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Illinois Waterway Risk Research – Summary Report

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16. Abstract (MAXIMUM 200 WORDS)

This report describes analytical risk research the USCG Research and Development Center (RDC) conducted with respect to Asian carp control measures that Federal government agencies may have considered, or are considering for implementation either in the vicinity of the electric dispersal barrier system (EDBS) in the Chicago Sanitary and Ship Canal (CSSC) or at Brandon Road Lock and Dam (BRLD) Navigation Project on the Des Plaines River, Joliet IL.

The project completed a preliminary risk assessment of possible effects on marine safety and navigation safety due to proposed control measures at BRLD that provided the Coast Guard Operational Commander evaluative input for the U. S. Army Corps of Engineers (USACE) Tentatively Selected Plan submittal. The input provided to the Operational Commander considered commercial and recreational vessel operations and activities and how a range of control measures might affect the safety of waterway activities or those activities that occur on the adjacent river and approach channel banks.

This report includes (1) a review of the BRLD Preliminary Marine Safety Risk Assessment, (2) analysis of commercial and recreational vessel activity in the vicinity of BRLD, (3) methodology to apply an invasive species control-measure risk model, and (4) guidance on how to test control-measure safety.

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EXECUTIVE SUMMARY

The spread of Aquatic Nuisance Species (ANS) to the Great Lakes poses a significant threat which can be mitigated through the implementation of technology countermeasures. However, these countermeasures come with potential safety and navigation risks. Since 2009 the Coast Guard (CG) Research and Development Center (RDC) served as the Ninth Coast Guard District (CGD9) and CG Marine Safety Unit (MSU) Chicago science and technology advisor and applied best practices in Risk Based Decision Making (RBDM) to evaluate the spectrum of risk surrounding barrier configurations and control measures. Past efforts included research to evaluate electrical hazards, safe rescue of a person in the water, and a formal risk assessment.

This report provides a cursory summary of past research related to the Electric Dispersal Barrier System (EDBS) in the Chicago Sanitary and Ship Canal (CSSC) at Romeoville, Il, but focuses on the most recent request from CGD9 to examine conditions regarding the future installation of ANS control measures on the Des Plaines River section of the Illinois Waterway, at Brandon Road Lock and Dam (BRLD), Rockdale, IL. The initial focus of the work was to evaluate how the control measures might interact with and effect waterway use and provide a preliminary assessment of change in the level of marine and navigation safety risk to guide the Operational Commander’s input to the U. S. Army Corps of Engineers (USACE) proposed plan for ANS control measure implementation.

For one control measure in the BRLD system, USACE proposed an electric dispersal barrier, as USACE has been safely operating the CSSC EDBS since 2009, approximately 10 miles closer to Lake Michigan. RDC determined “person-in-the-water (PIW) electric shock” is a primary risk factor for the CSSC EDBS; consequently, we evaluated possible events that might result in a PIW at BRLD.

RDC carried out a comprehensive analysis of commercial and recreational vessel activity in the vicinity of BRLD to quantify types of activity, including tow flotillas needing reconfiguration due to lockage and activity of deckhands, boat operators, or other persons on deck, i.e., candidates for PIW events.

RDC also examined the number of times a “box-to-rake” (barge stern to barge bow) junction occurred on upbound tow flotillas. This examination followed a discussion at a navigation safety workshop which indicated USACE might require tow reconfiguration to minimize the box-to-rake occurrences to decrease fish entrainment.

In 2013, RDC completed the quantitative CSSC Marine Safety Risk Assessment to determine Safety Zone and Regulated Navigation Area rule adequacy for CGD9. Since the future timeline for ANS control measure implementation is not certain, this report includes a *model* for event-tree scenario development that the Operational Commander can use following the analysis methods RDC used in the 2013 risk assessment.

Continued CG situational awareness and involvement in the design and testing of new control measures, e.g., “bubble curtain,” acoustic deterrence, and CO_2, is not only important in an interagency approach to address the ANS threat, but also to understand safety and navigation risks.

Finally, since only the electric dispersal barrier has been in continuous operation, this report provides guidance for the Operational Commander to consider when coordinating with USACE to plan and execute future safety testing of full-scale control measures.

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ANS	Aquatic Nuisance Species
BRLD	Brandon Road Lock and Dam
CGBI	Coast Guard Background Information
CGD8	Eighth Coast Guard District
CGD9	Ninth Coast Guard District
CSSC	Chicago Sanitary and Ship Canal
dBa	Decibels in Air
EDBS	Electric Dispersal Barrier System
ERDC	Engineering Research and Development Center
GLMRIS	Great Lakes and Mississippi River Interbasin Study
L&D	Lock and Dam
LDB	Left Descending Bank
LOA	Length over-all
MISLE	Marine Information for Safety and Law Enforcement
MM	Mile Marker
MSD	Marine Safety Detachment
MSDD	Marine Safety Detached Duty
MSRA	Marine Safety Risk Assessment (CSSC)
MSU	Marine Safety Unit
PIW	Person in the Water
PMSRA	Preliminary Marine Safety Risk Assessment (Brandon Road)
RDB	Right Descending Bank
RDC	Research and Development Center
UMR	Upper Mississippi River
USCG	U. S. Coast Guard
USFWS	U. S. Fish and Wildlife Service
USGS	U. S. Geological Survey

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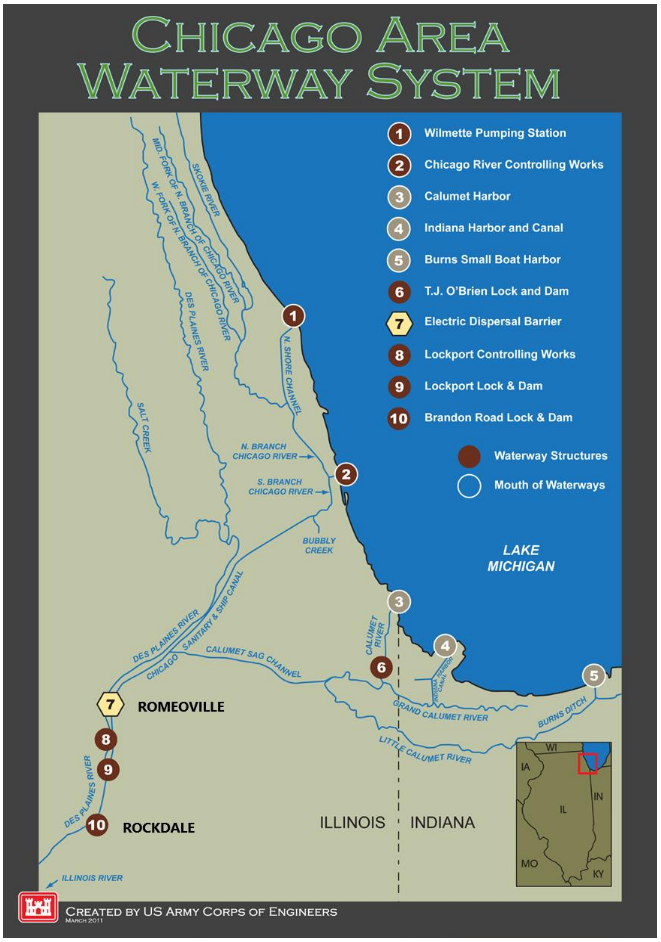
1 INTRODUCTION

To combat invasive Aquatic Nuisance Species (ANS), particularly the spread of Asian carp from the Mississippi River Basin to the Great Lakes, the U. S. Army Corps of Engineers (USACE) installed electrified barrier systems at Romeoville, IL on the Chicago Sanitary and Ship Canal (CSSC). These barriers create an “electrified zone”, or a significant electric field in the water and along the shore that presents risk for vessel navigation and human activity. USACE is in the planning and preliminary design phase for a combination of Asian carp control measures in the vicinity of Brandon Road Lock and Dam (BRLD) near Joliet, IL.

Figure 1 shows the locations of the CSSC Electric Dispersal Barrier System (EDBS) (labeled as 7) and Brandon Road Lock and Dam (BRLD) (labeled as 10), noting their relative proximity to Lake Michigan.

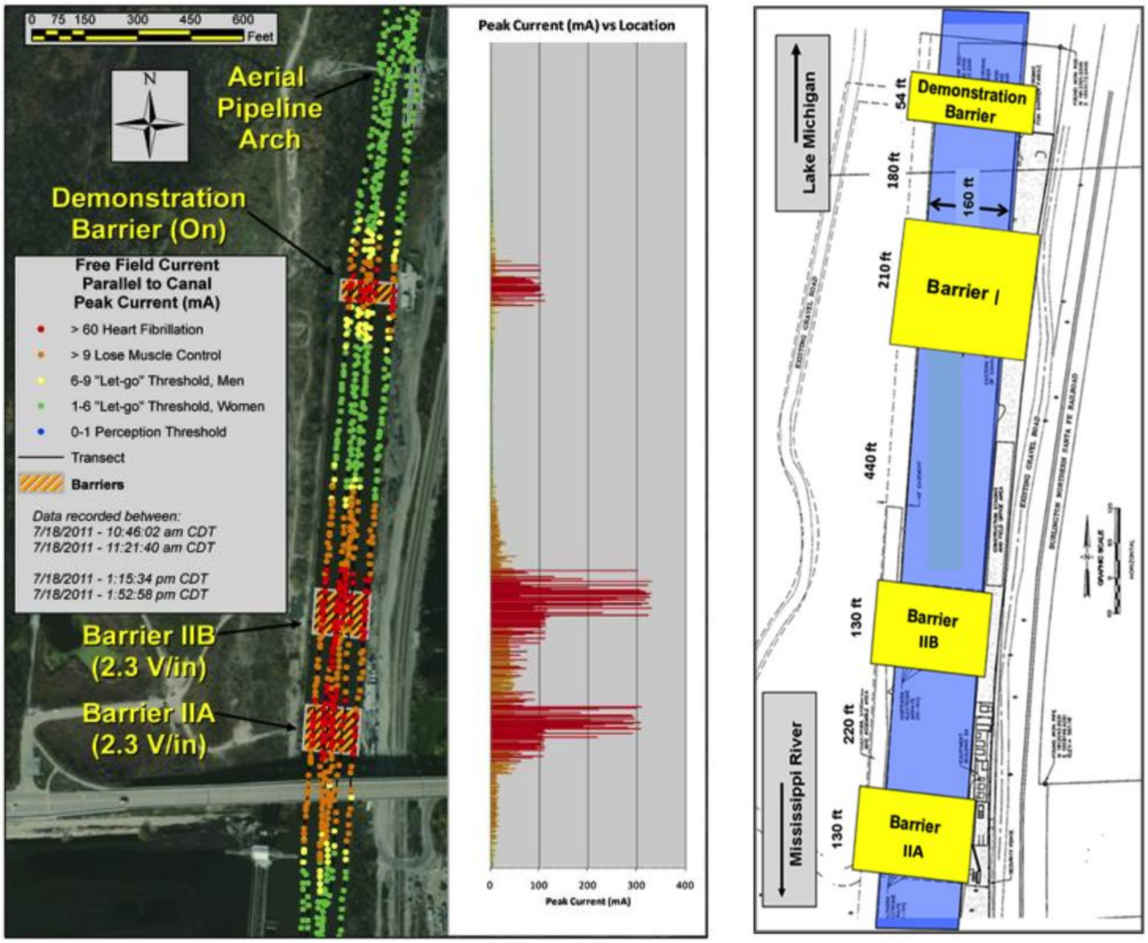


Error! Bookmark not defined. Figure 1. Chicago area waterways (USACE 2012).

Starting in 2009, the U. S. Coast Guard (USCG) Research and Development Center (RDC) conducted marine safety-related research pertaining to ANS control measures on the Illinois Waterway at the request of the Ninth Coast Guard District (CGD9). RDC efforts included (1) validation of USACE testing for shock hazards and sparking among tows and between tows and moored barges, (2) evaluation of whether first responders could safely rescue an individual from the CSSC in or near the electrified zone (Slater, et al., 2011), (3) quantitative assessment of risk to categorize and rank risks to marine and navigation safety in the vicinity of the CSSC EDBS, including if stray electric fields posed hazards to longshore workers at a facility near the electrified zone (Lewandowski, et al., 2013), (4) research on transportability and survivability of immature fish in barge tanks and voids (Heilprin, et al., 2013), and (5) a Preliminary Marine Safety Risk Assessment to identify marine safety risk research requirements for Asian carp control-measure technologies at BRLD on the Des Plaines River at Rockdale, IL (Lewandowski, 2016).

