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CSSC Fish Barrier Simulated Rescuer Touch Point Results, Operating Guidance, and Recommendations for Rescuer Safety

Interim Report

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N O T I C E

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CSSC Fish Barrier Simulated Rescuer Touch Point Results, Operating Guidance, and Recommendations for Rescuer Safety, Interim Report

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16. Abstract (MAXIMUM 200 WORDS)

Purpose: The Chicago Sanitary and Ship Canal (CSSC) has two electric fish barriers in operation to prevent the dispersal of aquatic nuisance species. The experiment was conducted to better understand what would actually occur during a rescue in the electrified waters. An additional purpose was to identify any methods, devices, or operating guidance to prevent potential harm to a rescuer.

Methods: Actual voltage measurements under different, controlled conditions were taken during transits in the regulated navigation area utilizing an instrumented dummy to simulate a person. Voltage readings and position were continuously monitored. Life rings/throw lines and non-conducting boat hooks were evaluated for potential use by a rescuer. The voltage measurements and position were processed to identify electric current levels and their likely impact on a person.

Results: Significant electrical currents at the barriers make it essential to get a victim away from the barrier before recovery. Under certain operating conditions and with non-conductive apparatus, rescuers can safely provide assistance to a person in the water (PIW) to move them away from the barriers. The rescuer and victim must be isolated from a vessel metal hull for recovery. Rescue at canal walls away from the barrier may also be feasible.

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EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE) constructed a demonstration electric fish barrier (Demonstration Barrier I) across the Chicago Sanitary and Ship Canal (CSSC) at river mile 296.5 and first energized it in 2002. USACE initially constructed the demonstration barrier to prevent dispersal of aquatic nuisance species, including the round goby and white perch, to and from the Great Lakes and Mississippi River Basins. The barrier is also intended to counter an invasive species threat from the Asian carp, which is seen as a significant threat to native species in the Great Lakes.

With the success of the demonstration barrier, USACE determined it necessary to construct a permanent barrier (Barrier II) in two phases, IIA and IIB. Barrier IIA was placed in operation in 2009, and Barrier IIB is planned for operational status in early 2011. Barriers IIA/B have more electrical capability than Barrier I (the demonstration barrier).

USACE conducted testing in 2008 on barge operations in the canal, with efforts made to evaluate the risk to vessels and humans from electrified waters. Under contract from USACE, the Navy Experimental Diving Unit (NEDU) published a study that found that voltage gradients measured in the CSSC could be life threatening, and could pose a significant risk to humans immersed in the canal near the fish barriers. As a result of these various tests and studies, specific precautions are required of all vessels and personnel transiting the barriers from river mile 296.1 through 296.7.

Coast Guard Sector Lake Michigan (SLM) is the Coast Guard operational field commander with overall responsibility for marine safety and maritime search and rescue (SAR) in the area of the electrified barrier. After the initial safety studies, SLM requested that the Coast Guard Research & Development Center (RDC) assist in developing a CSSC Fish Barrier SAR policy. RDC conducted a short-term project that reviewed and summarized the previous work. Recommendations of the project were to further investigate SAR mission capabilities and gaps for electrified water conditions and to identify or develop specialized SAR equipment (non-conductive poles, rescue loops or other devices) for safe retrieval of persons in the water (PIWs).

The primary purpose of this study is to focus on the ability to provide safe rescuer response actions to assist a PIW. At certain levels, electrical current through the human body can have a range of effects: from a tingle sensation at the threshold of perception, to muscle contractions that cannot be controlled, to direct effects on the heart. This study focuses on assessing conditions that could be encountered during victim rescue, specifically the amount of electrical current that could be experienced by the rescuer.

RDC and Science Applications International Corporation (SAIC) designed and conducted a series of tests at the CSSC on 17, 18, and 19 November, 2010. These tests followed a variety of specific data acquisition and test apparatus set-up protocols outlined in a formal test plan to assess whether identified rescue techniques are safe and effective for use in a real rescue scenario within the electrified area. Experimental efforts focused on measuring electrical current flow through a simulated human rescuer under each touch point condition outlined in the test plan.

Preliminary data analysis showed that significant electrical currents could be encountered within the electrified area of the CSSC and, without precautions, could endanger rescue personnel. Voltage levels in the canal were of sufficient strength, and with a sufficient level of electrical current capacity to impart potentially harmful electrical currents to rescuers. In general, non-conductive or resistive materials, such as rubber, plastic and fiberglass, are effective in reducing the electrical current risk to a rescuer, so long as rescuers understand the electrical current paths, and take actions to avoid or minimize them.

WARNING

Under no circumstances should a rescuer enter or immerse any part of their body directly into the electrified waters in the CSSC. A rescuer should not make contact with any PIW (in the electrified area) unless the rescuer is electrically isolated from the PIW. Any attempt at rescue in electrified water conditions is inherently hazardous. This report offers recommendations to *mitigate* hazards to rescuers, but acting on the recommendations will not *eliminate* them. Nothing in this report should be construed to imply that rescue in electrified water is anything but a hazardous undertaking.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

µS/cm	Microsiemens per centimeter
A/D	Analog-to-digital
AC	Alternating current
AED	Automated external defibrillator
amp	Ampere
AWG	American Wire Gauge
COTP	Captain of the Port
CSSC	Chicago Sanitary and Ship Canal
DC	Direct current
EKG	Electrocardiogram
GMT	Greenwich Mean Time
GPS	Global Positioning System
HDOP	Horizontal dilution of position
Hz	Hertz
ID	Identification
IL	Illinois
kHz	Kilohertz
L&R	Lakes & Rivers Contracting, Inc.
mA	Milliampere
mph	Mile per hour
ms	Millisecond
NEDU	Navy Experimental Diving Unit
PFD	Personal flotation device
PIW	Person in the water
PVC	Polyvinyl chloride
RDC	Research & Development Center
RF	Radio frequency
RMS	Root mean square
SAIC	Science Applications International Corporation
SAR	Search and rescue
SLM	Sector Lake Michigan
TSS	Three-conductor, shielded, shipboard
U.S.	United States
USACE	United States Army Corps of Engineers
USB	Universal serial bus
USCG	United States Coast Guard
VDC	Volts direct current
VHF	Very high frequency

1   INTRODUCTION

The United States Army Corps of Engineers (USACE) operates a series of electric barriers in the Chicago Sanitary and Ship Canal (CSSC) in an effort to reduce the risk of inter-basin transfer of fish between the Great Lakes and Mississippi River Basins via the CSSC. USACE installed Barrier I (Demonstration) in 2002; it operates at a nominal level of 1 volt/inch, with a 5 Hertz (Hz) repetition rate and 4 milliseconds (ms) pulse duration. It was initially constructed to prevent dispersal of aquatic nuisance species, including the round goby and white perch, to and from the Great Lakes and Mississippi River Basins (Reference 1). The barrier is also intended to counter an invasive species threat from the Asian carp, which is seen as a significant threat to native species in the Great Lakes. Various species of Asian carp (Reference 2) were originally imported into the United States (U.S.) in the early 1970's for use in Arkansas fish farms to improve water quality and increase fish production (Reference 2).

USACE conducted testing in 2008 on barge operations in the barrier zone, with efforts made to evaluate the risk to vessels and humans from electrified waters (Reference 3). Under contract from USACE, the Navy Experimental Diving Unit (NEDU) published a study that found that voltage gradients measured in the CSSC could be life threatening, and could pose a significant risk to humans immersed in the canal near the fish barriers (Reference 4). As a result of these various tests and studies, specific precautions are required of all vessels and personnel transiting the barriers from river mile 296.1 through 296.7, from Romeo Road Bridge to the aerial pipeline arch. Testing to date has also (1) characterized the electrical voltage field in the barrier zone, (2) determined its effects on surface vessels and barges, and (3) evaluated electrical contacts among vessels comprising a long tow. This testing showed the need to electrically connect all vessels in a tow entering the barrier zone to minimize the risk of electrical sparking (Reference 5).

With the success of the demonstration barrier, USACE determined it necessary to construct a permanent barrier (Barrier II) in two phases: IIA and IIB. Barrier IIA, a permanent barrier which is larger and more powerful than the demonstration barrier, has been operational since 2009, initially with the same operational parameters as the demonstration barrier; then in August 2009, USACE increased the strength of the electric field produced by Barrier IIA to 2 volts/inch, with a 15 Hz repetition rate and 6.5 ms pulse duration. USACE has completed construction on a third barrier, Barrier IIB, which was not energized during the November 2010 data collection period. USACE built and installed a series of metallic "parasitic" structures in the barrier zone in an effort to better control the shape and extent of the barrier electric field. These structures were installed before the testing described here, and data collected reflects their presence within the CSSC. This study is not intended to characterize the electric field itself, but to focus on the effects of the field on potential rescuers and rescue scenarios (Reference 6). Section 2.4 provides a brief tutorial on the affect of electric currents on the human body.

2   METHODOLOGY

We conducted all testing in accordance with an experiment test plan (Reference 3) that laid out the test conditions, resources, and experimental apparatus for each scenario. We conducted testing from a vessel in the canal. Prior to testing each day, the Test Director provided a briefing to all embarked personnel, and reviewed communications and safety procedures. Coast Guard Sector Lake Michigan (SLM) stationed a vessel nearby during all test days for immediate response, if required. We conducted all test vessel operations in accordance with a regulatory waiver from the USCG Captain of the Port (COTP) Lake Michigan.

2.1   Mobilization and Test Set-up

Each day of the experiment, Lakes & Rivers Contracting, Inc. (L&R) launched the test vessel, by crane, from their facility along the canal near Lemont, Illinois (IL). L&R kept the vessel on-shore overnight to prevent damage by passing barge traffic. Once on the water, we carried the sensor array onboard and secured it on deck and out of the water, enabling a more rapid transit from the mooring to the survey site. Once near the survey site, in an electrically safe area, north of the Citgo overhead pipeline arch, we lowered the sensor array into the water and attached it with bungee cord to the starboard railing of the test vessel. Next, we confirmed the operation of the sensor array and data acquisition system and proceeded to perform the scheduled survey with the vessel maintaining a speed (measured by a Global Positioning System (GPS)) in the range of approximately 0.5 to 3.0 miles per hour (mph). This speed permitted high spatial density data acquisition. The hydraulic drag on the sensor array frame was minimal at this speed, with no observable signs of significant distortion or stress to the frame. We arranged the transects to acquire data along tracks near the eastern and western walls and in the mid-channel of the canal within the barrier zone. Barge traffic was minimal during most of the survey runs with long periods without any traffic, enabling continuous uninterrupted data collection. Barges typically transited the zone approximately once per hour, and most often would hail the test vessel operator on very high frequency (VHF) radio to coordinate navigation in advance. When required to make changes in the sensor configuration, and at the end of the day, the test vessel held station well north of the oil pipeline arch, in an electrically safe zone. At that time, the team could safely remove the sensor array from the water for modification, repair, or stowage for transit back to the L&R facility. Figure 1 shows the general arrangement of the barrier Safety Zone with major landmarks.

