC.

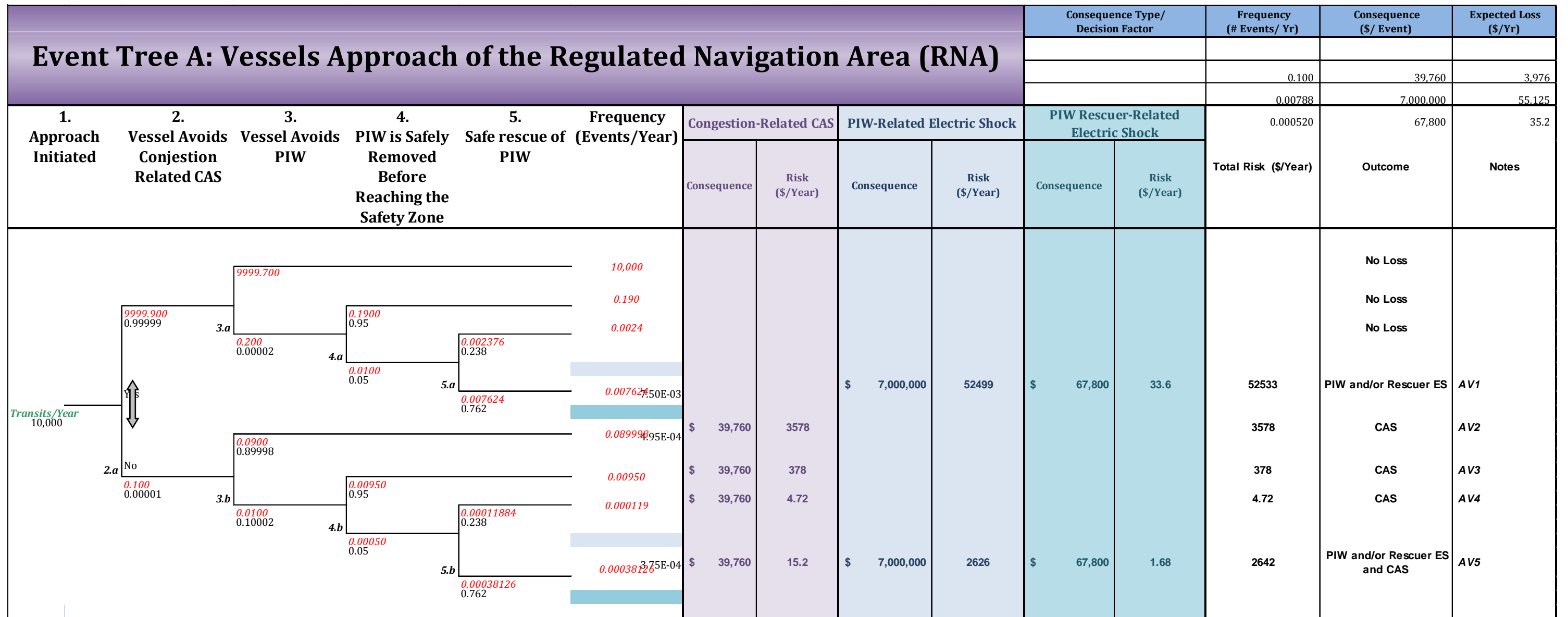


Figure E-5. Event Tree A: Vessels Approach of the Regulated Navigation Area (RNA).

Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore						Consequence Type/ Decision Factor		Frequency (# Events/ Yr)	Consequence (\$/ Event)	Expected Loss (\$/Yr)			
								0.00770	7,000,000	53,865			
1. Shore Personnel Enter the RNA Shore Area	2. Shore Personnel Avoid Being Near the Water	3. Shore Personnel Avoid Entering the Water	4. PIW is Safely Removed Before Reaching the Safety Zone	5. Safe Rescue of PIW	Frequency (Events/Year)	PIW-Related Electric Shock		PIW Rescuer-Related Electric Shock		Total Risk (\$/Year)	Outcome	Notes	
						Consequence	Risk (\$/Year)	Consequence	Risk (\$/Year)				
						\$ 7,000,000	53,865	\$ 67,800	35.7	53,901	PIW and/or Rescuer ES	Barrier deactivation during rescue may result in ineffectiveness of the fish barrier	

Figure E-6. Event Tree S: Personnel on the Regulated Navigation Area (RNA) Shore.

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**APPENDIX F. OCTOBER 2012 CSSC SHORE MEASUREMENT
DATA AND ANALYSIS SUMMARY**

Separate PDF file.



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