Plans to implement a combined, control-measure system at BRLD present uncertain marine-safety risk challenges. Depending on final control-measure configuration selected, complex interactions involving an electric barrier system, other control measures, and extensive commercial and occasional recreational vessel traffic, the exact nature of the change in risk is not easily quantified.

Upcoming modifications to the CSSC electric barrier system at Romeoville (raising electrodes higher from the canal bottom and activating a "new" Barrier I) require physical measurements and reassessments of risk. To highlight this example, Figure 2 (a) (Slater, ibid.) depicts the free field current near the EDBS measured in 2011. With the future activation of Barrier I as depicted in Figure 2 (b) (USACE, 2012) cursory comparison might indicate either reduction or total elimination of the not-as-hazardous area upstream of Barrier II-B.



(a) (b)

Figure 2. a) 2011 CSSC Free Field Current (Slater, et al., 2011), (b) EDBS arrays, (USACE, 2012).

Also, in November 2018, CITGO-Lemont Refinery initiated discussion with USCG Marine Safety Unit (MSU) Chicago and USACE to determine whether conditions of operation for their petroleum-coke loading operation north of the EDBS may be subject to change due to the change in EDBS operations.[1] Because the electrical field drivers will change, the only way to determine the degree of field change and whether there is any increased risk due to the EDBS changes, is to conduct physical measurements similar to those completed before. As USACE continues to investigate different barrier configurations and control measures, there will be a need for active risk monitoring.

This report summarizes the project's overall efforts, including: (a) the BRLD Preliminary Risk Assessment and subsequent updates to control-measure plans, (b) in-depth investigation of vessel transit activity and tow configuration in the vicinity of BRLD, (c) discussion of a modeling technique to develop control-measure specific risk scenarios and to determine specific needs for further control measure research, and (d) provides the Coast Guard Operational Commander background information to help assess future control-measure testing as USACE implements other control measures in the Illinois Waterway.

2 PRELIMINARY MARINE SAFETY RISK ASSESSMENT, BRANDON ROAD LOCK & DAM INVASIVE SPECIES CONTROL MEASURES

The Preliminary Marine Safety Risk Assessment (PMSRA), Brandon Road Lock & Dam (BRLD) Invasive Species Control Measures report (Lewandowski, 2016) described risk research RDC conducted with respect to Asian carp control measures that USACE (with input from other Federal government agencies) was considering for implementation in the vicinity of the BRLD Navigation Project.

The report provided the Coast Guard operational commander (CGD9) stand-alone documentation of possible effects on marine safety and navigation safety due to the planned BRLD control measures. The preliminary risk assessment supported CGD9 evaluative input to the USACE Tentatively Selected Plan submittal, prior to USACE project authorization. It considered commercial and recreational vessel operations and activities and how a range of control measures might affect the safety of waterway activities or those activities that occur on the adjacent river and approach channel banks.

Because the report was preliminary, before project authorization, the report addressed *possible* BRLD invasive species control measures and included descriptions and potential consequences. As stakeholders frequently referenced BLRD control measures to the CSSC EDBS, the PMRSA included a comparison of the two sections of the Illinois Waterway, highlighting the differences in physical layout and vessel operations in the vicinity of each.

Figure 3 (USACE, 2017) and Figure 4 (USACE, 2018) show the differences in control measure configurations between that submitted in the 2016 draft study and the revised 2018 Final Plan. The PMRSA included review of control measures at their then-estimated locations. As of November 2018, in some cases control measure location changed e.g., "complex noise" near the lower miter gate (Figure 3) and "acoustic deterrent" near the proposed electric barrier (Figure 4). If the project had completed a full quantitative risk assessment in 2016, the risk values, based on control measure interaction would no longer apply. In another case, an indicator of a possible, tentative 2016 control measure, a "mooring area" shown at the bottom left in Figure 3, no longer appears in Figure 4.[2]

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[1] In conjunction with the CSSC Risk Assessment (Lewandowski, et al., 2013), the Commanding Officer of USCG MSU Chicago requested that RDC determine whether electrical currents associated with the EDBS Demonstration Barrier posed a risk to workers at the then-Oxbow Industries coke loading facility. Appendix F of the Risk Assessment documented touch-point voltage measurements that a worker might experience and determined that operations did not pose any unusual increase in risk provided workers followed standard safety practices.

[2] Section 3.2 below discusses secondary effects of the "mooring area" concept.

Figure 3. 2016 Tentative BRLD ANS control measure configuration (USACE, 2017).

Boat Launches: Provides access for nonstructural measures, safety and OMRR&R.

Flushing Lock: Flushes floating life stages from the Lock.

Acoustic Fish Deterrent: Underwater sounds to deter targeted fish

Engineering Channel: Creates a concrete channel without fish habitat. Increases the effectiveness and reduces the impacts of some measures and is a platform for future technologies.

Electric Dispersal Barrier: Creates an electric field that deters fish.

Fish Entrainment Deterrent: Bubble curtain removes small and stunned fish entrained in spaces between barges.

Support Facilities: Infrastructure to support operations and maintenance of controls.

Figure 4. Fall 2018 BRLD ANS control measure configuration (USACE, 2018).

Though the planned physical configuration may have changed, development of risk relationships due to possible interactions of different control measures remains a logical way to begin risk quantification. Section 4 of the PMSRA also introduced "combined" control-measure risk assessment considerations. Figure 5 is one example. When developing this model, RDC considered the possible events associated with one control measure (lock flushing) and used the initial consequences as event entries for determining consequences for a second control measure (electric barrier). At the time RDC developed this model, analysts assumed an electric barrier immediately adjacent to a location subject to lock-flushing turbulence. Whether a future BLRD control-measure configuration will yield turbulence at a location that might yield an increased risk of a person in the water event in close proximity of another control measure is not certain. However, the example illustrates the utility of the PMSRA as a risk framework to evaluate future configuration and control measure changes.

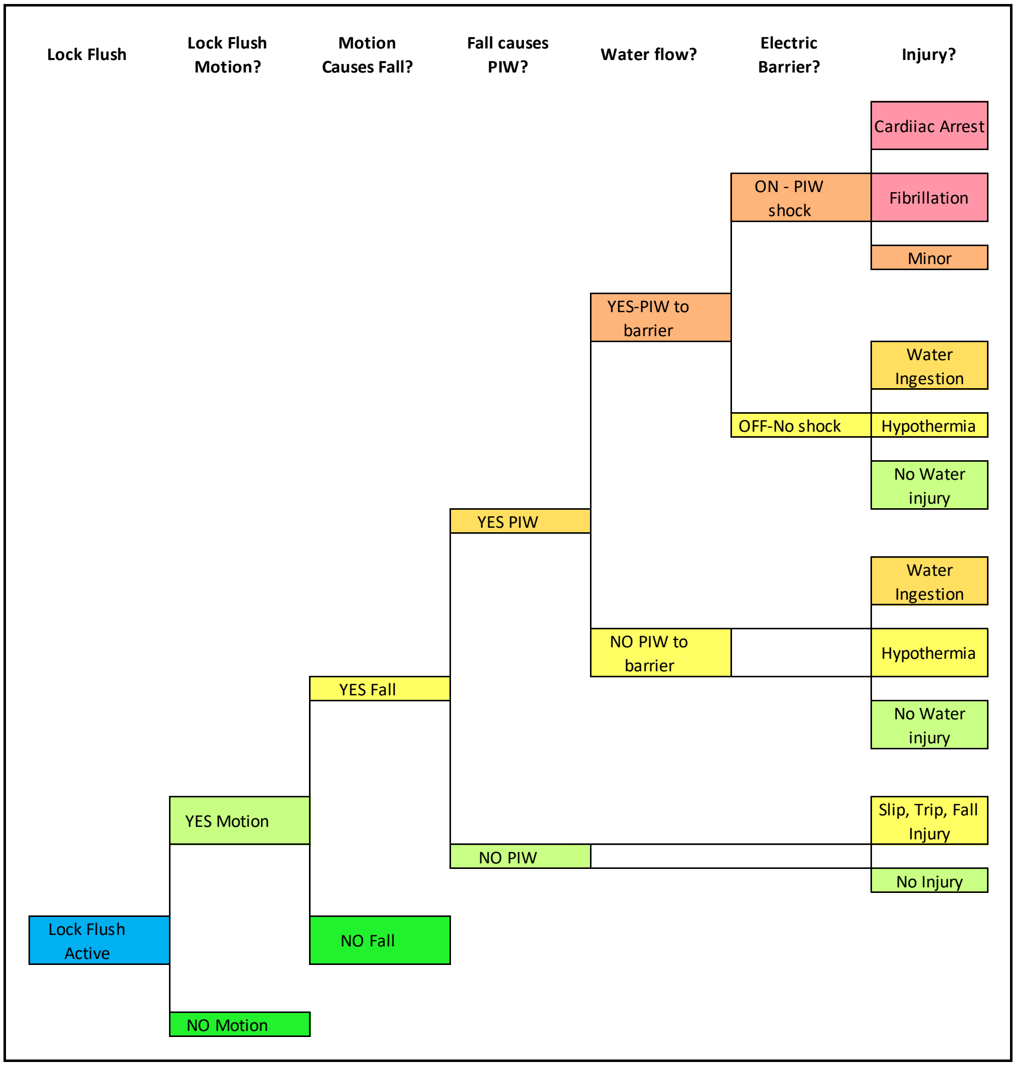

Figure 5. Example event tree for flushing lock-electric barrier combination.

The PMSRA also included detailed marine-safety risk mitigation strategies concerning project design, construction, and operation (Section 5.1), safety testing and analysis (Section 5.2), and vessel operations, geographic and behavioral restrictions (Section 5.3). The PMSRA concludes:

> "Despite the significant degree of uncertainty associated with individual elements of the control-measure system, we [RDC] are confident that through both technical and operational engagement with USACE and navigation interests, including input to the specific goals of individual control measure modeling and testing, the Coast Guard can be well-prepared to evaluate, in a timely manner, phased or concurrent control-measure implementation in terms of navigation and marine safety."

This report also includes analysis of vessel operations and vessel-personnel activity in the vicinity of BRLD as might be impacted by proposed control measures.

3 VESSEL TRANSIT ACTIVITY AND TOW CONFIGURATION IN VICINITY OF BRLD

To provide for future risk assessment, RDC needed to determine the type of activity that normally occurs in the area just south of BRLD (i.e., in the "approach channel"). Knowledge of vessel activity, particularly the number of specific activity occurrences over time, provides "frequency" basis when later making quantitative risk calculations.

RDC made multiple visits to BRLD to gain familiarity with lock operations, including the multiple tow configurations, on-deck activity, recreational vessel traffic behavior, and the interaction of lock operations with vessel traffic (e.g., how turbulence in the approach affects moored barges). RDC considered camera installation on the Brandon Road bridge-tender house to collect video recordings, but elected to use the existing downstream monitoring camera and recording system at the Brandon Road lock operation building.

As the CSSC risk assessment showed, the ability to document and later analyze activity was extremely effective by repeated review of operational surveillance camera recordings. By reviewing the video recordings, an analyst could document a week's activity in approximately eight hours, due to the ability to "fast-forward" through hours of no activity.

Throughout the term of this project, the one control measure that USACE has included in all proposed plans, as a given, is an electric dispersal barrier similar to that at Romeoville, IL. In the CSSC Risk Assessment (Lewandowski, et al., 2013), research showed that the single highest contributor to marine safety risk was person-in-the-water (PIW) related electric shock. Since the CSSC is a regulated navigation area (RNA), numerous provisions exist to mitigate risk, especially as it relates to PIW electric shock with the most restrictive being "*all personnel on vessels transiting the RNA should remain inside the cabin, or as inboard as practicable.*"[3] Because locking-through requires deckhands to position themselves at the head of the tow, the project wanted to determine the extent that routine vessel operations might preclude incorporating the primary, CSSC PIW electric shock risk-mitigation measure at BRLD.

In addition to RDC site visits, the project team reviewed over 90 days of video from the Brandon Road Lock surveillance camera recordings.[4] The goal of the effort was three-fold: (a) categorize towboat-deckhand on-deck activity while downstream of the lock chamber, either while headed upstream on approach to the chamber, or upon leaving the chamber headed downstream, (b) determine nature of tow configuration, i.e.

