Acquisition Directorate

Research & Development Center

CSSC Marine Safety Risk Assessment – Interim Summary

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1 INTRODUCTION

The Coast Guard R&D Center (RDC) conducted four phases of a marine safety risk assessment for the waters of the Chicago Sanitary and Ship Canal (CSSC) in the vicinity of the Aquatic Invasive Species Electrified Dispersal Barrier (MM 296.5), Romeoville, IL. The main goal of this work is to determine the adequacy of present risk mitigation strategies, and if necessary, recommend alternatives to the present strategies. To date, the work includes: (1) a data-driven, event-tree based preliminary risk analysis, (2) shore measurements to categorize electrical currents at the Oxbow Midwest Calcining barge loading facility, (3) review and analysis of canal transits through the barrier zone, and (4) review of regulatory development and rule changes since the initial operation of the barrier through the present.

2 PRELIMINARY RISK ANALYSIS

RDC contracted ABSG Consulting to perform this work. Most of the government furnished information for this work came from Coast Guard Business Intelligence (CGBI) data, Marine Information for Safety and Law Enforcement (MISLE) records, Waterborne Commerce Statistics, and dedicated, video-recording data collection. The risk analysis focuses on 6 "Loss Event Categories:"

(1) Vessel Activity-Related Electric Shock,
(2) Vessel Contact-Related Electric Shock,
(3) Person in the Water Electric Shock,
(4) Rescuer-Related Electric Shock,
(5) Spark-Related Vapor Ignition, and
(6) Congestion-Related Collision, Allision, or Sinking.

The risk analysis arrived at "quantitative values" by estimating probable occurrence of different types of events that could lead to "loss event categories" or "consequence," and estimating a dollar value associated with each loss event category. (Basic definition of risk: Probability x Consequence).

We used CGBI and MISLE as the baseline to estimate probability of events. MISLE review and analysis indicated that during the course of barrier operation, there was one adverse or loss events associated with barrier operations (one disabled recreational vessel between Barrier I and Barriers II). Because of this lack of reported events, we use other bases for estimating probability.

Instead of using zero for commercial loss events, we were able to validate the annual number of transits through the zone for various user groups (e.g. 5,000 commercial operations per year), then we postulated that in seven years of safe and event free operations, if the very next transit resulted in a loss event, we could estimate the worst case probability of that loss event occurring as "1 in 35,000 opportunities" or a probability equal to 0.00002857. Conversely, successful operations would happen at a rate 1 minus that or 0.99997143.

Table 1 summarizes risk as an "expected dollar-loss per year." A full, detailed explanation of the methodology, probability and cost assumptions, and attribution will be in an appendix to the final report. Though the actual expected dollar-loss per year numbers will vary based on both the probability of a event occurring, and an estimated consequence value (e.g., loss of human life is estimated at $7M), the *relative* costs associate with each risk condition can be compared to provide a basis of which risk conditions may

need to be addressed more than others. Or, in following the strategy of this study, whether the present regulatory guidance provides appropriate risk mitigation.

Table 1. Risk results for six CSSC RNA marine safety risk conditions.

Risk Conditions	Commercial Vessel Transit of Safety Zone [$/year]		Recreational Vessel Transit of Safety Zone [$/year]		Vessels Approach Regulated Navigation Area (RNA) [$/year]	Personnel on RNA Shore [$/year]	Totals [$/year]
	Red Flag	Non-Red Flag	Greater than 20 feet	≤20 feet & PWC			
Commercial/ Recreational Activity-Related Shock	0.2	2	50	50	N/A	N/A	**102**
Contact-Related Shock	0.002	0.02	N/A	N/A	N/A	N/A	**0.03**
PIW Shock	20	200	6,000	20,000	700	20,000	**46,920**
PIW Rescuer Shock	0.009	0.09	2,000	1	1	3	**2,000**
Spark-Related Vapor Ignition	0.001	N/A	N/A	N/A	N/A	N/A	**0.001**
Congestion-Related Collision, Allision or Sinking	N/A	N/A	N/A	N/A	4,000	N/A	**4,000**

Table 1 shows highest risk relates to person in the water (PIW) shock. The two main components of this risk are PIW from recreational vessel transit and PIW from shoreside activity. Compounding factors include the probability of an "unrecognized PIW," (i.e., an individual becomes a PIW and nobody else realizes it), and the increasing certainty of personal injury the closer a PIW is to the actual barrier arrays.