The test vessel followed pre-set transects up and down the barrier zone for each test condition, while we acquired electrical and positional data throughout each transect. In general, we collected data along the middle of the canal and along both sides to investigate any differences due to side-to-side location in the canal. The experiment test plan (Reference 7) describes specific geometries more fully. We evaluated a total of six test conditions. Table 1 summarizes the test conditions conducted during the data collection period. All "human" elements (rescuer, person in the water (PIW), etc.) were simulated.
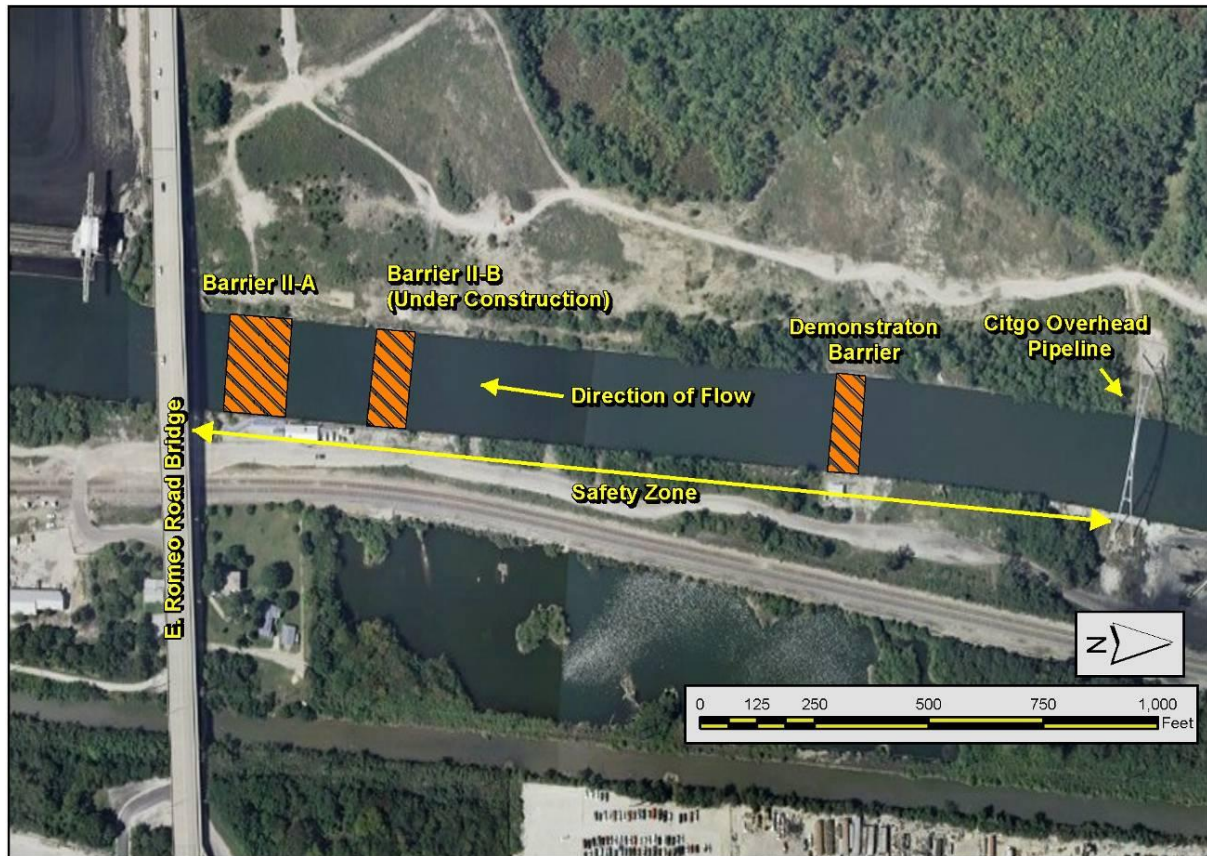
Figure 1. General arrangement of Safety Zone and major landmarks.

Table 1. Test conditions conducted.

Test Condition	Title	Description
1	Free-field current	Measure electrical current flowing through the chest area of a simulated PIW exposed to electric fields
2	Rescue vessel recovery touch point current	Measure maximum current flow from a simulated PIW to grounded rescuer on a metal-hulled test vessel
3	Shore recovery touch point current	Measure the maximum current flow from PIW to grounded rescuer on the canal wall
5	Free-field current, dry suit	Measure electrical current flowing through the chest area of a simulated PIW exposed to electric fields while wearing a dry suit
6A	Life ring throw, poly line	Determine if a polypropylene soft-line, when soaked with water, provides a potential electrical path to a rescuer pulling a simulated PIW
6B	Life ring throw, nylon line	Determine if a nylon soft-line, when soaked with water, provides a potential electrical path to a rescuer pulling a PIW
6C	Life ring throw, non-conductive rescue hook	Determine if a non-conductive rescue hook, when wetted with water, provides a potential electrical path to a rescuer pulling a PIW
7	Surface voltage survey	Measure open-circuit voltages (baseline conditions) of the near-surface electric field

We acquired data for test conditions described in Table 1 during a three-day period from 17 November to 19 November 2010. We completed Test Condition 1 on 17 November, Test Conditions 2, 3, and 6A through 6C on 18 November, and remaining test conditions on 19 November.

2.2 Data Acquisition Set-up

The apparatus and data acquisition set-up incorporated recommendations and lessons learned from USACE experience in electric field data collection in the CSSC.

1. The test team constructed and affixed a rigidly mounted sensor frame to the test vessel.
2. The test used commercially available, Tektronix P5200 high-voltage differential probes in series with the measurement system to provide isolation safety to personnel and electronic circuitry due to the high voltages present in the barrier zone.

2.2.1 Sensors

2.2.1.1 Input Electrodes

The team constructed input electrodes to ensure that the simulated "victim" (PIW) presented a realistic level of electrical resistivity to the electrical current sensing circuitry when submerged into the water. Following techniques developed for geological electric field sensing, the team designed the probes to approximate the bulk resistivity of the human body using a resistive mix of diatomaceous earth and sodium chloride to form an electrically resistive, yet conductive, clay. We then encapsulated the clay around a 1/2" diameter, 6-inch long copper rod, and then tightly wrapped it with cotton cloth to allow water permeation and conduction between the clay and the water when submerged. We prepared the clay mix with a conductivity of 5 microsiemens per centimeter (μS/cm) which approximates the resistance of human appendages such as arms and legs. Once formed, we wrapped each electrode with colored electrical tape for identification purposes, and temporarily wrapped it in aluminum foil to maintain the moisture level during transportation and set-up. The team removed the foil prior to submerging the electrodes on the sensor array frame.

During assembly, we soldered a short length of 12 American Wire Gauge (AWG) stranded copper wire to the copper rod within each electrode. For each electrode pair, we joined electrode wires to separate conductors of a shielded, commercially available, underwater-rated electrical cable (three-conductor, shielded, shipboard cable (TSS)-2, 18 AWG stranded copper). Electrode pairs shared a single signal cable to minimize interference from external sources during testing. Figure 2 shows an input electrode.

Figure 2. Input electrode.

2.2.1.2   *Configuration of Electrode Sensor Array*

We configured a frame to mount the electrode sensor array, fabricating the frame out of 10' lengths of 2" white polyvinyl chloride (PVC) pipe and 5-foot lengths of 2" x 4" lumber. We lashed the vertical PVC pipes to the horizontal lumber supports using heavy-duty black nylon tie-wraps, spacing and positioning these wooden horizontal supports to provide secure mounting points to the railing of the test vessel and to maintain the sensor depths required for the experiment. We lashed the bottom end of the vertical pipes to a horizontal section of PVC pipe using heavy-duty black nylon tie-wraps, with all lashings reinforced with several wraps of duct tape.

We mounted six electrodes to the frame to create three pairs of electrodes as seen in Figure 3 and Figure 4. We attached the cloth-wrapped, salinated clay electrodes to the vertical pipes of the frame using waterproof electrical tape along with nylon and Velcro® tie-wraps to provide extra security, and wrapped with colored electrical tape (yellow, red, and blue) to provide ease of identification for each pair of electrodes: yellow 4-foot horizontal separation, blue 2-foot vertical separation, and red 4-foot vertical separation. These dimensions were selected to simulate the relative separation between hands, feet, and torso of an unconscious PIW wearing a Type I personal floatation device (PFD). We routed and secured the electrode signal leads along the PVC pipes and connected them above the water line to the data acquisition system input cable.
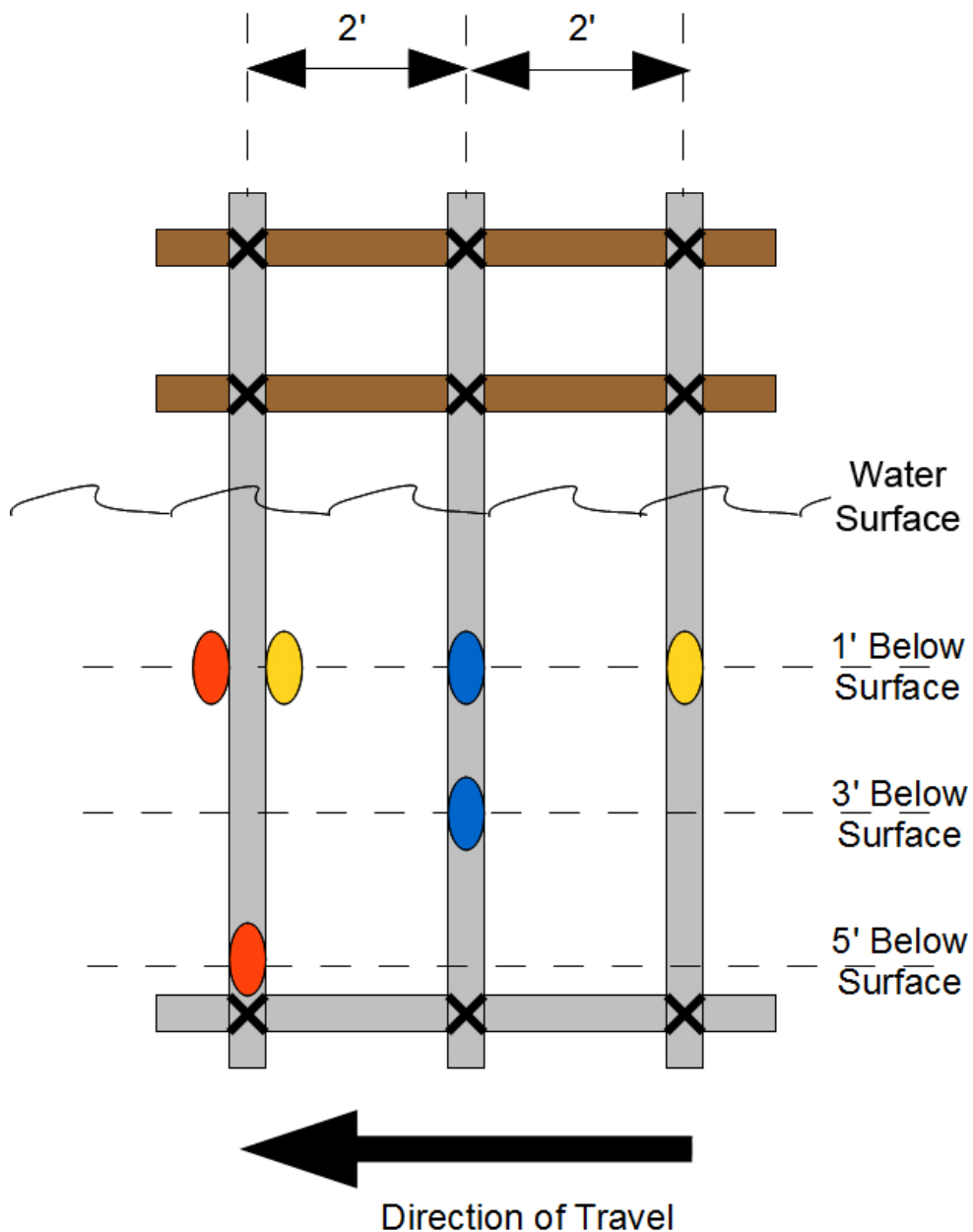
Figure 3. Configuration of electrode sensor array with color-coded electrode pairs.
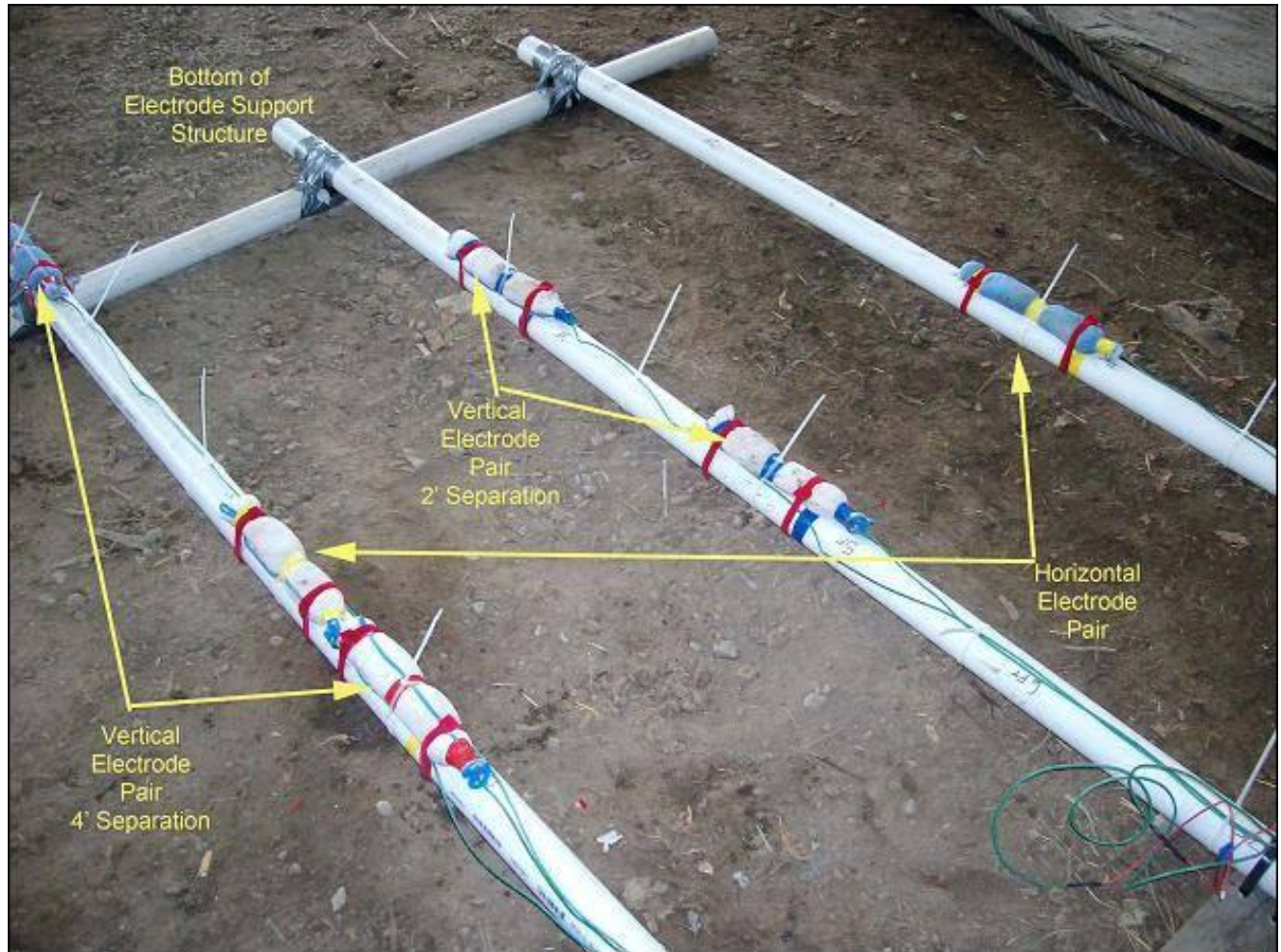
Figure 4. Electrode installation on sensor frame.