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[3] 33 CFR 165.923 (b) (2) (ii) H

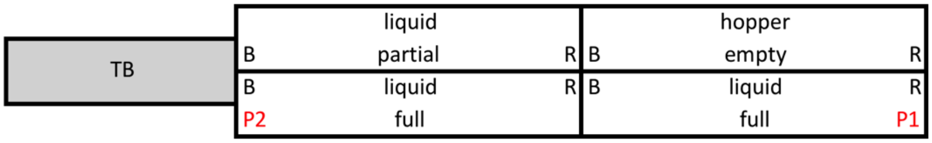
[4] RDC provided the lock master two video recorders, in-line connected, one at a time, with the USACE recorder and asked the lock staff to swap-out the recorder every 30 days so the RDC could review and analyze the video recording and then send the recorder back to BRLD. A total of 98 days of activity was recorded between 9 August 2016 and 6 December 2016.

number and sizes of barges, and their orientation to each other (specifically looking for “box to rake” connection), and (c) whether the tow was large enough to require “a cut” where a portion of a tow would lock through, and the remainder of the tow would require a second drain or fill of the chamber to lock through, or a “knock-out” or “set-over” where the towboat would need to either maneuver a barge to the side of the flotilla, or break off from astern of the tow and make-up alongside to lock through in the same lockage.

Figure 6 is an example of what the analyst reviewed. In this image from the video-recording, dusk and lighting glare on the camera dome pose some difficulty to clearly discern barge type and load condition, let alone the on-deck activity. The analyst only counted on-deck activity where they could clearly discern it, possibly leading to an *undercount* of on-deck events.

Figure 6. Example of video-recording imagery for analyst use.

With multiple reviews, including freeze-frame, slow motion and fast forwarding (fast forwarding the video increased conspicuity of on-deck activity for the analyst), the analyst noted conditions in a spreadsheet, to allow entry for barge type and load condition, persons (P), rake (R) or box (B) ends, and other details. Figure 7 gives the spreadsheet depiction of the flotilla configuration shown in Figure 6.



		liquid			hopper	
TB	B	partial	R	B	empty	R
	B	liquid	R	B	liquid	R
	P2	full			full	P1

Figure 7. Spreadsheet depiction of Figure 6.

In addition to the commercial towing activity, a significant amount of "small craft" activity occurred in the area. The project reviewed this activity as well; however, from the video recording, analysts could often not determine actual vessel size, nor nature of the vessel activity.

3.1 On-deck Activity

In a user-group/government agency Navigation Safety Listening Session (Will County Office Building, Joliet, IL, 18 August 2016) a USACE representative brought up the issue of applying the CSSC RNA guidelines to the BRLD complex, particularly concerning on-deck activity during barrier zone transit approaching the BRLD. Vessel operators expressed extensive concern that on-deck activity was necessary for safety, as standard practice is having a deckhand advising the pilot of distances from the head of the tow to either the approach wall, the Brandon Road Bridge, or to the lock chamber's lower miter gate. From the video review the analyst noted that in 95.5% of the upbound transits through the lower approach at least one person was on deck. Table 1 presents the actual on-deck activity the analyst could discern from the video review.

Table 1. Brandon Road transit summary, people on deck.

Month	Total Barge Transits	# Upbound Flotillas (2 or more)	# Upbound Flotillas (1 row)	Total Upbound	# Barge Transits with People	Upbound with no People	% Upbound with People
August	176	72	10	82	144	3	96.3%
September	174	78	8	86	135	2	97.7%
October	166	62	19	81	121	5	93.8%
November	233	86	26	112	150	5	95.5%
December	41	10	8	18	30	2	89.0%
Total	**790**	**308**	**71**	**379**	**580**	**17**	**95.5%**

For standard flotillas, there were usually at least two people, one on the bow of the forward barge near the bank (usually the starboard bow for watching the distance to the left descending bank) and one on the stern of the aft barge. There were often more people, especially if preparing for a cut. The people were usually visible in their positions from a distance of at least 1,000 feet downstream, the approximate limit of the resolution of the video image. In other words, they were already on station by the time the traffic was close enough to the lock for the people to be distinguished in the video image.

For downbound tows, crewmembers were visible on deck on a lesser frequency than on the upbound tows, i.e., only 53% of the time. In general, on downbound tows the crewmembers could often be seen heading back towards the towboat.

This data is representative. There actually may have been more people on deck than visible on the video recording. Using the camera presented limitations:

- In bad weather, the video image could be too blurry to make out the details of the people and sometimes even the barges themselves.
- At sunset, glare made it difficult to distinguish people.
- In certain configurations, there were parts of the barge (such as hopper covers) obscuring the view of where people might have been, especially if they were on the side of the barges toward the right-descending bank (RDB).
- At night, crew activity could often only be clearly determined at a distance if the crew were using flashlights or if the lock-approach lighting illuminated retro-reflective patches on life jackets.

Regardless of data collection limitations, the on-deck activity found in the review is substantial and necessary. Whether to give the towboat pilot additional "eyes" 1,000 feet ahead of the wheelhouse to accurately report closure rates or to prepare for mooring, the deckhands add an element of safe practice to minimize allision damage to the facility infrastructure or to the vessels while approaching the lock. Depending on the final BLRD control measure configuration and control measure operating plan, the USCG Operational Commanders and USACE planners and operations staffs must accept tow-flotilla on-deck activity as a given and include safety measures that recognize that activity.

3.2 Tow Flotilla Configuration

U. S. Fish and Wildlife Service (USFWS) research (Davis, et al., 2016) indicated a potential vulnerability of the EDBS that could allow small fish to survive passage across the barrier arrays. It found that as barge tow progresses upstream, the void between the box stern of a leading barge and the bow rake of a following barge provided a volume of relative shelter from the electric current where entrained fish remained alive while transiting the barrier zone.

At an 18 August 2016 navigation safety workshop, a USACE planner raised the issue of barge-flotilla reconfiguration so as to minimize the number of rake to box occurrences that would cross a new electric barrier, including whether having tows reconfigure, downstream of a BRLD electric barrier zone could be feasible.[5] The Coast Guard Operational Commander noted that any flotilla "reconfiguration" or mooring area would become a de-facto "fleeting area" subject to Marine Transportation Security Act-mandated regulatory action and requirements.[6] Prior to that workshop, there had been mishaps involving fleeting operations on the Gulf Intracoastal Waterway and Lower Mississippi River, and as a result, RDC determined it would be important to record the actual number of box to rake match-ups that might occur, and investigate if barge fleeting operations posed an additional risk above normal transit.

From the video-recording review, an analyst determined that an average of forty percent of the upbound barge traffic with least two barges in a row, had the rake-to-box end configuration (Table 2). This traffic might require mooring, breaking the tow, and remaking it before entering the Brandon Road Lock approach if regulatory change required eliminating the rake to box-end configuration.

Table 2. Brandon Road transit summary, upbound barge flotilla configuration.

Month (2016)	# Days	# Upbound Flotillas	Rake to Box	% Rake to Box
August 9-31	23	72	35	49%
September 1-19	19	78	34	44%
October 12-31	20	62	23	37%
November 1-30	30	86	39	45%
December 1-6	6	10	2	20%
Total	**98**	**308**	**122**	**40%**

Besides the delays a tow would encounter through reconfiguration, establishing a new "fleeting operation" could pose changes to risk categorization. Potential congestion, with an increase in risk of collision, is one factor. However, on an individual flotilla basis, risk would change due to the on-deck activities, additional vessel motions, and barge-to-barge contact involved with breaking a tow, turning 200-foot or 300-foot barges end-for-end in a 700-foot wide reach, and remaking the tow.

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[5] Tow reconfiguration would occur in the "mooring area" called out in Figure 3.

[6] MTSA implementing regulations in 33 CFR Part 105—Maritime Security: Facilities

In 2015-2016, two incidents occurred in the Eighth Coast Guard District (CGD8) that involved fleeting operations with loss of life. The project reviewed cases from the Coast Guard's MISLE database to see if there was any correlation between fleeting and vessel casualties, particularly incidents involving personal injury or persons-in-the-water.

Table 3 shows MISLE case data with tow-related incidents in CGD8. Table 4 shows similar data for CGD9. Where possible, an analyst identified cases where barge fleeting was apparent, either where "fleeting" appeared in the case description or text comments, or where the analyst determined comments indicated activity directly associated with "fleeting" activity (e.g., making or breaking a tow, adding barges to a flotilla, or making a "cut" during lockage). If text comments did not provide enough information to determine if fleeting was involved, RDC considered those cases as not to involve fleeting.

Table 3. CGD8 towboat/barge incidents 2012-2016.

	Fleeting Related Injury	Other Injury	Person in Water Fleeting	PIW Other	Fleeting Related Breakaway	Other Breakaway
MSD Cincinnati	1	5	2	1		
MSD Nashville	1	3	1	1		1
MSD Peoria		2				6
MSD Quad Cities	2	6		1		4
MSD ST Paul		2			1	4
MSD Vicksburg	1	1	1	1	3	35
MSD-Victoria TX		1				
MSDD - Fort Smith AR	2					1
MSU Baton Rouge	1	3				2
MSU Houma		2		1		2
MSU Huntington	3	9				3
MSU Lake Charles		5		1		
MSU Morgan City		7				3
MSU Paducah	2	7	1	1	1	15
MSU Pittsburgh	2	11			1	1
MSU Port Arthur		2		1		
MSU Texas City		5		1		2
Sector Corpus Christi		1		1		1
Sector Houston/Galveston		8		3		1
Sector Lower Mississippi		7		5		16
Sector Mobile	1	17		1		4
Sector New Orleans	6	20		3		3
Sector Ohio Valley	1	9	1			8
Sector Upper Mississippi	4	9			2	39
TOTAL	**27**	**142**	**6**	**22**	**8**	**151**

Table 4. CGD9 towboat/barge incidents 2012-2016.

	Fleeting Related Injury	Other Injury	Person in Water Fleeting	PIW Other	Fleeting Related Breakaway	Other Breakaway
MSU Chicago	6	4			2	3
MSU Cleveland				1		
MSU Toledo						1
Sector Sault Ste Marie		1				
TOTAL	**6**	**5**	**0**	**1**	**2**	**4**

Overall in CGD8, 16% of the barge injuries, 23% of the PIW incidents, and 5% of the breakaways were related to the fleeting process. However for MSU Chicago 60% of barge operation injuries and 40% of the breakaways were related to the fleeting process. For the cases recorded, most injuries were relatively minor and breakaways quickly resolved. An exception was the 2013 incident involving a 14-barge flotilla breakup, which disabled the Marseilles Dam and caused flooding in the city of Marseilles, IL.[7] In that incident, no injuries occurred and there were no persons in the water. It is important to note, this incident DID NOT involve fleeting operations.

3.3 Tow Flotilla Size

In order to define the amount of on-deck activity to make a single lockage (in the relatively still water of the lock-chamber before fill), or to make a “cut” of the tow (or towboat), and waiting downstream during the lock drain before a second lockage,[8] RDC performed and evaluation of the number of flotilla transits, highlighting the number that require a configuration change to lock through the 600’ x 110’ Brandon Road Lock. This review noted whether the towboat needed to break from flotilla and come alongside the flotilla to pass through in a single lockage, whether the towboat and a barge needed to “set-over” for a single lockage, and whether the towboat and flotilla were large enough to require a “cut” for a double lockage.

Table 5 provides data from the video record. Though approximately one-half the flotillas required some degree of reconfiguration for a single lockage, 11% required a “cut” and a double lockage.

Table 5. Flotillas requiring reconfiguration and more than a single lockage.

Month (2016)	# Days	# Flotillas	Requiring Reconfiguration	%	Requiring >1 lockage	%
August 9-31	23	175	104	59%	25	14%
September 1-19	19	174	94	54%	18	10%
October 12-31	20	167	89	53%	18	11%
November 1-30	30	234	119	51%	19	8%
December 1-6	6	40	16	40%	3	8%
Total	**98**	**790**	**422**	53%	**83**	**11%**

Figure 8 below highlights an example of a flotilla that needed reconfiguration for lockage. It shows an upbound tow from 4 December 2016.

