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Marina Risk Reduction

FINAL REPORT BY:

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FOREWORD

Electric Shock Drowning (ESD) can directly electrocute a swimmer in the water or cause a level of paralysis that ultimately results in drowning. Reports in the mainstream media indicate this is a concern in the vicinity of public and private marinas, boatyards and floating buildings. This has been addressed in the FPRF Proceedings of the "Marina Shock Hazard Research Planning Workshop" held in August 2015, among other activities and earlier works. This problem has not been resolved and needs to be further addressed.

This project is intended to address ESD in public and private marinas and related facilities from all common and plausible sources. The Marina Shock Hazard Research Planning Workshop held in August 2015 suggested possible sources of ESD hazards from both shore based and non-shore based sources, and this latest effort hopes to provide focused guidance on the optimum solution(s) using a risk based approach. The intent is to consider and assess ***ALL*** realistic solutions whether they are technical, awareness (including human behavior) or regulatory focused. Further, relief is sought for this hazard using a comprehensive risk focus rather than a focus on only technical or other narrow singular solutions. ESD is a serious concern to the safety community, and there is a strong desire to identify and prioritize steps that will provide meaningful impact towards its mitigation. The deliverables from this project will provide a roadmap to promote substantive solutions.

The goal of this project is to provide a comprehensive risk assessment and associated action plan to prevent, mitigate and/or eliminate the harmful effects of ESD in the vicinity of marinas, boatyards and floating buildings. Utilizing the concepts described in "Guidance Document for Incorporating Risk Concepts into NFPA Codes and Standards" (FPRF, March 2007), this project provides the following:

- Summary of previous applicable literature, projects and activities in support of the goal of this project;
- Definition of risk assessment elements for this application, including risk metrics and acceptability criteria;
- Identification, summary and categorization of the hazards and hazardous scenarios of impact;
- Evaluation of the risks through estimation of frequency and consequence;
- Recommended action plan to manage the risk, including measures to eliminate, prevent, and/or mitigate the risks;
- Recommended methodology for evaluating the potential effectiveness of the action plan that addresses the effectiveness of the plan elements versus the cost to implement them.

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About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

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Keywords: risk, risk reduction, marina risk reduction, electric shock drowning, ESD, marina, motorcraft, electricity, NFPA 70, NEC, NFPA 302, NFPA 303

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National Fire Protection Association

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Marina Risk Reduction
Final Report

Submitted to the

Fire Protection Research Foundation

Submitted by

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EXECUTIVE SUMMARY

Electric Shock Drowning (ESD) can directly electrocute a swimmer in the water or cause a level of paralysis that ultimately results in drowning. Reports in the mainstream media indicate ESD is a concern in and around public and private marinas, boatyards, and floating buildings. The aim of this project was to explore the literature available regarding ESD, and to the extent practicable, develop a comprehensive approach for ESD risk assessment. identify potential ESD risk management strategies, and outline associated action plans to prevent, mitigate, and/or eliminate the harmful effects of ESD in the vicinity of marinas, boatyards, and floating buildings.

As part of this project, a range of literature associated with Electric Shock Drowning (ESD) has been reviewed. The environments of concern for ESD as addressed in this work have been defined as the interactions of boats-people-water, docks-people-water, and boats-docks-people-water. Valuable information on ESD hazards, ESD impacts to people, means to assess ESD impacts, and potential ESD mitigation measures has been identified, data on potential ESD fatalities and near misses, and works of significance regarding assessment of ESD risks are identified.

To place the assessment and mitigation of ESD risks in context, various approaches to risk assessment and management have been explored, and frameworks for characterizing and presenting risks and managing them within regulatory environments have been identified. Considering the various environments of focus, the risk factors, and the various approaches to identify and manage risk, use of an ESD Concepts Tree (ESDCT), much like the Fire Safety Concepts Tree (FSCT), has been developed as a tool for identifying scenarios of concern and mitigation options for consideration. The top level of the ESDCT is illustrated in Figure 3.15 below. Additional levels of the ESDCT can be found in the body of the report.