We carried the array on the deck of the test vessel and only deployed it into the water upon arriving at the survey area. We mounted the deployed sensor array to the test vessel railing using bungee cords (Figure 5). During the survey, the probe frame proved to be quite robust and stable at the typical range of survey speeds of up to 3 mph. Upon completion of each test day, we retracted the electrode array from the water and stowed it on deck for transit back to the L&R facility at Lemont.

2.2.2   Electrical Sensing and Recording

The data acquisition collection system included a Dell D520 laptop computer, a 4-channel analog-to-digital (A/D) converter, high-voltage differential probes, measurement resistors, and input electrodes. Figure 6 depicts a top-level block diagram of the data acquisition system. We wired the input electrodes installed on the array frame to the data acquisition system inputs via submersible electrical cables. We used the electronics, which were housed in a weather-proof case, to sample, digitize, and store collected data onto the laptop hard drive for real-time monitoring, playback, and analysis.

Figure 5. Installation of probe frame on test vessel.
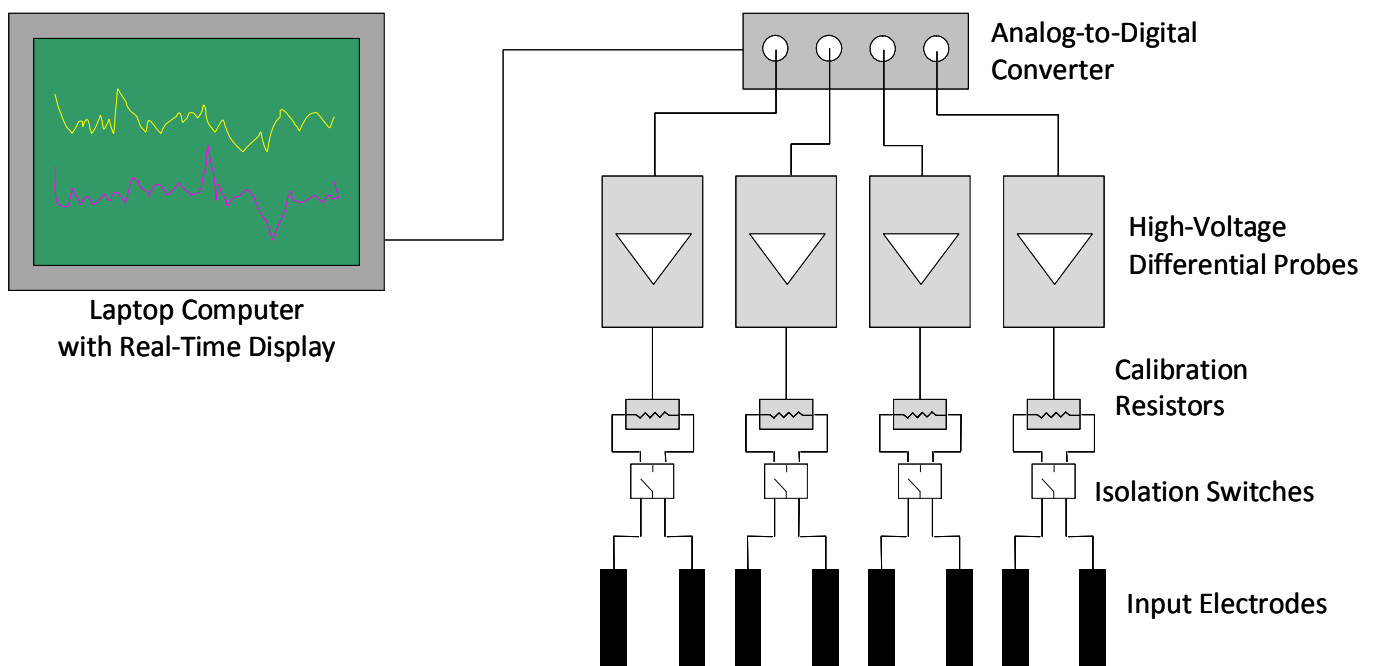
Figure 6. Electric field recording system block diagram.

We wired three-pole, double throw switches to the input side of the test box to enable the user to completely disconnect and isolate the test box from electrodes in the water if required for testing or system reconfiguration. We used these switches between test condition set-ups, and they were necessary during troubleshooting of the system while deployed. We used Tektronix P5200 High-Voltage Differential Probes for each channel of measurement for voltage stepdown and circuit protection and personnel safety. Each P5200 contains optical isolation circuitry that prevents excessive voltages on the signal side of the unit that could damage the low voltage circuits on the recorder. This protection was necessary due to the high voltages produced by the barriers. The P5200s were powered by a 9 volts direct current (VDC) supply and were configured for a 1:50 stepdown rate.

We measured voltage levels across commercial high-power resistors of a nominal 100 ohm resistance. The high power rating (100 watts) allowed safe use and substantial power dissipation when exposed to high voltages from the barrier. We wired the measurement resistors in series with the input electrodes. We prepared a set of current-sense devices powered by a 12 VDC supply in the event that the 1:50 high-voltage probes did not allow sufficient dynamic range to capture sensed electrical current. We did not use these current sensors for data collection during the test period. Figure 7 shows the measurement test box; Appendix A provides an electrical schematic.
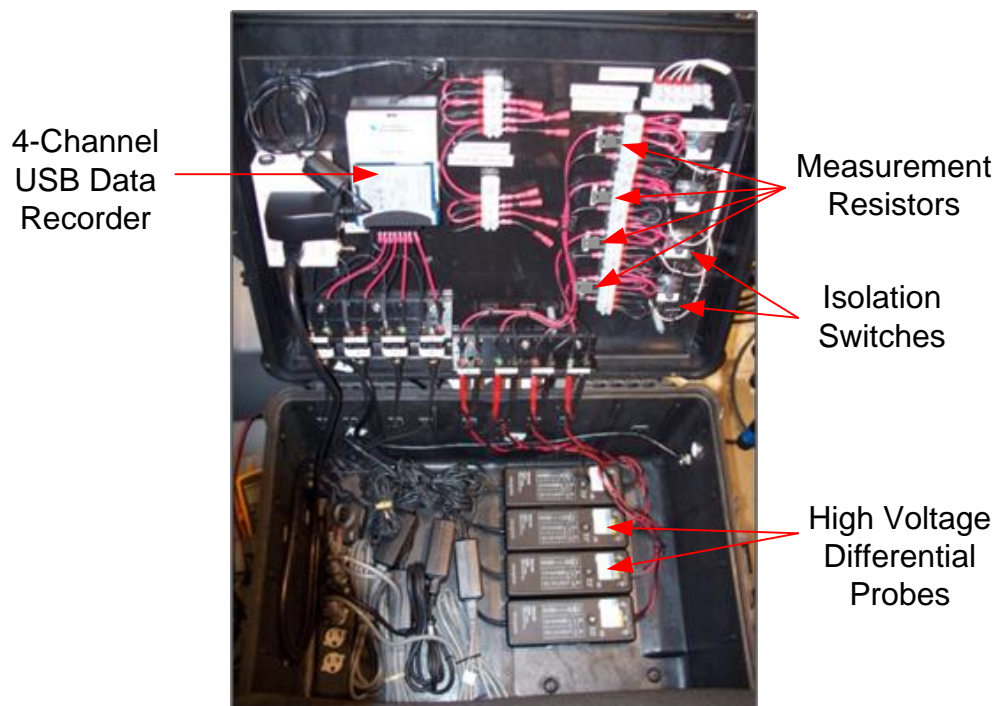
Figure 7. ShockWave test box physical set-up.