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[7] National Transportation Safety Board. Marine Accident Brief 1411, Allision of the Dale A. Heller Tow with Marseilles Dam. NTSB accident ID DCA13NM01. 13 June 2014. https://www.ntsb.gov/investigations/AccidentReports/Reports/MAB1411.pdf

[8] The lock operator keeps a log and records whether a flotilla requires a knock-out, set-over, or tow cut to lock through. A full detailed record of towboat name and tow configuration is available through USACE’s Lock Performance Management System (LPMS) database.

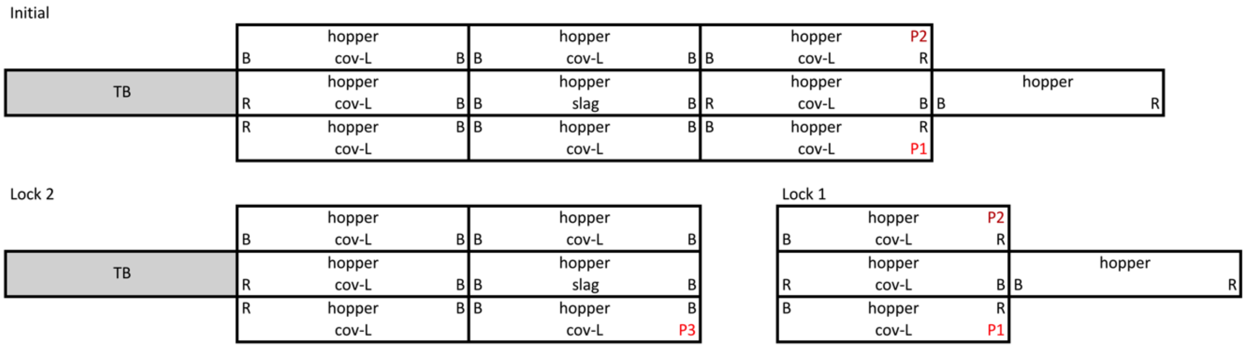

Figure 8. Depiction of flotilla configuration approaching BRLD and after cut for double lockage.

The top of the figure shows the configuration in the lower pool approach: ten standard (195’ x 35’) hopper barges with towboat having an overall length of approximately 900’ and overall breadth of approximately 105’. The analyst was also able to discern two persons on deck (P1 and P2) during the approach. The bottom of the figure shows how the flotilla was “cut” so each portion, including the towboat, could fit the 600’ chamber. Note that the cut required a third person (P3). Before the second portion of the tow locks through, the lock operator drains the chamber, subjecting the barges and towboat to turbulence as the lock drained (Figure 9).

Figure 9. Turbulence in BRLD downstream approach channel during lock-chamber drain.

Changing flotilla configuration and making a cut are routine occurrences along the inland rivers. A review of CG MISLE statistics did not indicate any occurrence of a person in the water (man overboard) during Brandon Road operations in the 2012-2016 reporting period. Addition of control measures that affect present operational procedures will require re-evaluation of the level of risk.

3.4 Small Craft and Recreational Vessel Activity

The Brandon Road Preliminary Risk Assessment addressed "recreational vessel" activity, but did not provide numerical values for the degree of activity. From the Brandon Road Lock and Dam Fact Sheet (USACE Rock Island District, 2017), 670 recreational vessels accounted for 373 recreational lockages in 2016. From the video review conducted for this project, the activity shown in Table 6 took place over 98-days observation. Table 6 identifies the total "activity" in the vicinity of Brandon Road Lock. The standard position of the lock operator camera is at the left descending bank (LDB) lower miter gate and centers on the downstream approach to the lock. In addition to vessels that lock through, the video recording provides a view of vessel activity that does not lock through. In Table 6, we account for these activities as "local" activity. "Through" indicates vessels that took lockage. The video showed multiple recreational vessels often would take a single lockage.

Table 6. Recreational vessel and small craft activity in vicinity of Brandon Road Lock.

Month (2016)	# Days	Activity	Through	Down	Up	Local
August 9-31	23	101	85	76	9	16
September 1-19	19	143	129	105	24	14
October 12-31	20	58	50	46	4	8
November 1-30	30	28	14	13	1	14
December 1-6	6	1	0	0	0	1
Total	**98**	**331**	**278**	**240**	**38**	**53**

Though "local" events are occasionally at the far capability of camera resolution, in some cases, an analyst was able to speculate on the nature of small-craft activity (Figure 10).

Figure 10. Small craft activity to the left of tow near downstream approach LDB as barge flotilla passes.

Over the early-August to early-December time frame, the vast majority of small craft and recreational traffic is downbound. Though not broken out here, the video review indicates that throughout the same period, most of the recreational vessels locking through are 30-50' length-overall, with an occasional 19-20 foot runabout, personal watercraft (usually in groups), or kayak. In all but one or two instances and except for easily identified government small craft, vessels under 20-25 feet make up the "local" activity that takes place in the lower approach channel and dam tailwaters.[9]

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[9] As mentioned earlier in the "on-deck activity" discussion , resolution of the video image and absence of a tool to accurately measure the length of various-sized vessels from the video, required the analyst to "best-estimate" length-overall.

3.5 Vessel Transit Activity and Tow Configuration Summary

The previous subsections covering commercial activity indicates a well-choreographed, safely-executed, frequent series of events that occur on a regular, routine basis. As with any other type of regular activity, changes to the nature of the regular activity, including timing, sequencing, or the operational environment *might* change risk factors.

There is a clear indication that safety and operations call for persons on deck during approach, mooring, and breaking and remaking a tow configuration prior to and after locking.

This section of the Illinois Waterway is primarily used for commerce (3,354 commercial-vessel lockages compared to 373 recreational-vessel lockages (USACE, 2017)), but a significant pattern of recreational use exists. Section 4 of the PMSRA discusses the long-distance vessel traffic and the "local" activity (i.e. fishing and hunting). The analysis of video recording events quantifies the amount of activity for the early-August to early-December time frame, though additional "local" activity downstream of the approach may have occurred outside the ability to record it.

The majority of recreational vessels that transit the lock are in the 30-50 foot range. As with the commercial traffic, locking of recreational vessels requires on-deck activity, though with the greater number of downbound vessels, crews stand a good chance of completing the activity prior to departing the immediate vicinity of the downstream miter gate.

Local activity involves smaller, open craft, especially for fishing and hunting. Video analysis could not clearly determine vessel size and activity and may not have fully accounted for events in waterfowl hunting season, though the number of recorded events in November was similar to that in the warmer months of August and September.

4 CONTROL-MEASURE-BASED MARINE SAFETY RISK ASSESSMENT MODEL

The Chicago Sanitary and Ship Canal (CSSC) Marine Safety Risk Assessment (Lewandowski, et al, 2013) provides a full breakdown of how to construct and apply a quantitative, risk-based decision model. The risk-model design concepts for the CSSC work remain valid. This report does not restate them. When conducting a quantitative risk assessment for changes to the CSSC electric dispersal barrier system or the BRLD project, the Operational Commander will need to update baseline conditions for the appropriate area under consideration (e.g. estimated number and types of vessel transits or activity, or changes to physical configuration of the waterways or control measures).

In the lead-up to actual implementation of control measures, the Coast Guard, USACE, and other agencies need to investigate how any of the control measures change the existing level of risk to marine and navigation safety. As stated in the CSSC Marine Safety Risk Assessment (Lewandowski, et al., 2013) and reiterated in the PMSRA for Brandon Road (Lewandowski, 2016), the greatest potential risk value identified to date can be attributed to person-in-the-water (PIW) electrical shock. Figure 11 illustrates a straightforward example of potential control measures combining to create different loss outcomes, with the highest loss category being person-in-the-water electrical shock.[10]

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[10] Figure 11 is similar to Figure 5 presented earlier

In Figure 11, colors represent the relative level of loss on a green-to-red basis. This *qualitative* approach provides a basis for further quantification, i.e., a start to the process. To reach a quantitative value, an analyst would calculate event probabilities for each outcome, ideally based on statistical or historical information. In this case where no record of an event actually exists, an analyst might begin by noting the number of transits that occur over a particular period of time, and pose the question, "what if an event occurred tomorrow?"[11] As noted in the 2013 CSSC work, full acceptance of risk assessment work relies on "ground-truthing" the statistics by user groups or subject-matter experts.

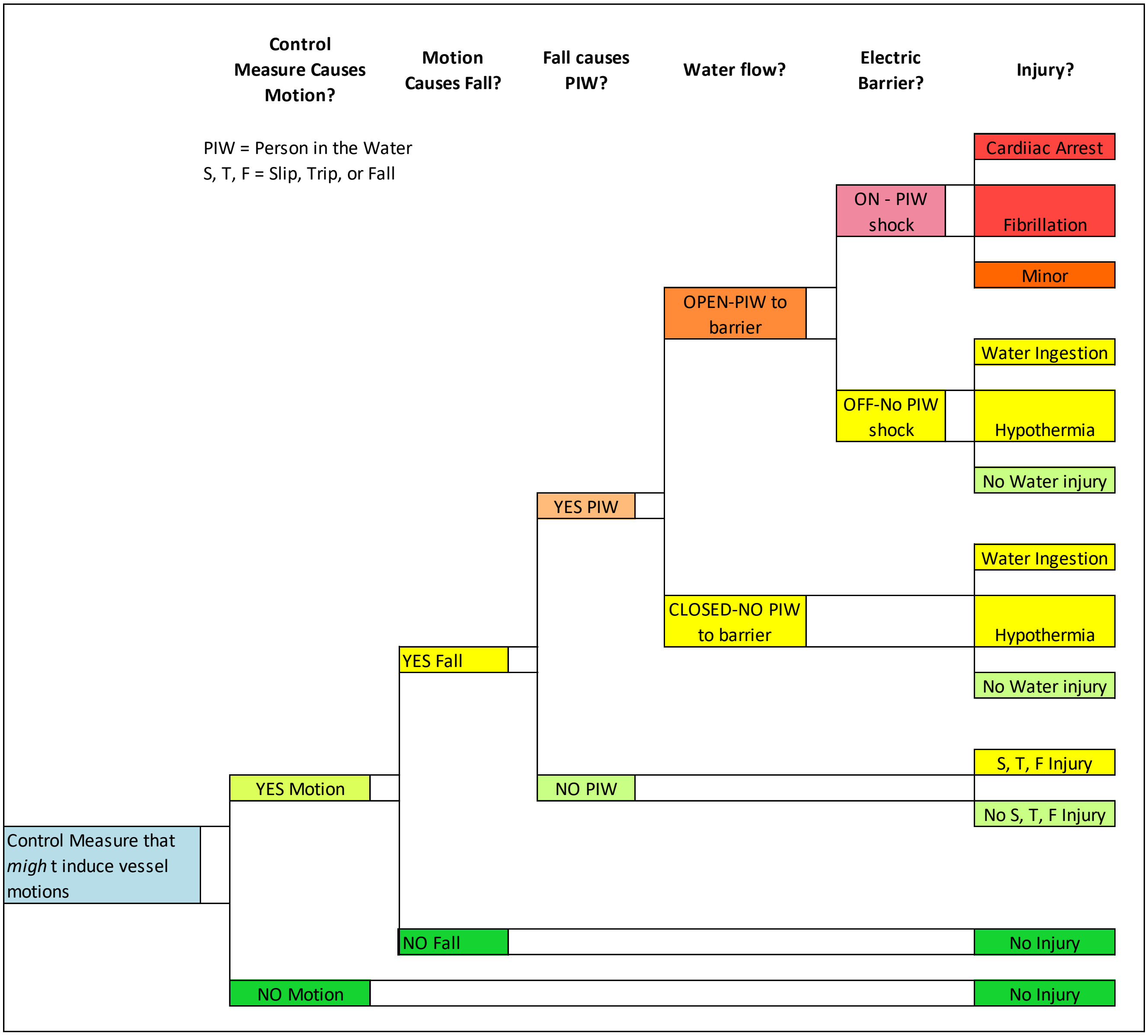

Figure 11. Example of control-measure combination event tree, PIW.

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[11] In the 2013 CSSC work, the project team convened a subject matter expert panel made up of towboat operators and first responders where the participants provide experiential input to derive, challenge, and reach a consensus on the event probabilities and consequence values (losses).

Figure 12 shows a second example of a control-measure combination risk event tree, with loss factors significantly different from those in Figure 11. This example also provides a second opportunity to combine multiple "entry conditions" for subsequent events. To illustrate, Figure 13 shows a combination of events in Figure 12 that lead to allision, where the allision becomes the entry to the person-in-the water event tree.