Though the near-barrier shore is generally fenced off, government and terminal facility personnel work on the canal bank daily. Maintenance, vessel loading, and construction all bring shore-workers near the canal edge, with some of these activities either in or immediately adjacent to the barrier arrays.

The probability of PIW injury applies also to vessels under 20 feet, particularly vessels where contact with the water surface is almost incidental to the watercraft use: personal watercraft (Jet-skis), human propelled craft (canoes, kayaks, stand-up paddleboards), and other small craft.

Another category of relatively high risk applies to PIW rescuers. The largest component here is associated with the risk a recreational mariner faces, should they attempt to rescue a companion. The risk assessment assumes that commercial mariners and shore workers are aware of previous studies on PIW rescue, and the recommended, rescue-related risk mitigation efforts, while the recreational mariner may not be aware of, or may disregard PIW rescue risks.

The third category that indicates a relatively high risk value is "congested-related" collision, allision, and sinking. The primary assumption here is that because of traffic restrictions in the barrier zone, the risk of collision and allision (and related sinking) exists during vessel approach to the RNA. MISLE statistics indicate one loss in the previous ten years, but that occurred at mile 307, well outside the RNA, but indicative of the potential for traffic situations that could result in collision or allision.

Two items found low risk are "contact related shock" and "spark related vapor ignition." In these instances, the likelihood of a severe incident occurring in the barrier zone is limited by the configuration of the area and the relatively low speeds of commercial vessel transits. As such, contact impact is low, e.g., scraped paint instead of damaged shell plating. Though the dollar-value of a vessel/cargo loss associated with vapor-plume ignition is high on an individual basis, ABSG's hazardous vapor-plume expert indicates American Petroleum Institute "hazard zones" (though one-half the distance in 46 CFR 111.105-31(l)1) indicate extremely low probability of a vapor plume concentration that would be susceptible to a spark that occurs at the deck-edge of a tank barge, particularly while a tank barge is moving.

The dollar-loss per year values associated with the six loss categories have not been "validated" with local subject matter expert and user-group (SME/UG) input.

3 OXBOW SHORE MEASUREMENTS

In October 2012, RDC and SAIC investigated whether electrical currents associated with the CSSC Dispersal Barrier pose a hazard to workers at the Oxbow barge loading facility. The team conducted the tests on a not-to-interfere basis, during barge loading and idle periods.

Figure 1. Oxbow Facility with shore measurement test points.

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

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

Barge movements, particularly multiple-tow transits through Barrier I, appear to impact electrical currents. The highest voltages measured during the experiment were near the southern mooring-shuttle-block during a northbound tow. (Note: the effect of tow-transit on electrical field was not designed as part of this experiment.) The testing did indicate anomalous water-to-ground voltage measurements at the southernmost extent of the Oxbow area (beyond present use-area) during an upbound, 3 x 2 tow transit while the tow was near the vicinity of Barrier I.

Table 2. Summary table; maximum voltage and current magnitude.

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

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

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

Table 3. Physiological effect of electric current on the body.

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

4 VIDEO RECORDING REVIEW AND ANALYSIS

A significant portion of the vessel traffic that transits the barrier stays within the confines of the CSSC between the USACE Lockport locks and either the Chicago River locks or the Obrien Lock on the Calumet River. Also, the Waterborne Commerce Statistic database does not provide the fidelity for determining actual make up individual tows or when a towboat transits as an assist boat. To capture actual vessel transit counts, including tow configuration, the project collected three, month-long video recordings (piggy-backing on the USACE video cameras at the barrier operations building). Vessel transit counts are the basis for event-probabilities in the risk assessment analysis. Potomac Management Group, and later Shearwater Systems, LLC provided data review and analysis support for this effort.