We wired the signals for each sensor to individual channels of a differential input, 4-channel National Instruments USB-9215A universal serial bus (USB)-powered A/D unit, which digitized the data at a 10 kilohertz (kHz) sampling rate and transmitted the digital data to the laptop computer. We equipped the laptop computer with customized automated signal processing LabVIEW™ software that received the data and formatted it for storage in a binary file format on the laptop hard drive. Data were continuously sampled and stored at 5-minute periods for all test conditions. We programmed the recording system to

autonomously record data for a continuous 5-minute period throughout the testing period. We saved data files in a time-tagged format to allow reconstruction with the vessel positional information. Section 2.3 describes details of each recording period.

2.2.3   Position Instrumentation

Portable GPS receivers with built-in data logging capabilities provided positional information during periods of data collection. We used two units to periodically record test vessel position as a function of time, one unit as the primary, and the other as a backup. We staged GPS units on the rear deck of the test vessel immediately adjacent to the sensor probe array (see Figure 8).

Figure 8. GPS receiver and logger on aft deck of test vessel.

During the survey, two onboard GPSs continually and simultaneously recorded the test vessel position at a rate of approximately 10 to 12 times a minute. Data recorded by the GPS included: latitude (DD.DDDDDD format), longitude (DD.DDDDDD format), date (ddmmyy), time (hhmmss) relative to Greenwich Mean Time (GMT), vessel speed (mph) and vessel track (degrees magnetic), and other data. Table 2 shows the basic recording format with a segment of run data from 18 November testing. We computed positional graphs of test vessel transects each run day for each test condition and time-synchronized them to the recorded electric field data.

Table 2. GPS data recording format.

Fix	Latitude (N)	Longitude (W)	Time	Date	Speed	Vessel Track	Altitude	HDOP*	Satellites
D	41.64565	88.05968	154222	181110	2.1	006	587	1.2	10
D	41.64568	88.05967	154226	181110	2.2	007	587	1.2	10
D	41.64572	88.05967	154230	181110	2.2	008	587	1.3	9
D	41.64577	88.05965	154236	181110	2.2	005	587	1.4	10
D	41.64582	88.05965	154240	181110	2.2	003	587	1.1	10

*horizontal dilution of position

The GPS latitude and longitude data acquired during each survey were synchronized in time with the recorded electrical data files, and plotted in ArcView over satellite imagery.

2.2.4   Test Vessel

The test vessel (Figure 9) was approximately 26 feet in length, and equipped with a cabin and rear work deck with safety railings. As previously described, we mounted the test electrode array outboard on the aft starboard rail, and routed waterproof electrical cables with electrical sensor signals from the electrodes to the recording sensing and recording equipment located in the vessel cabin. The test vessel's aluminum hull provided reliable electrical continuity to the water in the canal. We did not determine the specific electrical path from the topside grounding location to the water via the hull.

2.2.5   Ancillary Data

USACE Barrier Data Logs

USACE personnel at each barrier logged operational conditions of each barrier, including the voltage and current output levels of each barrier, and conductivity measurements of the water in the canal. Appendix B provides summary values of the barrier operating conditions during the test days for Barrier I (demonstration barrier) and Barrier IIA.

2.2.5.1   Conductivity

We used a commercial hand-held conductivity meter and probe to measure the electrical conductivity of the water in the canal each test day. Table 3 shows measured values which were taken over the side of the test vessel outside the electrified zone near the pipeline arch, at the water surface. Water conductivity differed slightly each day, and values agreed within a few percentage points. Measured values were approximately 20 percent higher (more conductive) than those logged by USACE personnel taken at the same time. The reason for this difference is not presently known.

Figure 9. L&R test vessel.

Table 3. Canal conductivity.

Date (2010)	Time	Measured Conductivity (µS/cm)	Conductivity from Barrier IIA Logs[1] (µS/cm)
17 November	07:30 AM	958	779
17 November	16:20 PM	995	783
18 November	08:09 AM	1010	777
19 November	12:48 PM	979	794

[1]Logged at approximately the same time as the measured values.

2.3   Data Collection and Analysis

We performed all testing in accordance with the experiment test plan (Reference 7). Table 4 provides a summary of the test conditions conducted, and start/stop times for each condition.

Table 4. Test condition log.

Test Condition	Test Condition Description	Start Date/Time	Finish Date/Time
1	Free-field current	11/17/2010 2:49 PM	11/17/2010 4:16 PM
2	Rescue vessel recovery touch point current	11/18/2010 9:13 AM	11/18/2010 10:39 AM
3	Shore recovery touch point current	11/18/2010 11:30 AM	11/18/2010 12:45 PM
5	Free-field current, dry suit	11/19/2010 8:54 AM	11/19/2010 10:55 AM
6A	Life ring throw, poly line	11/18/2010 13:12 PM	11/18/2010 13:22 PM
6B	Life ring throw, nylon line	11/18/2010 13:33 PM	11/18/2010 13:45 PM
6C	Life ring throw, non-conductive rescue hook	11/18/2010 13:53 PM	11/18/2010 2:10 PM
7	Surface voltage survey	11/19/2010 11:44 AM	11/19/2010 12:07 PM

Note: Test Condition 7 was identified in Reference 7 as an optional condition, but was not given a specific test condition number. It is therefore designated Test Condition 7 herein.

We conducted time-series analysis for each test condition, correlating specific maximum current (or voltage) events to a given test condition. We analyzed data recordings in back-to-back 5-second long periods, synchronizing results with the GPS positional data using Microsoft® Office Excel® and MATLAB® functions. For each 5 second period, we determined the peak voltage across each calibration resistor by locating the absolute value of the single sample with the highest magnitude within that period. In general, this single peak occurred at the "top" of the pulsed waveform, and occurred with both positive and negative polarity, depending on the location of the test vessel with respect to the pulser electrodes. In addition, we computed the root mean square (RMS) amplitude of each 5 second period to establish the average current measured through each resistor during the period. We computed electrical currents using Ohm's Law by dividing the measured voltage across each calibration resistor and dividing by the known resistance (100 ohms).

The measurement environment was very noisy from an electrical perspective. Several times during the experiment period, we intermittently observed external sources of electrical or radio frequency (RF) energy in the recorded data. Because the pulsed energy from the barriers provided a highly recognizable waveform, we were able to edit the suspected interference patterns from the data and did not process them for peak or RMS data results.

For five test conditions, this report provides graphical charts that show the data results, and indicate the measured electrical current to human threshold sensitivity with a colorized scale.

Published human sensitivity data for electrical current were not available for the frequencies produced by the barrier pulsers (5 Hz and 15 Hz). Therefore, we analyzed human sensitivity to 60 Hz alternating current (AC) current following the human responses as described in the Navy Experimental Diving Unit (NEDU) report (Reference 4) to approximate the expected response. In all cases, the peak currents are shown, which provides a more conservative (i.e., "safer") estimate compared to the average or RMS current for the same test condition.

2.3.1 Test Condition 1: Free-field Current

The objective of this test was to measure the electrical current flowing through the chest area of a PIW exposed to electric fields immersed in the CSSC. This condition simulated a PIW, wearing a Type I PFD, with outstretched arms, and hand-to-hand separation of 48 inches, hands in the water. Data from this condition verified voltages between electrodes from earlier USACE testing, and provided confidence that the instrumentation was working correctly. Measured levels parallel with the canal varied substantially as the test vessel transited across each barrier. Measured data did not vary significantly across the canal (center of the canal to the canal wall).

We observed significant electrical currents in this test condition. Electrical current flow varied with electrode separation because a wider probe separation provided a larger voltage gradient between electrodes. The maximum current measured occurred horizontally along the direction parallel to the canal axis, with peak levels of 380 milliampere (mA) (see Table 5). Figure 10 shows the peak free-field electrical current between horizontal electrodes, 48 inches apart, oriented parallel to vessel track. Maximum vertical levels measured were 184 mA with a 48-inch vertical electrode spacing, which simulates the position of a person in the same orientation, and with wetted feet and neckline, submerged below the water surface. We observed maximum levels adjacent to Barrier IIA, which was the expected result due to the higher voltage levels produced by this barrier in comparison with the levels produced by Barrier I (the demonstration barrier).

Table 5. Test condition 1.

Test Point/ Channel ID	Test Point Description	Peak Current (mA)	Location (Latitude, Longitude)
A_0	Channel 1, free field current, 48" spacing, vertical	184	41.64128, -88.06015
A_1	Channel 2, free field current, 24" spacing, vertical	129	41.64128, -88.06015
A_2	Channel 3, free field current, 48" spacing, horizontal	380	41.64128, -88.06042
A_3	Channel 4, terminated into 100 ohms, reference noise, cable on deck	0.2[1]	41.64128, -88.06042

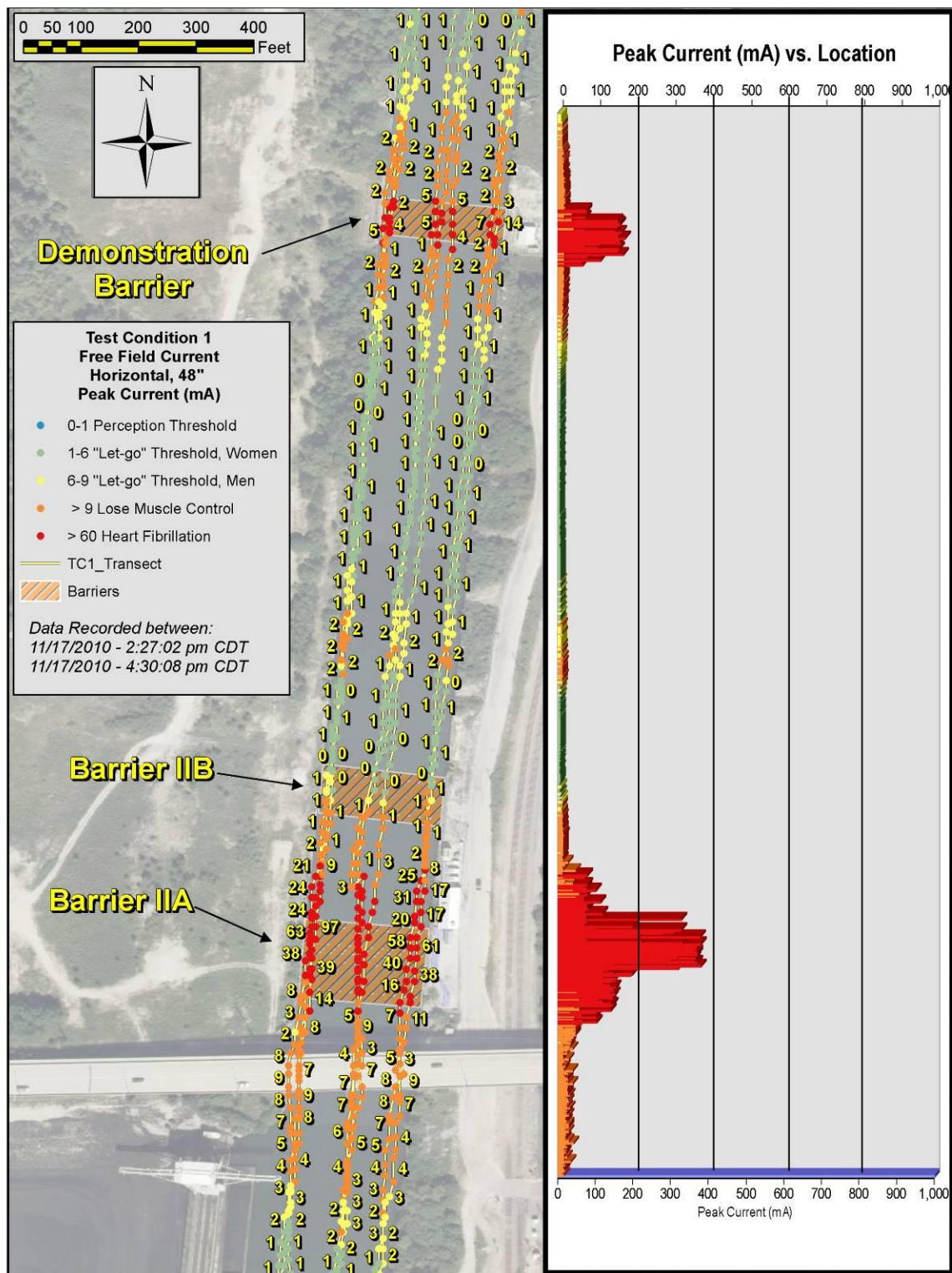[1]RMS current noise, not peak value. Channel used to assess system noise floor.