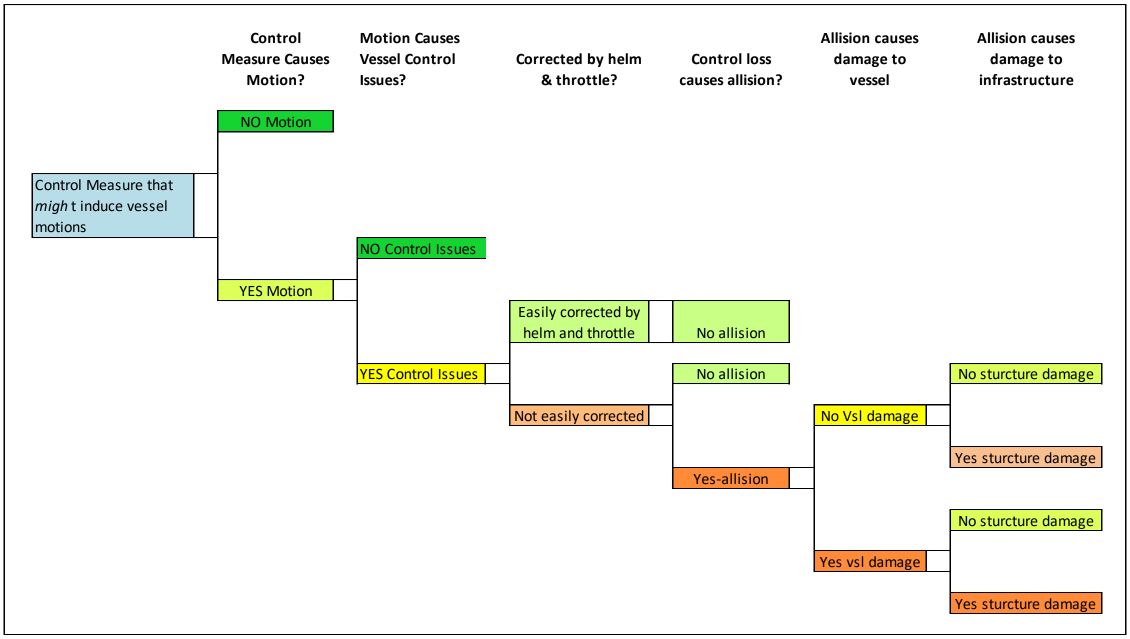

Figure 12. Example of control-measure combination event tree, allision.

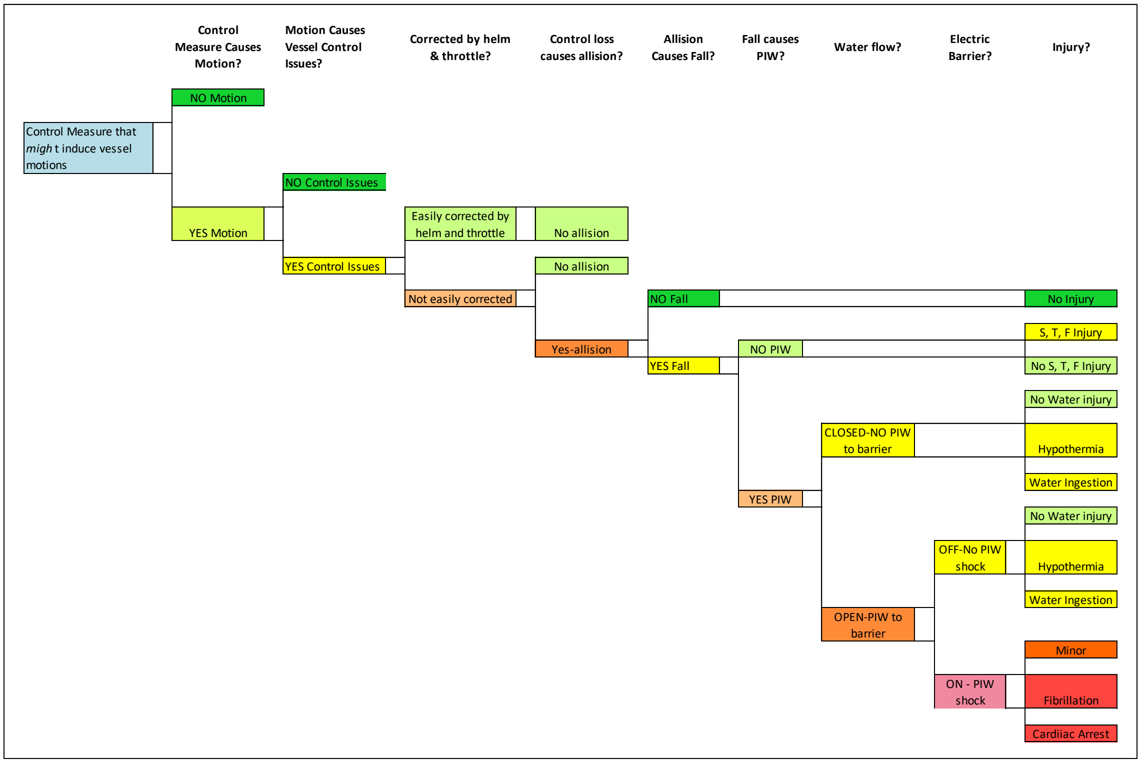

Figure 13. Example of control-measure combination event tree, with combined event outcomes: allision and PIW.

The above examples establish the event-tree situational analysis that an Operational Commander can use to help analyze risk. The CSSC risk analysis showed the probability of an individual event with a loss outcome is extremely low. In many cases, probabilities were less than one event in 100,000 transits. As an example, an agreed-to (by a user-group/SME panel) probability in 2013 indicated it was reasonable to expect one PIW event at the CSSC barrier zone approximately in 10,000 transits. As multiple versions of an electrified barrier have been operating safely since 2002 (enhanced barrier configuration since 2009) without any PIW events for an estimated 3,200 transits annually, actual frequency of a PIW event is less than 1 in 58,000. Despite the extremely low overall probability values, once the analysis provides consequence values (e.g., the 2013 study used the value of a human life at approximately $1.7 million), relative risk values result.

To quantitatively evaluate and assess the overall risk a system of control measures presents, the methods described in the 2013 CSSC risk assessment with updated information can provide a straightforward review for changes to the CSSC EDBS. When an analyst uses these CSSC-developed methods with the concept of control-measure combination event trees, they can address the BRLD system.

5 SUBSEQUENT CONTROL MEASURE SAFETY TESTING

To minimize duplicity of effort and resulting delays due to waterway closure, the Coast Guard must provide early input to and coordination with USACE (particularly USACE Engineering Research and Development Center (ERDC)) and other agencies in planning and executing control-measure related safety testing. Early notice from USACE to the USCG Operational Commander of safety-test planning will allow timely agreement on the proper level of coordination and participation among the agencies.

5.1 Change in CSSC EDBS Array Configuration and Operation

Activating the new Barrier I and raising Barrier II-B change the electrical field associated with the CSSC EDBS. The original USACE safety testing of the entire barrier zone indicated a hazard area from south of the Romeo Road bridge to the gas-pipeline arch north of the demonstration barrier. The Coast Guard based the limits of the regulated navigation area on these conditions. After the original safety tests, RDC was asked to determine whether rescuers could safely retrieve a person-in-the-water in the hazard zone. Slater (ibid.) showed that there were substantial, less-hazardous areas where effects of exposure to the electric field might not be lethal.

After CSSC EDBS modifications, a series of in-water and along-shore tests that re-map the electric field will provide a revised picture for responders, barrier-operations staff, and longshore workers at the barge-loading facility on the LDB, adjacent to the pipeline arch.

5.1.1 Test for Electric Field Distribution in CSSC for Simulated PIW Configurations

Slater, et al. (2011) provides detailed procedures for conducting specific tests relating to rescue of a PIW. Measurements include: surface to six feet water depth, six feet cross-canal, six feet along canal axis, from a simulated rescue position the canal bank to surface of the canal (RDB), and from simulated rescue craft.

To account for changes to Demonstration Barrier voltage (originally 1.0 volt/inch), testing for field measurements must extend beyond the barrier zone to determine the extent of the electrical field in different barrier operating configurations (new Barrier I, raised anodes, different voltages).

5.1.2 Long-tow Sparking

A series of 2011 USACE ERDC tests (McInerney, et al., 2011) determined that sparking could occur due to allision between a "long tow" and barges, moored alongside the Will County Generating Station on the RDB just south of the Romeo Road Bridge. Though barge mooring and fleeting there stopped in September 2012, introduction of new Barrier I and operating the Demonstration Barrier at higher voltage may cause similar conditions in the area north of barrier zone that include "normal" barge loading positions and configurations at the CITGO-Lemont barge-loading facility on the LDB.

Though likelihood of an allision is low, operators both shoreside and on a passing tow need to be aware of possible hazard, if in fact, test measurements indicate such.

5.1.3 Shore-safety Considerations at the CITGO-Lemont Coke Loading Facility

As part of the 2013 CSSC MSRA (Lewandowski, et al., 2013), RDC took shore-based electrical "touch-point" and "step" measurements at the then-Oxbow Calcining (now CITGO-Lemont) barge loading facility. Those readings indicated that longshore workers that followed normal safety precautions would generally avoid electrical hazard and that workers and surveyors using the fall-prevention device while aboard the barges could avoid the potential of falling in the water.

With change in Demonstration Barrier voltage, and implementation of new Barrier I, follow-up testing is appropriate. Appendix F of the PMRSA provides complete details for conducting similar tests.

During the final stages of shore-based testing at Oxbow, researchers found that a tow crossing the Demonstration Barrier possibly caused an increase in electrical field and touch-point potential as the lead barge(s) came abeam of the barge-loading facility. This gap in the existing data requires further data collection and resolution.

5.2 BRLD Structural Control Measure Testing

As implementation of these control measures at BRLD will not occur until approximately year 2025, the Coast Guard needs to evaluate conditions at various sites when control measure feasibility testing takes place. In some instances, USACE has completed computational fluid dynamics or physical modeling and testing. In others, USACE and other agencies conducted limited, full-scale experiments at locations other than BRLD. This report discusses structural control measures identified in The Great Lakes and Mississippi River Interbasin Study (GLMRIS) Brandon Road Final Integrated Feasibility Study and Environmental Impact Statement - Will County, Illinois (USACE, 2018) (the Final Study), but also includes other control measures that appeared in the draft report or in related experiments.[12]

5.2.1 Entrainment Prevention

In Section 3.2, this report discussed the possibility of fish entrainment in the rake-to-box gap between barges. Initial studies and models indicated that "water jets" on the bottom of the waterway offered a probable mechanism to remove small entrained fish from the rake-to-box gap. In response, agencies tried a large-scale

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[12] USCG RDC work under this project began before completion of the USACE tentatively selected plan report to the Chief Engineer, and ended after publishing of the 2018 GLMRIS-BR Final Study. Changes in planned control measures and their specific locations presented a "moving target" in preparing this report.

test in the CSSC that revealed water jets, though effective, would be infeasible for a Brandon Road application (Davis, Shanks. 2017).

The Final Study (USACE, 2018) indicated that a "bubble curtain," similar to those in use at other navigation locks for ice-management strategies, would replace the water jets. RDC researchers are not familiar with the "bubble curtain" effect in use at various navigation locks for ice management. However, either entrainment prevention control measure introduces turbulence into the waterway to disperse or prevent fish entrainment. Though RDC observations of the 2017 CSSC testing indicated that the water jets resulted in an almost imperceptible increase in motion on a barge deck, the water-jet array was limited to an extremely small section of the CSSC (Figure 14).

Figure 14. Visible turbulence from CSSC water jet, fish entrainment control measure testing, August 23, 2017.

Either method (water jet or bubble curtain) would need to be significantly larger and include significantly larger volumes of water (or air) to clear entrained fish on a 100-105 foot-wide tow.[13] *The risk research completed to date does not include the effect on water turbulence from a full-scale entrainment prevention control measure as might affect a moving towboat, tow flotilla, or recreational vessels.*

5.2.2 Acoustic Deterrence

Research indicates that certain acoustic tones tend to deter motion of Asian carp toward the source of the tones (Vetter, et al, 2017). Both the Tentatively Selected Plan (Draft and the Final Study) indicate use of an array of transducers (speakers) to provide and maintain acoustic deterrence, downstream of the Brandon

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[13] After assessing design requirements to operate a water jet system along the width of the downstream approach channel at Brandon Road Lock, engineers determined pumping requirements and needed water volume to operate such a system would be infeasible (USACE, 2018).