Table 4. Annual ***estimated*** electrified barrier transits.

	Transits	Down	Up
Total	**6400**	**3300**	**3100**
Recreational	470	270	200
Gov't., public	280	110	170
All Commercial	**5500**	**2700**	**2800**
Tow Boat only	1900	900	1000
All tows	**3600**	**1800**	**1800**
Bow Boat Tows	540	280	260
Other Tows	3100	1600	1500

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

Figure 2 is shows a situation that caused the project team to consider whether non-compliance with 33 CFR 165.923 is intentional or due to misunderstanding the rule.

Figure 2. Tow alongside CSSC East bank.

Figure 2 is a frame-capture, seven minutes into a one-hour video segment of vessel activity in the CSSC. The tow, a downbound single, jumbo-sized tank barge (not fully-laden), lays-up against the east bank, between the Enbridge pipeline arch (upper-right in figure) and the sign marking the north-end of the barrier zone (just north of Barrier I). Fifteen minutes later, a second downbound tow of two hopper barges abreast, passes the tank barge. Thirty-five minutes later, an upbound towboat noses into the bow rake of the tank barge, and two crew climb the boat's push-knees, go to the port and starboard extremes of the barge rake, and make up the towboat as a bow-boat, climb back aboard the boat, and then the newly made-up tow proceeds downstream, through the barriers.

As this particular example indicates multiple instances of rule non-compliance, the project team presumed that the tow needed a bow boat, and waited a full hour for one, though not complying with multiple other sections of the rule. Because of this, the project undertook a review of the rule, itself.

5 REGULATORY DEVELOPMENT AND RULE CHANGES

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

Through the rule history, authors made various changes to the rule. As an example, from 1 January 2006 until December 18, 2009, all personnel on deck were required to wear a "Type I personal flotation device." After that time, the rule specified "a Coast Guard approved personal flotation device." The project team also noted that in the most recent versions of the rule, "Safety Zone" regulations only apply to carriage of non-potable water; all other requirements dealing with vessel and personal "safety" appear under the "Regulated Navigation Area" (RNA).

Another significant example of rule change concerns size and type of vessels allowed in the waterway. As of December 1, 2010, the rule required "vessels be greater than 20 feet in length," and "vessels must not be a personal watercraft of any kind (e.g. jet-skis, wave runners, kayaks, etc.)." Authors omitted these vessels in the present rule (December 1, 2011). The project team noted no regulation of speed in the barrier area. While reviewing the video record, the team documented instances where small watercraft transit the area at estimated speeds greater than 15 knots.

All loading-related operations at the Oxbow facility occur within the RNA. Barges are moored, tows are made-up and broken, and towboats "loiter" until barge loading operations are complete. Both Oxbow and much of the Materials Service Corporation facility are in the RNA. As the RDC project team did not have a copy of Oxbow's waterfront facility permit, the project team allows that all activities may be permitted.

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

6 CONCLUSIONS

1. The preliminary risk analysis yielded low risk values associated with marine activity near the dispersal barrier, an estimated annual, total loss-value of ~$53,000. The largest marine safety risk (highest expected loss of ~$47,000 per year) is shock to a person in the water. The preliminary analysis further associates the largest contributors to the risk as recreational vessel transits (vessels ≤ 20' and PWCs) and persons on the shore in the RNA. Note: Discussion with Oxbow staff indicated their intent to install a fall-protection system, a significant risk-mitigation measure. The project did not investigate existing safety procedures and policies for USACE or their contractors who have worked without PIW incident.