Figure 10. Peak free field electrical current (mA) between horizontal electrodes, 48 inches apart, oriented parallel to vessel track.

2.3.2 Test Condition 2: Rescue Vessel Recovery Touch Point Current

The objective of this test was to measure the electrical current flowing through the touch point of a rescuer on an aluminum boat, in contact with a floating PIW, with a current path through the rescuer's body, returning to the canal water through the aluminum hull of the test vessel. As in Test Condition 1, we observed significant electrical currents in this test condition. The maximum current measured in this condition was 973 mA in the vicinity of Barrier IIA (see Table 6), or nearly 1 ampere (amp) of current by grasping a floating PIW while the simulated rescuer is grounded to a metallic hull. Figure 11 shows the peak current flowing from a PIW in direct contact with the metallic hull of a rescue vessel. This test condition demonstrated that significantly higher electrical currents can be generated if a rescuer touches a metallic object electrically connected to the canal and then makes contact with a well grounded PIW. Furthermore, this test showed that the PIW should not be directly touching the hand of a rescuer on an aluminum boat. For this test, we executed a several transects through the center of the barrier zone and along both sides.

Table 6. Test condition 2.

Test Point/ Channel ID	Test Point Description	Peak Current (mA)	Location (Latitude, Longitude)
A_0	Channel 1, vessel touch point current, 72" deep	703	41.64133, -88.06012
A_1	Channel 2, vessel touch point current, 36" deep	823	41.64127, -88.06013
A_2	Channel 3, vessel touch point current, 12" deep	973	41.64133, -88.06012
A_3	Channel 4, terminated into 100 ohms, reference noise, cable on deck	0.2[1]	41.64133, -88.06012

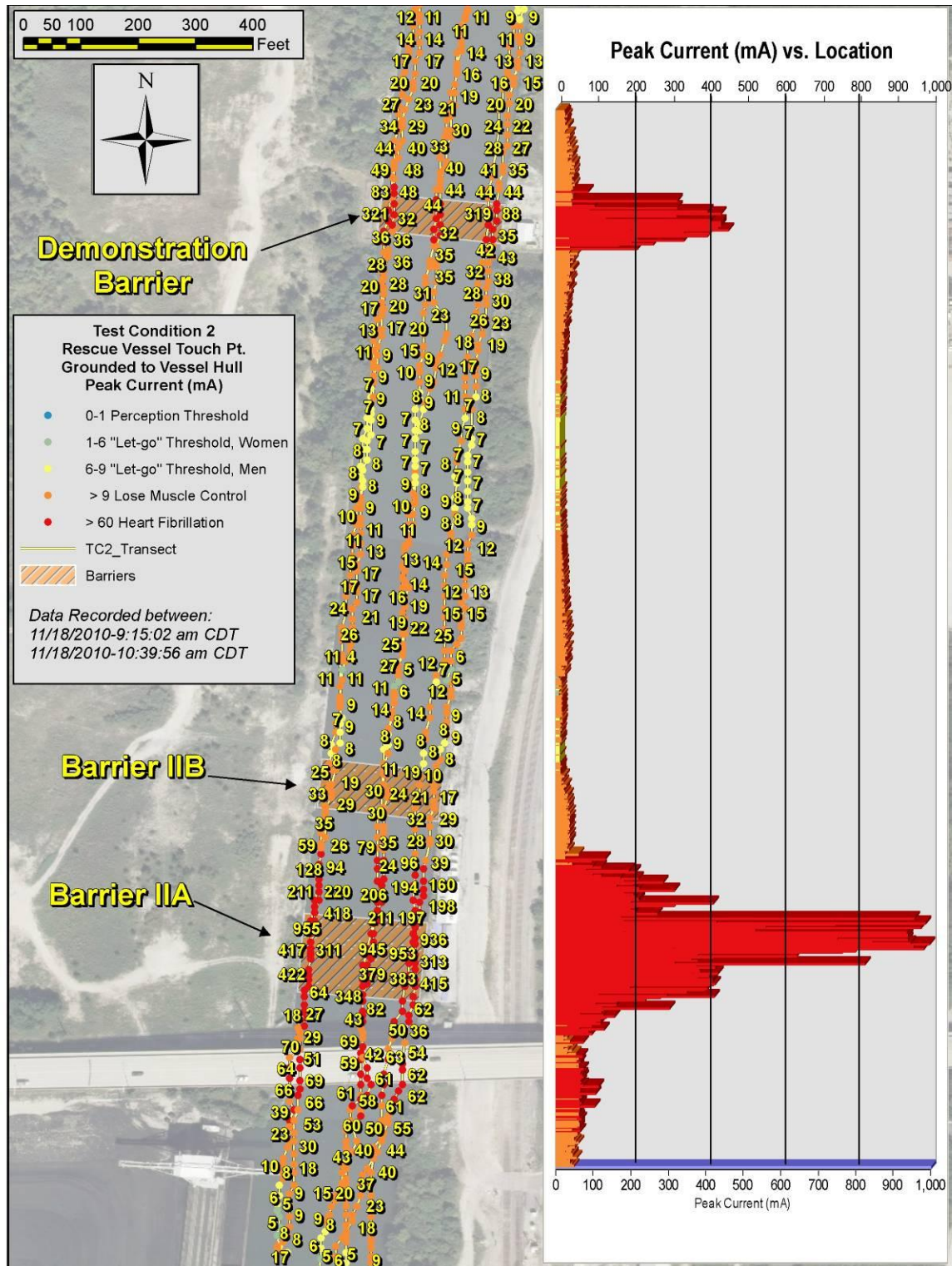[1]RMS current noise, not peak value. Channel used to assess system noise floor.

Figure 11. Peak rescue vessel touch point electrical current (mA) between simulated PIW and simulated rescuer on an aluminum boat.

2.3.3   Test Condition 3: Shore Recovery Touch Point Current

The objective of this test was to measure the maximum current flow from a floating PIW to a grounded rescuer on the canal wall, with a current path from the PIW to the rescuer, then returning to the barrier via a conductive path through the ground. We implemented this test condition with open cell sponges with intimate electrical contact with an input electrode wired to an in-water electrode to simulate a rescuer in contact with the canal wall, grasping a simulated PIW. A non-conductive PVC pole held the simulated rescuer electrode (see Figure 12) such that the test engineer could hold the electrode against the canal wall during recording while the test vessel operator maneuvered the test vessel near the wall.

Because of the difficulty in holding position, we had to limit data cuts to 30 to 60 seconds in each location. We surveyed a total of 11 locations for touch point current, all of which were in the "hot zone" of Barrier IIA. At each location, the test engineer held the sponge electrode submerged near the wall to get an in-water baseline reading and to fully saturate the electrode, then he raised it from the water and held it against the canal wall approximately 18" above the waterline, finally releasing it and holding the electrode aloft (in the air). Thus, for each location, we established three data points: (1) electrical current flow with electrode in the water, (2) electrical current flow with electrode placed on the canal wall, 18" above the waterline, and (3) electrical current flow with electrode in-air; e.g., no contact with PIW or the water. Table 7 summarizes typical results, where the highest canal wall current flow readings were obtained. At this location, maximum current flow with the simulated rescuer on the wall with contact with a PIW was 41 mA. The nominal quiescent current with the probe in the air was approximately 0.14 mA (RMS). Figure 13 shows the test engineer equipped with the sponge electrode and pole apparatus.

Figure 12. Input electrode wrapped with open cell sponge.

Table 7. Test condition 3 highest peak currents.

Test Point/ Channel ID	Test Point Description	Peak Current (mA)	Location (Latitude, Longitude)
A_0	Channel 1, touch point current, 100 ohms load, electrode in water	349	41.641320, -88.059880
A_0	Channel 1, touch point current, 100 ohms load, electrode on canal wall, 18" above waterline	41	41.641450, -88.060430
A_0	Channel 1, open circuit current, 100 ohms load, electrode in air	0.14[1]	41.641450, -88.060430

[1]RMS quiescent current, not peak value.

Figure 13. Preparing for canal wall touch point current with pole and sponge electrode.

2.3.4   Test Condition 5: Free-field Current, Dry Suit

The objective of this test was to measure the electrical current flowing through the chest area of a simulated, dry suit-clad PIW exposed to electric fields while immersed in the CSSC. The test apparatus for this test condition included simulated human input electrodes, but located within and attached to a commercial dry suit with enclosed feet. To measure the dry suit's ability to provide some level of electrical protection to a suited PIW, we placed electrodes to simulate hands in the water, with the exposed neckline/head in the water and the feet enclosed inside the dry suit. The dry suit was completely sealed against water intrusion at the neck and wrists. Figure 14 shows the dry suit apparatus used for this test condition.

Figure 14. Dry suit test apparatus mounted to sensor array frame.

The maximum current noted through the simulated PIW in this condition was 20 mA, which was measured in the vertical direction (wetted head/hand-to-dry foot). This does not represent the maximum possible exposure to a dry-suited person, which in this case would be hand-to-hand. We did not conduct horizontal testing between head/hand-to-foot or hand-to-hand. Because not all possible conditions were evaluated with the dry-suit condition, no specific results were noted for this test condition.

2.3.5   Test Condition 6: Life Ring Throw

Test Condition 6 evaluated possible electrical circuit paths to a rescuer pulling a PIW to the test vessel or the shore using a soft line or non-conductive rescue hook. This test condition modeled a PIW who was floating in the water, with a pole or line in direct contact with both the PIW and the rescuer. The simulated rescuer was grounded to the test vessel aluminum hull. We modeled the PIW by affixing an input electrode to simulate a low-resistance body in the water to the recovery line/pole, and then to a life-ring to keep the apparatus near the surface. Electrical conductivity simulating the PIW was maximized by wrapping the electrode with aluminum foil. See Figure 15. The test vessel then towed the simulated PIW behind it (see Figure 16) through the electrified zone. We conducted a single transect for each of three test conditions (polypropylene line, nylon line, and non-conductive rescue hook) because side-to-side variability of the measured field was not significant as shown in Test Conditions 1 and 2.

Figure 15. Simulated PIW with input electrode and life ring.

Figure 16. Test vessel towing life ring and simulated PIW with polypropylene recovery line.