Road Lock. Between the draft (USACE, 2017) and the Final Study (USACE, 2018), the position of the array moved from immediately downstream of the lock chamber, to locations in the approach engineered channel, immediately below and upstream of the electric dispersal barrier.

RDC was unable to participate in the January 2018 acoustic deterrent trials at the CSSC in Romeoville, IL. In these tests, USACE and USFWS researchers deployed a transducer mounted to a moored towboat to provide an acoustic signal in a horizontally oriented pattern across the canal. Researchers noted that within the towboat hull, noise levels approached 86 decibels in air (dBA), but were otherwise minimal to passing tows. Investigators must take advantage of another acoustic trial at Barkley Lock, Kentucky in 2019, where the transducers will be mounted on the lock approach bottom, to ascertain noise levels through barge hull to deck, and to towboat pilothouse. *RDC has no information on the effect of acoustic deterrence arrays on recreational craft and operators*.

5.2.3 Lock Flushing

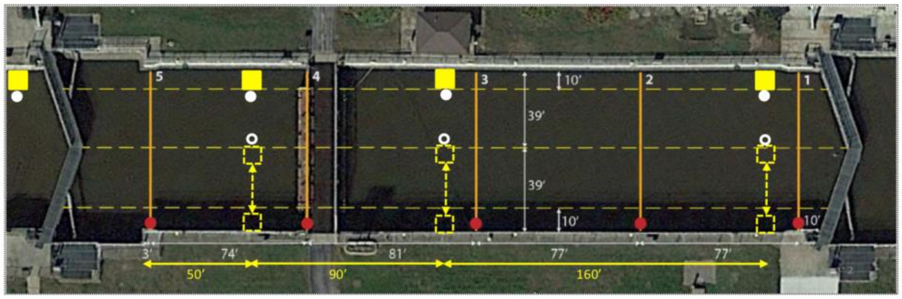
RDC has not evaluated this control measure, as it is not a regular practice. Section 9 of the Final Study (USACE, 2018) indicates a need for physical modeling during pre-construction engineering and design.

5.3 Carbon Dioxide (CO_2) Treatment

USACE did not include this control measure in either the 2017 draft study or in 2018 Final Plan. However, ERDC completed a comprehensive study on the subject. The 2017 report "Preliminary Feasibility and Risk Analysis of a Carbon Dioxide Barrier at Brandon Road Lock and Dam" (Nestler, et al., 2017) identified the uncertainties pertaining to risk to human health and survival. Specifically, the report addressed CO_2 intoxication, loss of consciousness, and asphyxiation during the course of a normal chamber fill; and vessel sinking and human drowning.

Risk and feasibility analysis for a CO_2 barrier requires knowledge of its size, mode of operation, and location. Unfortunately, a field-scale elevated CO_2 barrier does not exist. Therefore, there can be no data on which to substantiate either the feasibility of such a barrier or the risks associated with system design features or system operation" (Nestler, et al.).

To address some of these issues, in 2018, RDC planned to participate in a joint U. S. Geological Survey (USGS)/USACE study of the effects of mixing CO_2 in a lock chamber as a control measure. This was to occur at the Auxiliary Lock at Lock and Dam (L&D) 14 on the Upper Mississippi River (UMR) near Bettendorf, IA. Of many concerns with this control measure, the most apparent was potential changes in air quality in the lock chamber, particularly if CO_2 mixing occurred with both miter gates closed, and in lock fill. Though our understanding of the proposed operating procedure was incomplete, RDC developed a rudimentary, air quality monitoring test plan, with physical layout illustrated in Figure 15.



Lock: 320 x 80
Positions A-C: RDB - 50', 140', and 300' from lower miter gate
Positions D-F: Centerline to LDB (variable) - 50', 140', and 300' from lower miter gate
Position G: LDB 10' from lower miter gate
🟨 - Float (white dot indicates sensor mount)
Floats at positions D-F will have rope and pulley outhauls to adjust cross-chamber position.

Figure 15. Proposed RDC Air Quality Monitoring plan for L&D 14, UMR.

Due to permitting issues, USGS was not able to complete the work. However, USGS intends to conduct a test on a smaller scale at a lock on Fox River, Wisconsin mid-2019.

5.4 BRLD Control Measure Marine Safety Risk Matrix

Throughout the GLMRIS-BR project, studies have generalized system risk into elements associated with the failure to prevent the intrusion of Asian carp past the control measures. As with the CSSC MSRA and the BRLD PMSRA, RDC focused on control measure risks associated with marine and navigation safety. Table 7 provides some examples of what Operational Commanders should consider when determining safety test requirements for the various control measures. Table 7 is not complete, and is intentionally left so, as every decision maker can develop their own list of "what ifs." However, Table 7 provides a framework for planning with USACE researchers. For each control measure, the table provides some events that might occur. These events would best be modeled and investigated under full-scale test conditions.

Table 7. Potential control measures and associated negative-consequence events.

Electric Barrier	Activity-related electric shock	Contact-Related electric shock	PIW-Related electric shock	PIW Rescuer-Related electric shock	Spark between vessels	Spark-Related Vapor Ignition
Entrainment Prevention	Excessive vessel motion, loss of control	Motion induced slips, trips, falls	Motion induced PIW	Motion induced damage	Motion induced allision	Failure of moorings/ hardware
Lock Flushing	Excessive vessel motion, loss of control	Motion induced slips, trips, falls	Motion induced PIW	Motion induced damage	Motion induced allision	Failure of moorings/ hardware
Acoustic Deterrence	Barge hull coupling resulting in high noise level	Distraction	Communi-cation Failure			
CO_2 Treatment	Intoxication or asphyxiation	Propulsion failure	Vessel loss of stability or buoyancy			

As noted in Section 4, developing a risk assessment model will require assignment of probabilities and allowing for compounding events. For instance, while lock flushing might result in motion-induced allision or motion-induced PIW, PIW could also occur from the motion induced allision.

6 CONCLUSIONS

The marine and navigation safety risk concerns for the Illinois Waterway due to ANS control measures continue to present challenges to Operational Commanders. The primary challenge is identifying how each control measure changes the degree of risk to mariners and shoreside personnel.

USACE and other agencies use various computer modeling techniques (computational fluid dynamics, hydrodynamic, electrical field models, etc.) and physical hydraulic models to determine potential efficacy of the various control measures. However, Operational Commanders should champion real-world, full-scale testing, and observe tests when they occur.

7 RECOMMENDATIONS

USCG Operational Commanders should continue to work with USACE and other agencies to understand the nature of the different ANS control measures, and then consider how control measures might affect marine and navigation safety, either individually or as a set of combined measures with complex interactions.

RDC recommends that Operational Commanders participate in planning with USACE as ERDC or other agencies develop various “safety testing” regimens. Section 5 of this report provides a rudimentary guide to possible control-measure concerns or focus areas subject to safety testing. Operational Commander representatives should observe safety testing, participate on-site, and review test results.

For subsequent risk assessment, RDC recommends Operational Commanders use the same event-tree analysis risk-assessment methodology as applied in 2013 to the CSSC (See Appendix A). Using the same approach can provide consistency among risk-value metrics.

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APPENDIX A. CSSC RNA MARINE SAFETY QUANTITATIVE RISK MODEL

Note: This appendix appeared as Section 2.3 of the CSSC MSRA. As excerpted, it does not include references to detailed, individual fault tree/event tree analyses and consequence calculations as covered in separate appendices in the MSRA. Also, though the entering premise for the CSSC quantitative risk model is an existing regulation, application to a "no regulation" condition is also appropriate.

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.

A.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.

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).

A.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.

A.3 Risk-Informed Process Supporting Regulatory Decisions

A.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 A-1 describes the main steps in the overall process of informing decisions regarding the effectiveness of 33 C.F.R § 165.923.

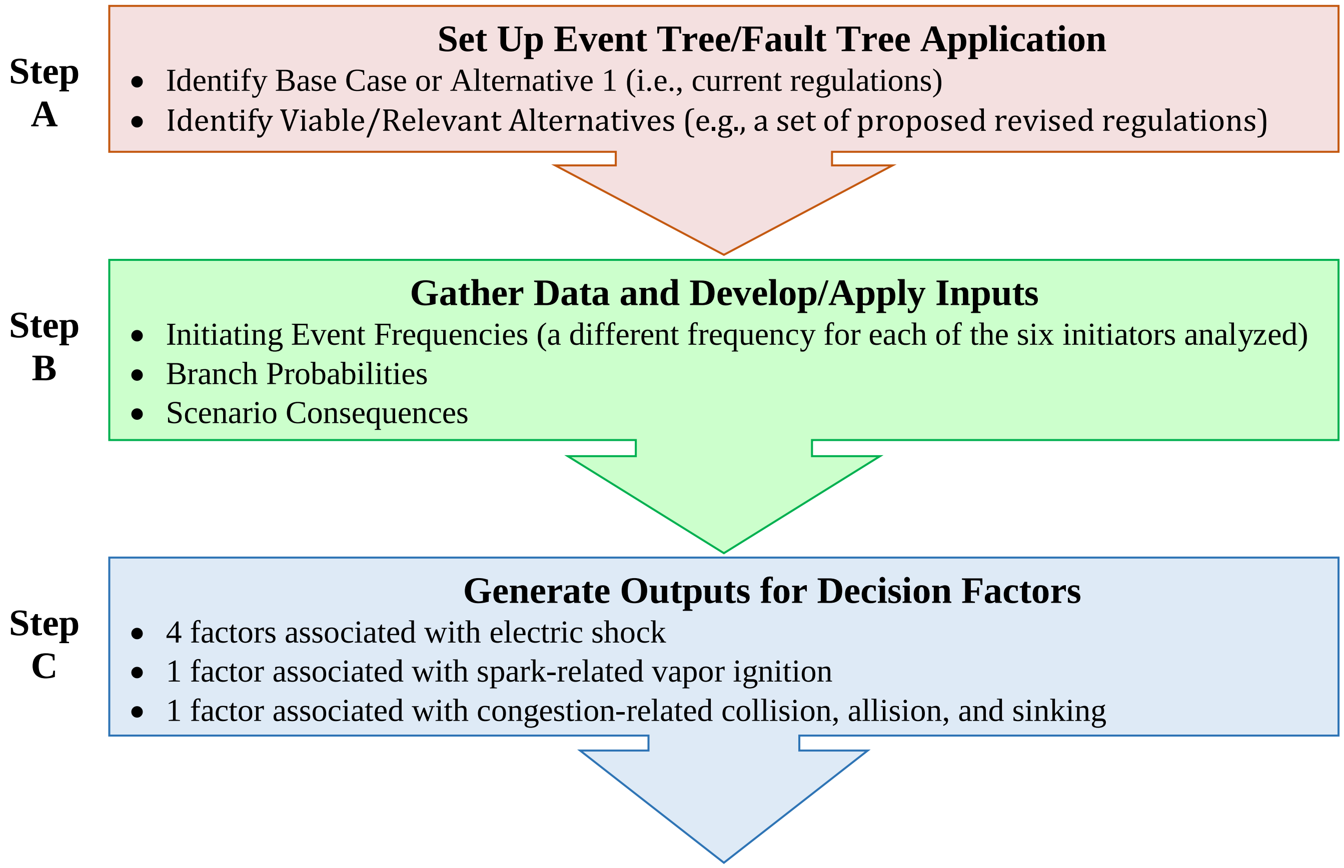


Figure A-1. Simplified flowchart of the risk informed process for supporting decisions associated with CSSC RNA Regulation.

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.

A.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.

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.