1a. The third largest loss sub-category is associated with recreational vessel transits (vessels > 20'). Review of the CSSC Safety Zone and RNA rulemaking indicates an omission of recreational vessels. Video records indicate that smaller craft, including those >20,' often transit the barriers at high speeds.

2. The preliminary risk analysis shows a negligible consequence value for a spark-related vapor ignition event. The project team reviewed the original Office of Design and Engineering Standards (then CG-521) recommendations from December 2009, and reviewed circumstances that would both lead to a concentration of ignitable vapors and the opportunity for a spark to occur. The most significant change since December 2009 is that barge loading and fleeting at the Will County Midwest Generation facility ceased in September 2012. This eliminates a significant number of the CG-521 spark-related ignition scenarios. The original CG-521 basis for requiring a bow boat on all red flag tows was limited to certain scenarios, particularly to prevent transiting tow contact with "metal on canal walls" and "fleeted barges" at Midwest Generation. As all vertical, barrier array conductor elements are either recessed or vertically drilled through the canal wall, the two primary reasons for the bow-boat measures no longer exist.

3. Measurements at Oxbow did not indicate hazardous electrical currents under present operating procedures. At the extreme southern end of the facility (south of the pipeline arch), the team measured higher voltages (and currents), and noted anomalous, higher measurements when a tow was proceeding northbound through and adjacent to Barrier I.

4. As the rule appears in the CFR, the "Safety Zone" and accompanying regulations (33CFR165.923(a)) strictly address the carriage of non-potable water [over the dispersal barrier]. On the other hand, the "Regulated Navigation Area" is defined in subsection (b), along with regulations that pertain to flammable liquid cargos, electrical connectivity, personal flotation devices, and transiting the RNA at one's own risk. After observing repeated mariner behavior and vessel operations, we conclude that mariners may be confusing the terms "Safety Zone" and "Regulated Navigation Area."

5. In the preliminary analysis, each event tree makes multiple assumptions and applies numeric values to individual branches of the tree. A full, subject matter expert/user group (SME/UG) validation has not been conducted. For successful validation, a local user's group/subject matter expert panel may require up to a two-day session, describing and getting buy-in to the methodology, and then adjusting probabilities for each event's occurrence. A decision to invest two days of participants' time might only yield relatively small changes to the already-small loss values in the final, "validated," risk assessment. With a validated risk assessment, local SME/UG become "owners" of the results, should the Coast Guard later apply the actual risk analysis values to rule revision. In either case, the project team is confident in the fault and event-tree analysis methodology.

7 RECOMMENDATIONS

1. Small craft and recreational vessels: We recommend regulatory changes to address recreational and other small vessel activity in the barrier zone. Though background information for the present rule addresses vessels < 20,' we recommend the regulation include specific language associated with craft whose normal use put operators in immediate proximity to the water, including personal watercraft (PWCs, i.e. jet-skis, wave-runners, etc.) human powered craft (HPC, i.e. canoes, kayaks, stand-up paddle boards, rowboats, pedal boats, etc.), and sail craft (dinghies, sailboards) not propelled by machinery. We also recommend speed limit regulations for small craft and recreational vessels.

We also recommend, through safety awareness programs, encouraging use of bridge-to-bridge radiotelephone by recreational mariners while transiting the barrier area.

2. Bow boat requirements: We recommend reconsideration of the bow boat requirement that applies to all "red flag" tows. Besides the elimination of the original spark-contact concerns (fleeting at Midwest Generation and exposed barrier conductors), a closer examination of the red flag barge traffic may determine that in most cases, vents or pressure-vacuum valves are greater than the ten or fifteen feet (respectively) from an edge of the barge that may make contact with steel structures or other vessels.

3. Oxbow loading facility: We do not have enough information to make a recommendation whether Oxbow operating procedures should allow them to shuttle barges to the southern turning block (between Point 1 and point 1A in Figure 1).

4. Rule language: We recommend a review of the existing rule to simplify the content and to eliminate the apparent confusion as to the size (and purpose) of the "Safety Zone" and the "RNA."