2.3.5.1   Test Condition 6A: Polypropylene Line

A commercially available life-ring rope bag (Stearns part number #I023ORG-00-000) with a 3/8-inch open-braid polypropylene line served as the test line for this condition. We submerged the rope prior to the test to ensure it was as wet as possible during the electrical current testing. The test vessel towed the simulated PIW and life-ring assembly approximately 30 feet (Figure 16) behind it. A length of the polypropylene line approximately 15 feet in length was out of the water during the tow, simply due to the light weight of the line. We grounded a 100-ohm calibrated resistor to the test vessel hull with a grounding wire and screw to simulate the current path for the rescuer. We tied off a dry section of line to the aft deck rail of the test vessel to provide electrical isolation of the towed apparatus (see Figure 16). Results from this test showed that peak electrical currents to the rescuer were not observable above the RMS background electrical noise of approximately 0.2 mA, or peak noise of less than 1 mA (see Figure 17 and Table 8 (below)).

2.3.5.2   Test Condition 6B: Nylon Braid Line

A commercially available nylon-braided dock line (West Marine part number 597239), 5/8-inch diameter, double-braid, served as the test line for this condition (see Figure 18). We submerged the rope prior to the test to ensure it was as wet as possible during the electrical current testing. We assembled the simulated PIW and rescuer as described for the polypropylene line described above.

Unlike the polypropylene line, the nylon-braided line easily retained water and sank when unattended (see Figure 18). We deployed this line while the test vessel was moving to avoid fouling the line in the propeller. Due to the entrained water in this line, results from this test showed that peak electrical currents to the rescuer could be observed at a maximum level of 1.2 mA when transiting over Barrier IIA, which was just slightly above the background RMS noise of 0.3 mA (see Figure 19 and Table 8 (below)).
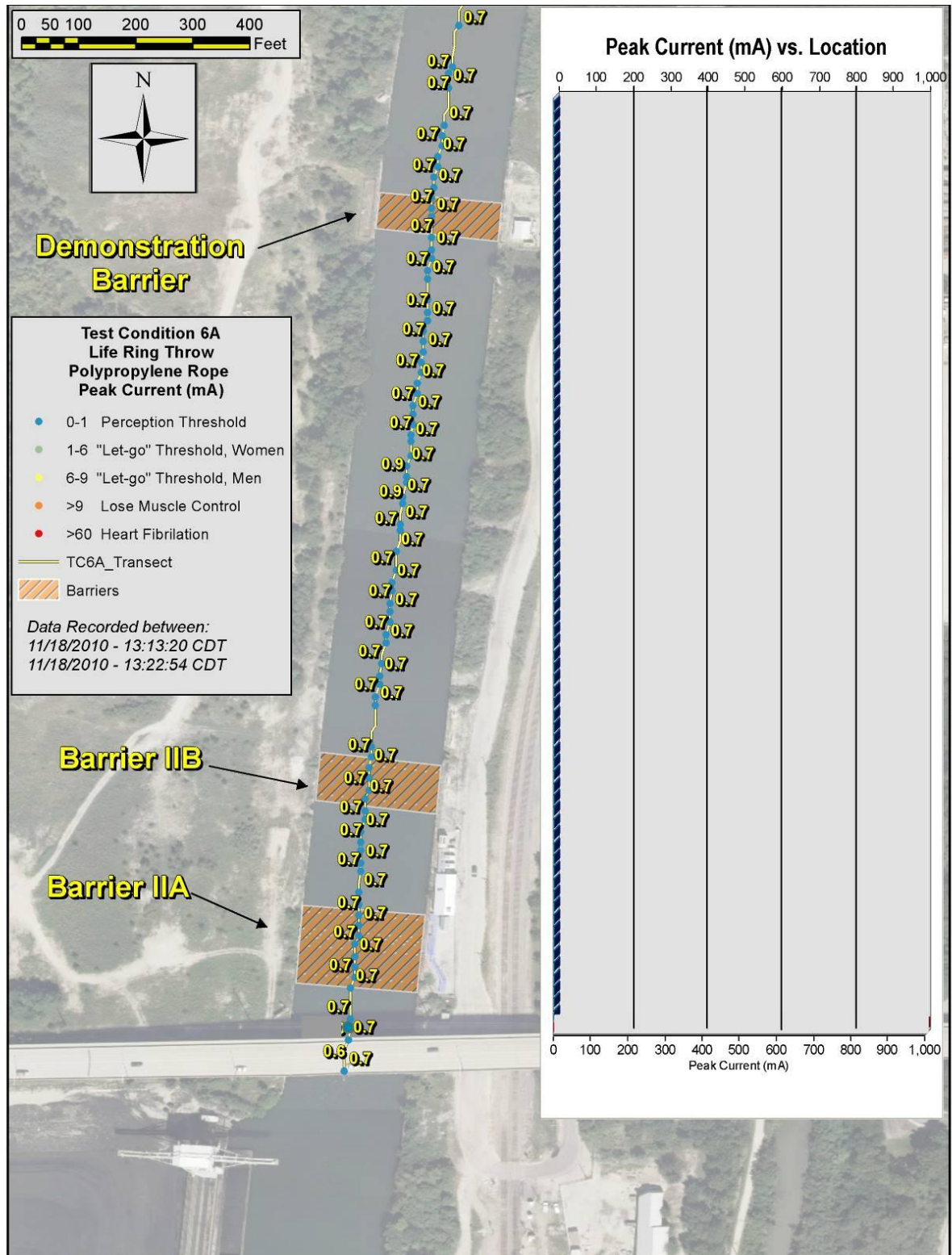
Figure 17. Peak electrical current through polypropylene line to rescue vessel.

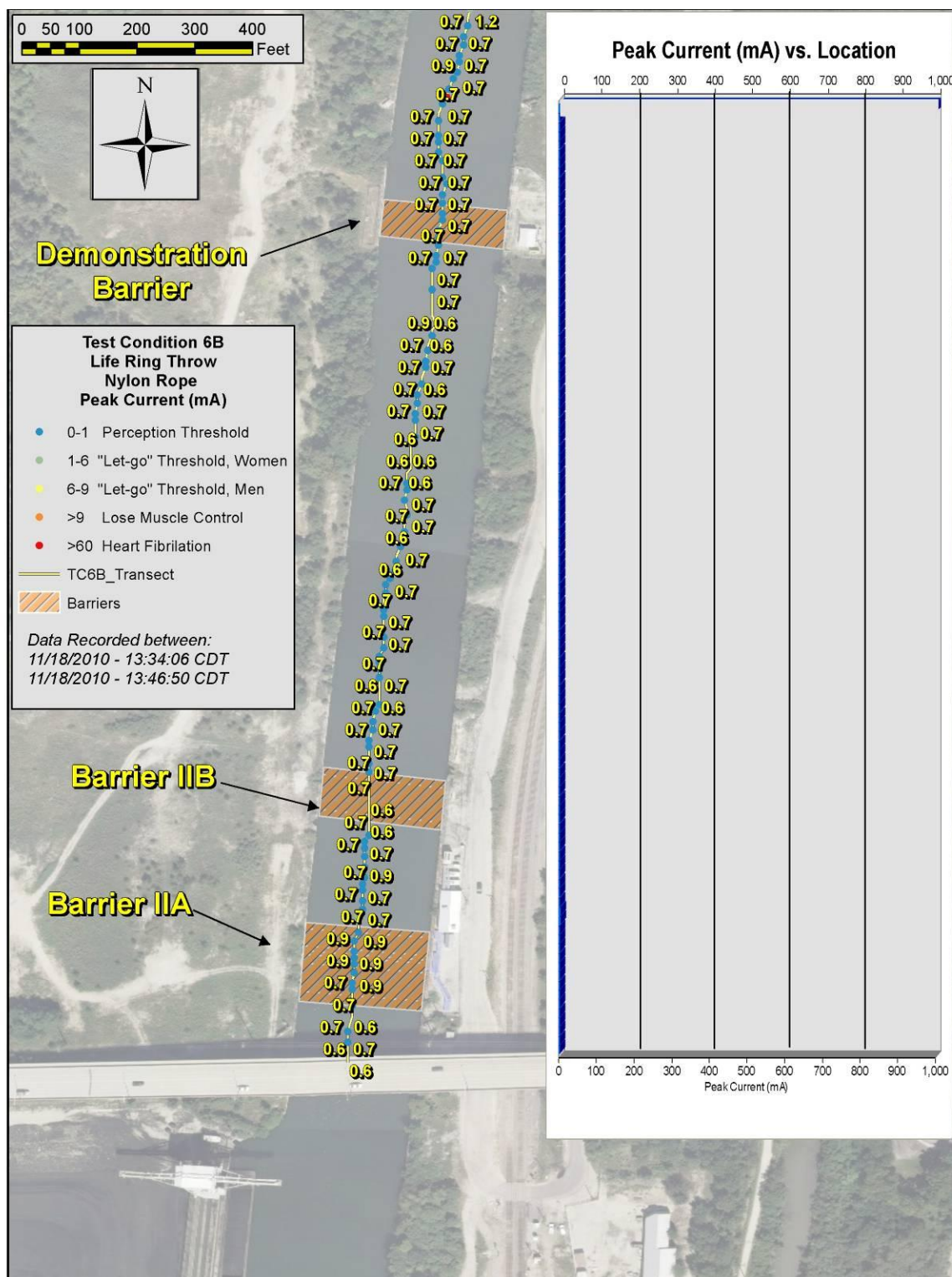Figure 18. Life ring deployment with nylon double braid recovery line.

Figure 19. Peak electrical current through braided nylon line to rescue vessel.

2.3.5.3   Test Condition 6C: Insulated Body Rescue Hook

A commercially available non-conductive rescue hook (Salisbury part number 24403) with an insulated fiberglass handle served as the recovery hook for this condition. We dipped the recovery hook in the water to ensure that the surface of the handle was as wet as possible during the electrical current testing. We wrapped an input electrode around the hook to provide solid electrical contact with the simulated PIW, the water, and the end of the rescue hook. We then electrically connected the handle end (the boat end) of the hook to the hull of the test vessel to simulate a rescuer grounded to the test vessel aluminum hull to complete the electrical circuit. We then connected the hook to the life-ring to keep it near the surface. The test vessel then towed the hook and life-ring through the electrified barrier. Figure 20 shows the test vessel towing the rescue hook apparatus.

Results from this test were similar to those with the polypropylene braided line. We did not observe any peak electrical currents to the rescuer above the RMS background electrical noise of approximately 0.2 mA, or peak noise of approximately 1 mA (see Figure 21). The peak background noise levels for this test condition were slightly higher (1 mA vs. 0.7 mA for Test Conditions 6A and 6B), which was indicative of higher background noise of this electrical test setup. Pulsed waveforms were not observed above background noise in this test condition.