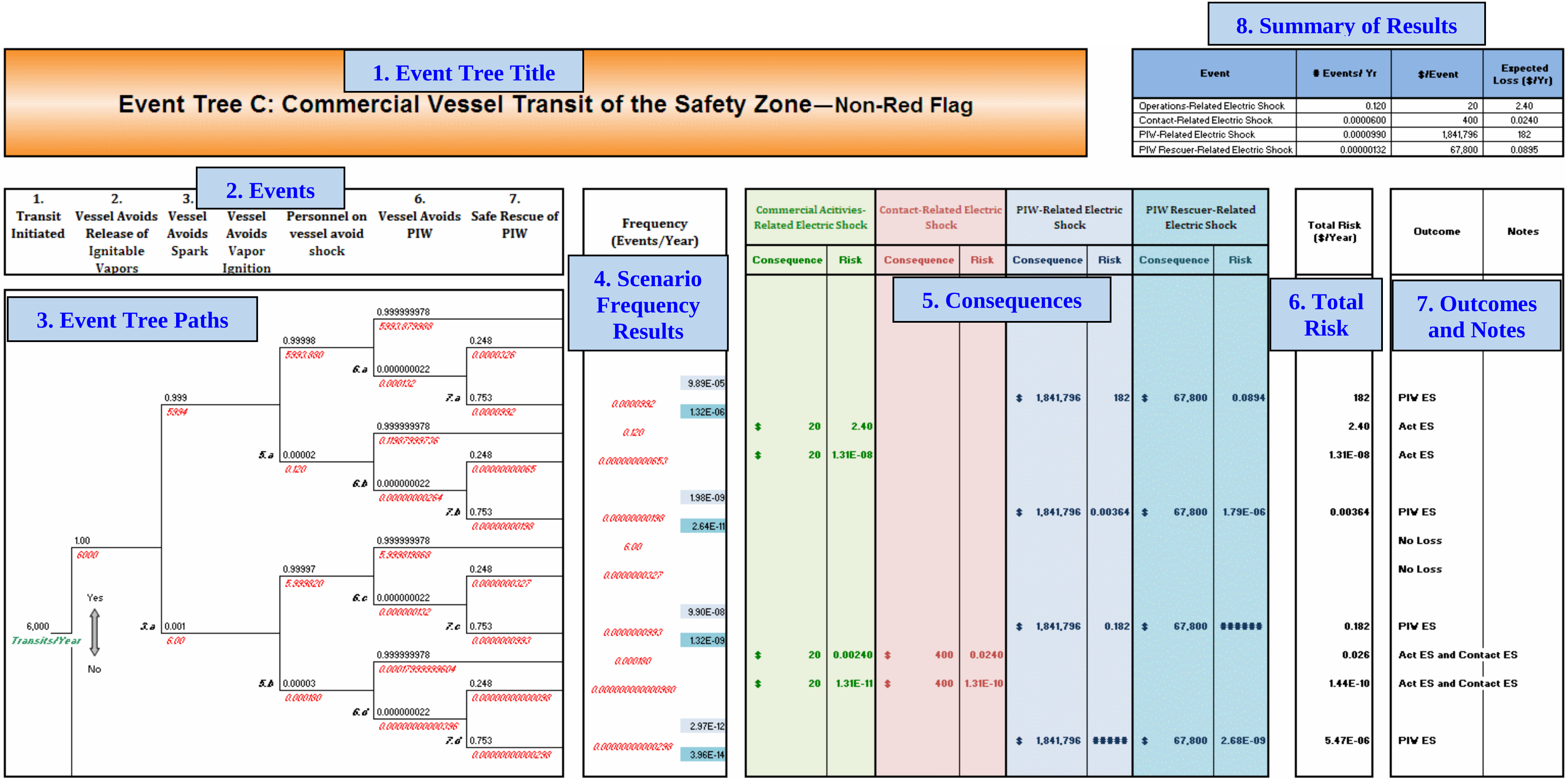
A.1. Event Trees with Risk Calculations

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 A-2). 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.

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 A-2 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

Event	# Events/ Yr	$/Event	Expected Loss ($/Yr)
Operations-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	0.00000132	67,800	0.0895

1. Event Tree Title

Event Tree C: Commercial Vessel Transit of the Safety Zone—Non-Red Flag

Frequency (Events/Year)	Commercial Acitivies-Related Electric Shock Consequence	Commercial Acitivies-Related Electric Shock Risk	Contact-Related Electric Shock Consequence	Contact-Related Electric Shock Risk	PIW-Related Electric Shock Consequence	PIW-Related Electric Shock Risk	PIW Rescuer-Related Electric Shock Consequence	PIW Rescuer-Related Electric Shock Risk	Total Risk ($/Year)	Outcome	Notes
0.0000992					$ 1,841,796	182	$ 67,800	0.0894	182	PIW ES	
0.120	$ 20	2.40							2.40	Act ES	
0.00000000653	$ 20	1.31E-08							1.31E-08	Act ES	
0.00000000198					$ 1,841,796	0.00364	$ 67,800	1.79E-06	0.00364	PIW ES	
6.00										No Loss	
0.000000327										No Loss	
0.000000993					$ 1,841,796	0.182	$ 67,800	######	0.182	PIW ES	
0.000180	$ 20	0.00240	$ 400	0.0240					0.026	Act ES and Contact ES	
0.00000000000000980	$ 20	1.31E-11	$ 400	1.31E-10					1.44E-10	Act ES and Contact ES	
0.00000000000298					$ 1,841,796	#####	$ 67,800	2.68E-09	5.47E-06	PIW ES	

Figure A-2. 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 A-3 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%.

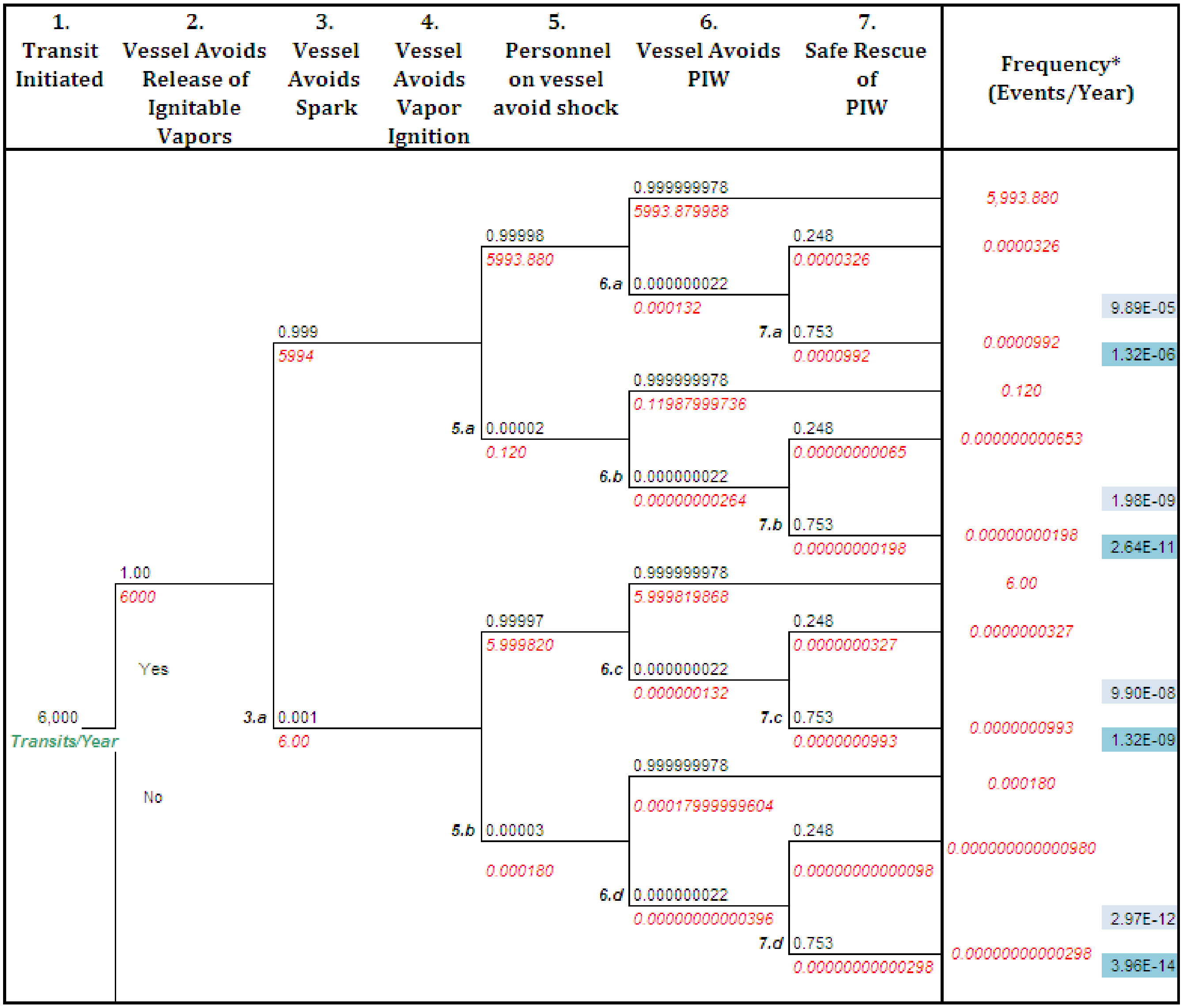
  Hence, Event 2 has one branch point, and in this case only the upper portion of the branch is shown because the success or Yes path has a probability of 1.0. Event 3 has one branch point. Event 4 has no branch points (i.e., doesn't apply) because there is no possibility of an ignition given there was 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 A-3 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 A-3 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 A-2 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.



* 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 A-3. 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 A-1 shows this loss summary for Event Tree C, “commercial vessel transit of the safety zone-non red flag.”

Table A-1. 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 A-4 illustrates how fault trees (on the left) are connected to failure events in the event tree. We will further examine one example.

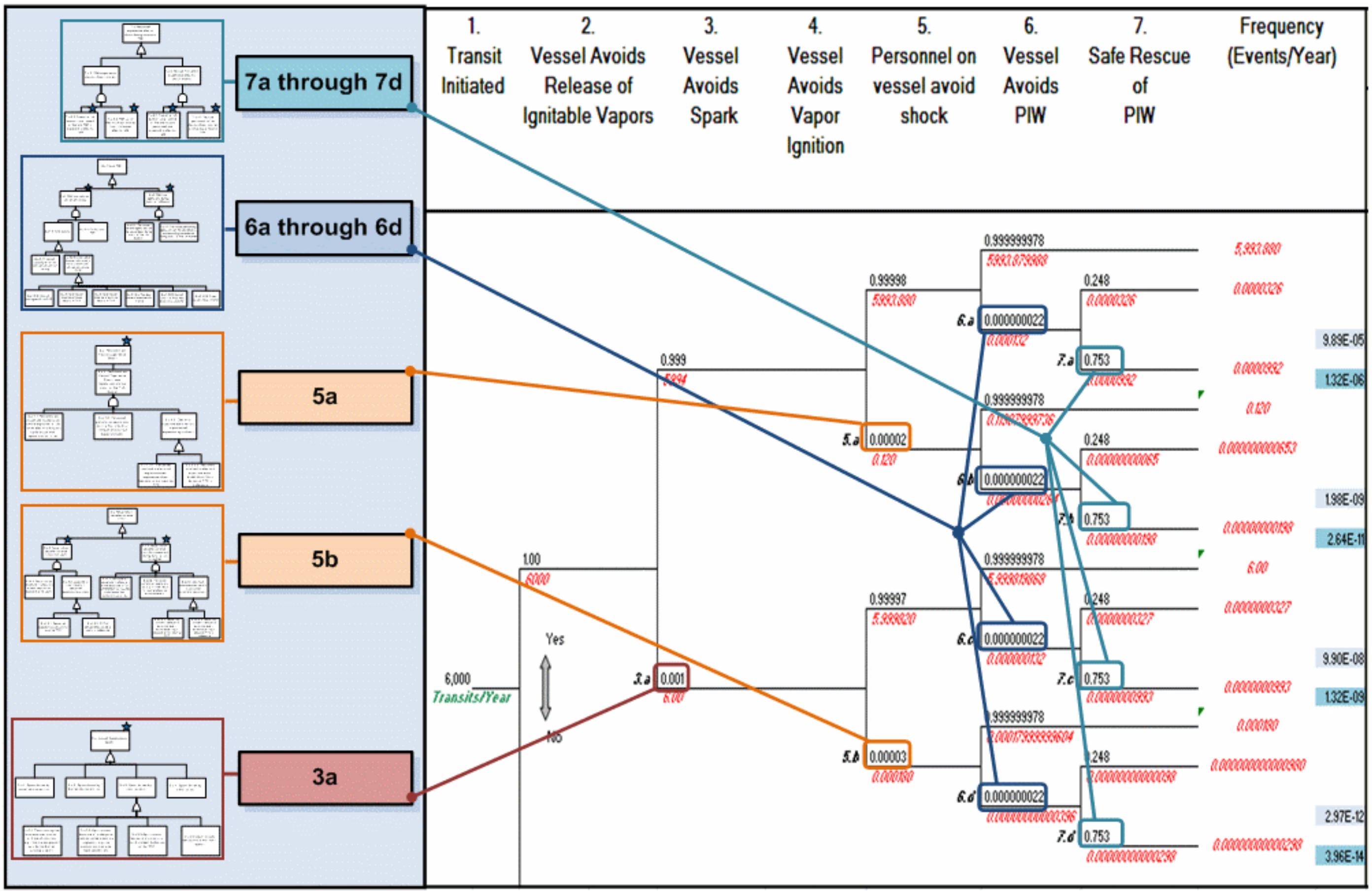


Figure A-4. Event tree (on right) with associated fault trees (on left).