Figure 20. Test vessel towing life ring and simulated PIW with non-conductive rescue hook.
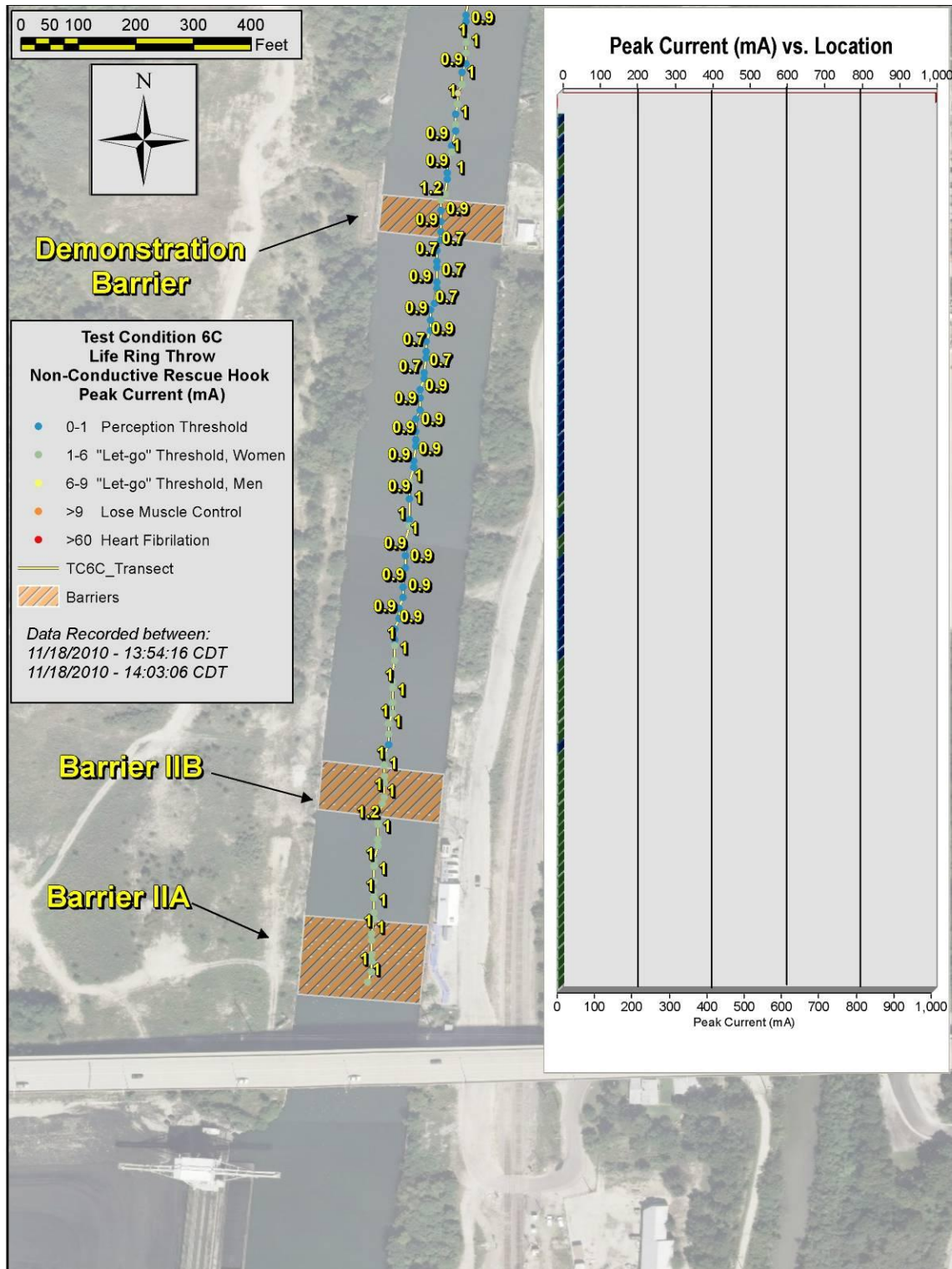
Figure 21. Peak electrical current through non-conductive rescue hook to rescue vessel.

Table 8 summarizes the results of Test Condition 6. Minor electrical currents were seen with a soaked braided nylon line, but produced peak currents of approximately 1.2 mA. Peak current while towing a simulated PIW from the vessel did not produce any measurable data above the background noise levels for either the polypropylene line or non-conductive rescue hook scenario.

Table 8. Test condition 6.

Test Point/ Channel ID	Test Point Description	Peak Current (mA)	Location (Latitude, Longitude)
A_0	Channel 1, touch point current, polypropylene line, Test Condition 6A	0.7[1]	41.64133, -88.06012
A_0	Channel 1, touch point current, braided nylon braid line, Test Condition 6B	1.2[2]	41.64127, -88.06013
A_0	Channel 1, touch point current, non-conductive rescue hook, Test Condition 6C	1.0[3]	41.64128, -88.06012

[1]Peak level of background current noise. No electrical pulses measured. RMS noise level in this condition was 0.2 mA RMS.

[2]Peak level of maximum pulses detected while over Barrier IIA. RMS noise level for this test condition was 0.3 mA RMS.

[3]Peak level of background noise. No electrical pulses measured. RMS noise level in this test condition was 0.2 mA RMS.

2.3.6 Test Condition 7: Open Circuit Voltage

The final test condition evaluated the open circuit voltages in the horizontal and vertical direction. We removed 100-ohm measurement resistors from the test box, allowing direct measurement of the open circuit voltages between electrode pairs. The primary objective of this test was to provide USACE a "quick look" of the levels and waveforms as a result of the recently installed parasitic barriers. Due to time constraints, we did not take an exhaustive set of transects in this test condition. Table 9 provides results of maximum conditions observed. As expected, we saw the strongest field in the direction parallel to the canal, with maximum levels of 87.6 volts noted, which equated to an electric field gradient of 1.82 volts/inch near the water surface. In the vertical direction, we noted a voltage of 36.7 volts, corresponding to a field gradient of 0.76 volts/inch. Results obtained for Test Condition 7 (open circuit voltages) were very similar to those measured for Test Condition 1, free-field conditions for the same 48-inch horizontal electrode spacing. The only significant test difference between these conditions was the use of a parallel 100-ohm resistor across the electrode pairs. Because the results were similar, this indicates that the barrier is able to drive a 100-ohm resistance without affecting the applied voltage level in the water.

Table 9. Test condition 7.

Test Point/ Channel ID	Test Point Description	Peak Voltage (V)	Filename
A$_0$	Channel 1, open circuit voltage, 48" spacing, vertical	36.7	11-19-2010 11.38 AM
A$_3$	Channel 4, open circuit voltage, 48" spacing, horizontal	87.6	11-19-2010 11.38 AM

2.4 Electric Currents and the Human Body

Electric currents can be described and their effects are explained well in the physical world. Electric currents traveling through wires, resistors, and capacitors, can be scientifically explained mathematically and demonstrated using modeling and simulation. Therefore, the effects of an electric current, and duty cycle, are easily tested and demonstrated using specific models allowing only the selected parameter to be changed over a range. This specific type model is not available when we look for specific answers concerning the effects of an electric current upon a human.

The NEDU study (Reference 4) makes this statement and it is worthy of repeating:

> The physiological effects of an electric current passing through a given individual's body depend on several variables: the duration, magnitude, and frequency of the current; the weight of the person; and the specific path the current takes through the body. The most dangerous consequence of such an exposure is the heart condition known as ventricular fibrillation, in which the blood immediately ceases to circulate.

The NEDU study also makes other important points concerning the effects of current on the human body. Please note that these effects are for alternating currents. It is also stated in the NEDU study that it is possible for the human body to tolerate "single shock" direct currents (DC) that are five times higher for a given physiological effect. The duty cycle of the barrier current may cause the effect to resemble something in between a direct current and an alternating current.

The NEDU study also states the following physiological effects to the human body with various levels of shocks due to exposure of 50 to 60 Hz AC RMS signals:

> ➢ "In order of increasing current, the most common physiological effects of electricity on the body are threshold of perception, muscular contraction, difficulty breathing, cessation of breathing unconsciousness, heart fibrillation, respiratory nerve blockage, and burning. The levels at which some of these effects occur are given below for 50-60 Hz AC:
> ➢ A 1 mA rms current is generally recognized as the threshold of perception, the level at which a person is just able to detect a slight tingling sensation in hands or fingertips.
> ➢ Currents of 1-6 mA rms (often called "let-go" currents), while unpleasant to sustain, generally do not prevent a person holding a charged object from being able to control his (or her) muscles and release it. For the 0.5 percentile population, 6 mA rms for women and 9 mA rms for men are the measured let-go threshold values.

➢ Currents of 9-25 mA rms may be painful and may make it difficult or impossible for the hand to release energized objects it has grasped. For still higher currents, muscular contractions could make breathing difficult. The effects of 9-25 mA rms currents usually are not permanent and disappear when these currents are removed, unless contraction is very severe and breathing is stopped for minutes rather than seconds.

➢ Currents of 60-100 mA rms can cause ventricular fibrillation, heart stoppage or cessation of respiration – and result in permanent injury or death."

Charts shown within this report are colorized to show human effects commensurate with those noted above from the NEDU study. It should be noted that these thresholds are stated for RMS shocks, not peak values.

The human body can and has been described in general terms as a huge resistor of about 500 ohms. The physical mathematical equations applied, and therefore answers, are only as valid as the general terms and the general model used. Why is this? First, we do not experiment with electricity on human beings – unless there is a potential benefit. We are, therefore, confined to the science of making scientific conclusions by extrapolation. The physiology of the human body causes each of us to react to various stimuli differently along a normal (Gaussian) distribution of reactions.

The point is simple. The interaction of the human with electricity is not an exact science. We cannot expect exact parameters; therefore, we must speak to electricity and the human interface with several standard deviations of safety because we are not sure who will withstand 100 mA and who will succumb to 1 mA of exposure delivered at the right time, and right conditions.

2.4.1   An Illustration

Three golfers are in a close group. Lightning makes an indirect strike (no direct hit) in their vicinity. Two of the golfers describe tingling (1-10 mA), the other drops dead. We can assume they each got about the same exposure. The "tingling sensation" felt by two of the golfers was caused by the same current that struck the third member at a critical period in his cardiac cycle and put him into ventricular fibrillation and arrest. This critical period of the cardiac cycle is during the electrical period called the "T" wave. This report must be concerned with the effects of small electric currents on the human being, so the authors are perhaps overstating for safety reasons that the same small "tingling" current delivered at a critical time could send a human into ventricular fibrillation and death.

2.4.2   Cardiac Physiology

The heart is made up of a special type of muscle. If left unattended, the muscle spindle will twitch (beat) at some regular rhythm. The group of muscles making up the atria and ventricles (upper and lower chambers of the heart) can be synchronized and perform work by an electrical stimulus passing through a set of fast conduction tissue (wires). Normally, the upper chamber (atrium) contracts, sending blood into the ventricles and simultaneously sending an electrical stimulus through a node to the ventricles which causes them to contract at just the right time to send blood into the body and lungs. When this electrical activity is recorded, it is called an electrocardiogram (EKG) and the waveform generated has several parts, with each representing something electrically happening in the muscle cell: contraction, relaxation, recharging, and a small moment of pre-excitement as it gets ready to receive the electrical signal to contract. The parts of this

pattern are called the p, q, r, s, and t waves of the EKG. These waves are the equivalent of the cell cycles of contraction, relaxation, and recovery to readiness of the cardiac muscle cells. The "t" wave represents a pre-excitement moment and the muscle is very susceptible to electric currents at that precise moment. If a very small current is applied at that moment, the cell shudders and causes other cells and muscles to shudder; this is called fibrillation. Small currents passed through the heart on the "t" wave can cause fibrillation and death. During fibrillation, each muscle cell is firing in an uncoordinated manner; therefore, no blood is being pumped from the heart. A very small current can cause fibrillation if it is conducted over a wire that is implanted in the heart such as a pacemaker wire and the spike hits on the "t" wave of the cardiac cycle.

Active defibrillation is necessary to convert fibrillation back to a physiological rhythm. Defibrillation generally takes larger voltages and currents. Defibrillation is an act of passing a strong-enough current across the heart that arrests all the cells, allowing the pacer cells to regain their supremacy and cause a normal rhythm to resume.

The studies we conducted within the barrier portion of the CSSC show currents and duty cycles that are capable of inducing cardiac fibrillation in a human being. This is especially true in the direct area of the barriers. However, the smaller currents recorded throughout the barrier zone are capable of causing fibrillation if the human being has an electrical wire such as a pacing cable implanted inside his or her heart. 1 mA may be sufficient to cause fibrillation if the current flows to the myocardium and arrives just at the time of the "t" wave in the cardiac cycle.

The common literature described in the NEDU study, and repeated for emphasis earlier in this report, describes tingling at 1-10 mA, 1-10 mA as "let go" currents, 9-25 mA as painful and muscular spasm, and 60-100 mA for ventricular fibrillation/cardiac arrest and death are most likely expressed at the mid portion of a Gaussian distribution of human beings. For safety and rescue planning, we must use the least possible danger level and circumstance and provide protection in the way of warnings and education for absolute protection for rescuers.

3   DISCUSSION OF RESULTS

Preliminary data analysis showed that significant electrical currents could be encountered within the electrified area of the CSSC and, without precautions, could endanger rescue personnel. Voltage levels in the barrier zone were of sufficient strength, and with a sufficient level of electrical current capacity to impart potentially harmful electrical currents to victims and rescuers alike based on expected human responses per the NEDU study (Reference 4). This condition is especially true while operating close to the barrier electrodes. Electrical hazards decrease with distance from the barriers.

Testing showed that use of non-conductive materials (e.g., polypropylene rope or rescue hook) to retain or tow a potential PIW resulted in very low electrical current through a simulated rescuer even in the most electrically active section of the barrier zone.

Electrical currents through a simulated rescuer when in contact with a simulated PIW were highest when in direct contact with the metallic hull of the rescue vessel. The metal hull provides a good grounding path for the electrical current, and successful rescue methods need to incorporate electrical isolation of the rescuer and victim alike from the hull via the use of non-conductive materials.

Electrical currents associated with a PIW in contact with the wall of the canal or a grounded simulated rescuer ashore were measurable, but were much lower in level than electrical currents either measured in contact with the aluminum rescue vessel or in a free-field. Through-the-body electrical currents were substantially higher with "hands in the water" compared with "hands on the canal wall." In other words, a PIW would be less exposed to electrical currents by placing hands on the canal wall or with an insulated rescuer ashore than they would by keeping them in the water at the same location.

4   CONCLUSIONS

In summary, the data obtained during 17-19 November 2010 at the CSSC provided insight into potential methods and apparatus that could be employed by rescuers to mitigate rescue risk and yet provide some degree of support to a PIW. The following are preliminary conclusions:

1. A human floating through the electrified zone would be subjected to potentially lethal, through-the-body electric currents that approach 1 amp. This would occur in the vicinity of the strongest electrical fields near Barrier IIA.
2. Exposure of simulated human electrodes to conductive canal water revealed that simulated wet human skin would not hinder electrical current flow. In other words, the electrical resistance of the simulated human body did not offer any protection against the flow of electricity.
3. Simulated human skin from a PIW in direct contact with the rescue vessel metallic hull is more hazardous than simply having no contact with the rescue vessel. Rescue methods need to isolate the PIW from metallic objects.
4. Polypropylene rope and a non-conductive body rescue hook were shown to conduct very low amounts of current to a simulated rescuer on an aluminum boat, and are potential rescue tools. Nylon braid, although not exhibiting a substantial amount of current, was not seen as a positive tool, due in part to the weight of the rope and its hydrodynamic behavior in water once soaked or submerged.
5. Touch point current with the canal wall showed that lower levels of current flow were observed compared to being in contact with the water directly. This result indicates that a PIW would be better off grasping the canal wall and being hauled out if conditions allowed compared with remaining in the water. This suggests that potential shore-side rescue may be viable, if such rescue could occur before the victim transits the "hottest" electrical zones. In such a scenario, the rescuer could use the rope and rescue hook to maneuver a victim away from the most dangerous zones to minimize risk to both the victim and the rescuer.
6. In general, non-conductive or resistive materials, such as rubber, plastic and fiberglass, are effective in reducing the electrical current risk to a rescuer, so long as the rescuers understand the electrical current paths and take precautions to avoid becoming part of the electrical circuit.
7. The location of the actual electric fields is not visibly apparent to anyone operating in the canal. Though the entrance and exit from the Safety Zone are marked (south of the bridge and north of the pipeline arch), there are no flags, signs, paint, or other markers to indicate the presence or strength of the electric field. Rescuers or PIWs may find it beneficial, even between Barriers I and II, to have immediately available visual indicators to know which direction to move to maximize safety, if conditions allow.

5 RECOMMENDATIONS

WARNING

Under no circumstances should a rescuer enter or immerse any part of their body directly into the electrified waters in the CSSC. A rescuer should not make contact with any PIW (in the electrified area) unless the rescuer is electrically isolated from the PIW. Any attempt at rescue in electrified water conditions is inherently hazardous. This report offers recommendations to *mitigate* hazards to rescuers, but acting on the recommendations will not *eliminate* them. Nothing in this report should be construed to imply that rescue in electrified water is anything but a hazardous undertaking.

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1. Do not, under any circumstances, permit a potential rescuer to enter the water or immerse any part of their body in the vicinity of the energized barriers. Use a non-conductive tether to prevent a rescuer from inadvertently entering the water, whether the rescuer is aboard a vessel or ashore.
2. When possible, use a non-metallic hulled rescue vessel for attempting rescue of a PIW in the barrier zone. If rescuers must use a metallic hull, do not allow the metallic hull to make direct contact with the PIW.
3. If unable to assist the PIW from a vessel, use a polypropylene throw-rope and life ring to reach the PIW from shore.
4. Use dielectric materials, including poly line, non-conductive rescue hooks, and lineman's gloves, to provide a safer means of making contact with a PIW. Use them to keep all rescuer body parts from making contact with the water or with the PIW while the PIW is in the electrified zone.
5. Use the dielectric materials to move the person out of the electrified zone as quickly as possible.
6. In conjunction with USACE and local first responders, develop special markings for the canal walls to delineate the areas within the barrier zone that allow a greater degree of rescuer safety than others.
7. Provide all potential responders a base level of electrical safety training that emphasizes circuit awareness, the risks associated with electricity and water, specific attention to variations rescue conditions in the CSSC electrified area, and deleterious effects of even extremely low currents on individuals with implanted electrical devices.
8. Keep an automated external defibrillator (AED) onboard or near-at-hand for any rescue operations.

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6   REFERENCES

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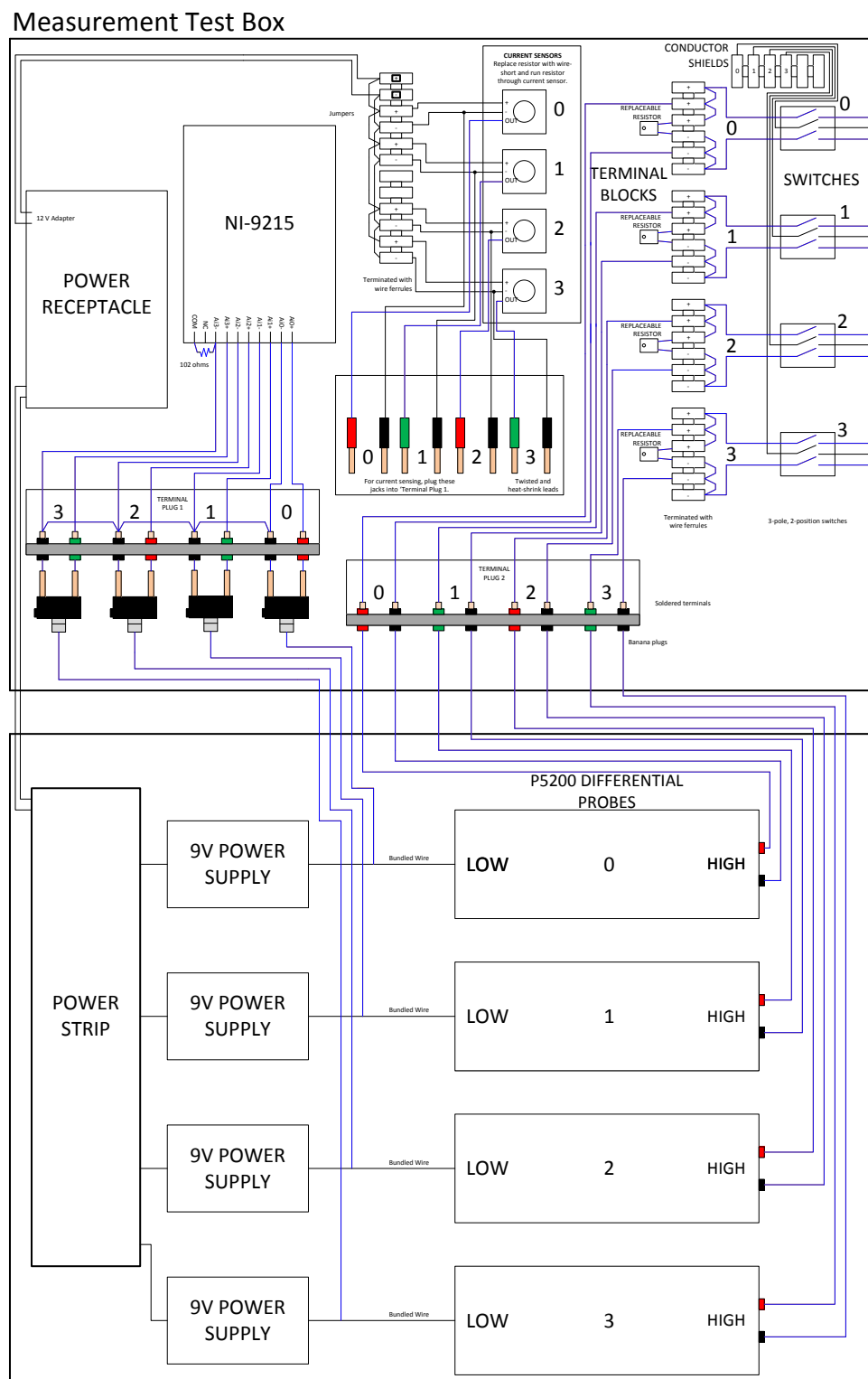
APPENDIX A   MEASUREMENT TEST BOX SCHEMATIC

Measurement Test Box

Figure A-1. Measurement test box schematic.

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APPENDIX B   BARRIER ELECTRICAL OPERATING PARAMETERS

Nominal electrical operating parameters are summarized in Table B-1 and Table B-2. Over the duration of the surveys (17-19 November 2010), the USACE Fish Barrier facility logs did not indicate any significant variations from the data shown.

Table B-1. Barrier I (Demonstration) nominal electrical parameters (17-19 November 2010).

Unit	Status	Voltage (Nominal)	Current (Nominal)	Power (Nominal)
Pulser 1	Master	400 V	1.5 kA	12 kW
Pulser 2	Slave	400 V	1.5 kA	12 kW
Pulser 3	Master	100 V	0.5 kA	1.3 kW
Pulser 4	Slave	100 V	0.5 kA	1.0 kW

Notes:
a. Exact values logged by facility personnel every day at 0200, 0600, 1000, 1400, 1800, and 2200 local time.
b. "Pulser 1," "Pulser 2," etc. are terminology used in the Barrier I facility log to indicate the individual hardware units.

Table B-2. Barrier IIA nominal electrical parameters (17-19 November 2010).

Unit	Voltage (Nominal)	Current (Nominal)
Pulser 1	1.6 kV	4.5 kA
Pulser 3	0.8 kV	1.5 kA

Notes:
a. Exact values logged by facility personnel every day at 0200, 0600, 1000, 1400, 1800, and 2200 local time. Actual values logged by facility personnel once each hour.
b. "Pulser 1" and "Pulser 2" are terminology used in the Barrier IIA facility log to indicate the individual hardware units.

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