Figure A-5 shows the fault tree for Path 6.a. The fault trees 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 stared 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.

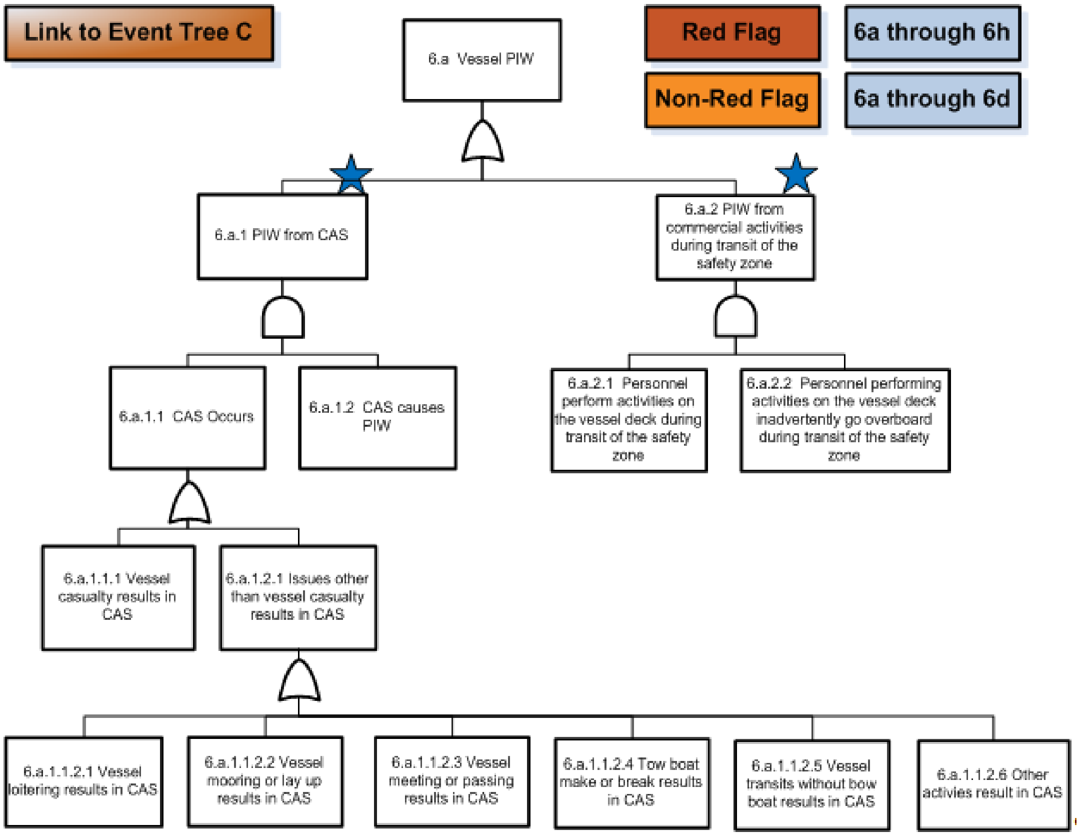


Figure A-5. Fault tree for path 6.a to 6.h vessel PIW.

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 A-2. 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 A-2 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 A-2 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.

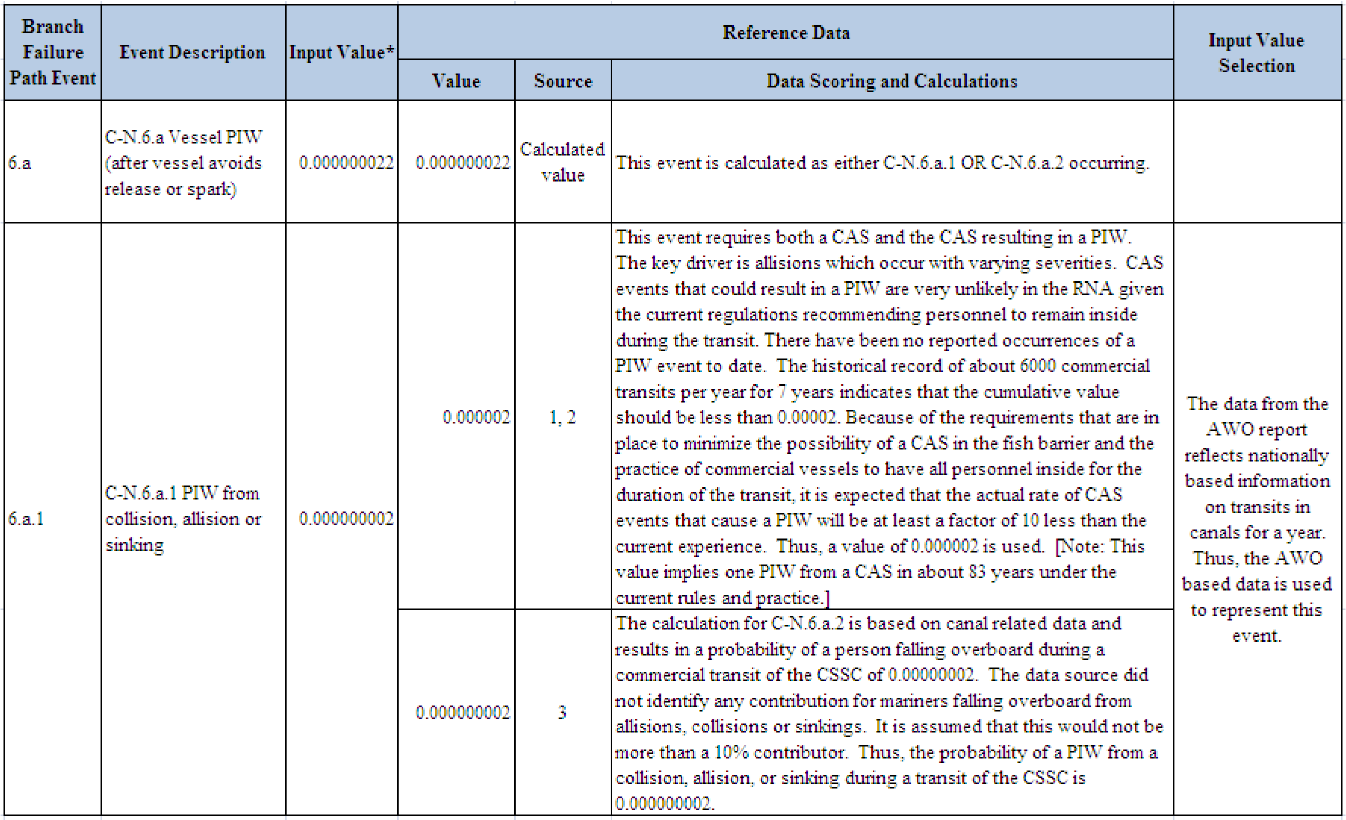
Table A-2. Probability categories for failure branch modes.

Category	Upper Bound	Lower Bound	Represent-ative 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 A-3*)* 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 A-3. 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	0.000002	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 A-2) 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.

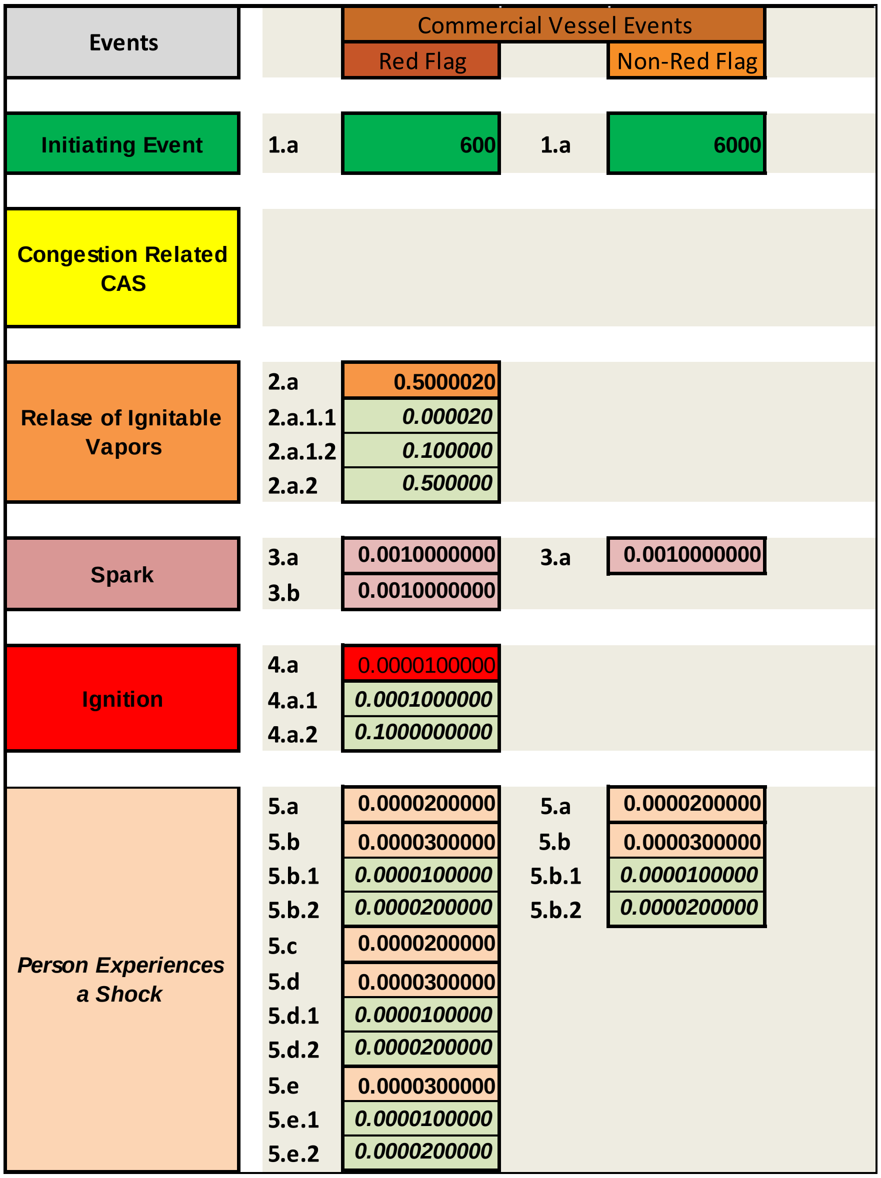
  Where the event represents a branch in the event tree (e.g., Event 6) with the calculation based on events in an associated fault tree (e.g., Events 6.a.1and 6.a.2); then the source for the event should reference all supporting events. The data scoring and calculations column should also describe the 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 A-4 shows an excerpt from the Frequency/Probability Inputs Table. The table provides the Input Value associated with the Event that corresponds to select frequency/probability values chosen.

Table A-4. 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				
Relase 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	0.0010000000	3.a	0.0010000000
	3.b	0.0010000000		
Ignition	4.a	0.0000100000		
	4.a.1	*0.0001000000*		
	4.a.2	*0.1000000000*		
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:

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.

A Coast Guard Consequence Equivalency Matrix from a 2009 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 work uses that basic structure to frame five severity categories with upper and lower bounds and a representative value (Table A-5).

Table A-5. 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 A-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 A-6 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 A-6 requires a unique set of severity fractions to establish the associated average consequence.

Table A-6. 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

The CSSC MSRA 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 A-6). 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 A-7 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. 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. 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 A-7. 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**

Table A-7 shows an average cost for each of the situations marked with an X in Table A-6.

Detailed Description for Step C: Generate Outputs for Key Decision Factors

Figure A-2 Figure A-2. 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 A-8 gives one example of the risk results for each decision factor (consequence type), showing the risk contribution for each initiator.

Table A-8. 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

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