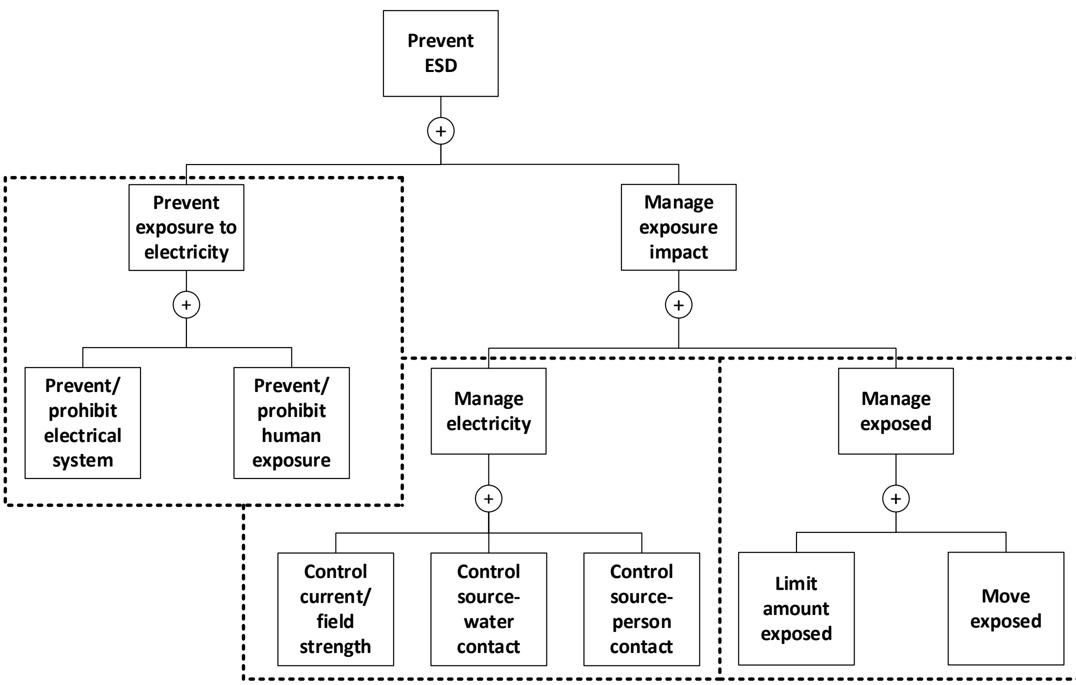

Figure 3.15 Top Level of ESD Concept Tree with Selected Lower-Tiered Gates.

The ESDCT approach is suggested as suitable for several reasons:

1. A quantitative risk assessment requires sufficient data on event frequency (or probability) to develop good risk estimates. In the case of ESD, frequency data are lacking, as are reliability data for infrastructure components.
2. Should a quantitative risk approach be desired, the framework developed by Ayyub et al. (2016) could be applied, as data become available. This may need to be enhanced with additional scenarios and issues of concern, as identified in this work.
3. The ESDCT approach can work in concert with the event tree analysis (ETA) and fault tree analysis (FTA) approach suggested by Ayyub et al. (2016), to move toward a quantitative risk approach in the future.
4. The ESDCT approach is designed to be applicable in all three environments of concern. It can also be extended to work in related environments (e.g., brackish water as well as fresh).
5. The ESDCT approach is designed to go into more detail on exposures and mitigation options than the approach by Ayyub et al. (2016), to facilitate better decision making.

While a reasonable amount of data and information was obtained regarding ESD hazards, risk assessment, and risk management approaches, several shortcomings were also identified. Significant gaps exist regarding actual frequency of ESD events, as well as specific contributors to ESD injuries and deaths. Deaths may be recorded as drowning, and electrocution/electric shock may not be indicated as a contributor, even when suspected. Investigation of the causes of ESD are often incomplete, in part due to lack of training by investigators, especially with respect to electrical systems, or by not using suitably educated and trained personnel (e.g., electrical inspectors). In addition, data are lacking on the number of marinas and docks, particularly private ones (e.g., docks of individual homeowners), which in addition may not be subject to regulation, including of electrical systems. Furthermore, data on the number of boats that have electrical power sources are difficult to obtain. Not all states or local jurisdictions require registration of boats and/or recording of such data. There is also limited control/inspection of boats once in use, especially on smaller waterways, and outside of commercial or large private marinas that may be subject to regulation.

Nonetheless, there are several options available for communicating ESD hazards and risks to various stakeholders, including boaters, swimmers, manufacturers, marina/dock owners, regulators, and enforcers. Various strategies for communicating both ESD concerns and mitigation options have been developed. To help frame the relative risk associated with boats and marinas/docks, as well as the relative effectiveness of mitigation strategies, a table has been developed that illustrates potential mitigation options, why they might or might not be effective, the relative cost effectiveness, and a qualitative reflection on the overall impact on reducing ESD risk.

Based on the literature review and assessment of hazards, risks, mitigation options, and potential mitigating strategies, key findings include the following:

1. ESD hazard characterization — current strength and relationship to body mass and contact:
    - An electrical current of 30 mA is a reasonable threshold for precipitating ESD (Ayyub 2016).
    - The relationship between current magnitude and body mass is proportional (C. F. Dalziel 1968).

- The relationship between current strength and shock duration is proportional (C. F. Dalziel, 1968).
- Equivalent touch or step voltage in terms of resistance of body is available (Lee 2011).

2. ESD hazard characterization — field strength and relationship to body mass and contact:
    - 2 V/ft of electric field can be used as a threshold (Smoot 1964).
    - Relationship between distance from energized materials and electric field strength is inversely proportional (A. W. Smoot, 1964).

3. Sources and control of electricity:
    - Finding source of the stray, continuous, uncontrolled current flow is important.
        - One source of stray uncontrolled current may be pole-mounted transformers (Zipse1999).
        - Other sources include batteries, cables, motors, mains, generators, etc.
    - Fault conditions of concern include improperly wired appliances and electrical cores, electrical ground faults, exposed conductors in contact with the water, and failure of the bonding system (Rifkin, Shafer 2008).

4. Potential mitigation measures — controls on electricity:
    - The following are from Rifkin and Shafer (2008):
        - Install a residual current device (RCD) in the shore power supply of a boat's electrical system.
        - Require that all underwater metals be connected to the shore bonding (grounding) conductor if AC shore power is being supplied to the boat.
        - Periodically test boats for AC leakage into the water.
        - Periodically determine the integrity of a boat's bonding (grounding) system.
        - Replace any shore power cord with insulation damage or any cord with electrical tape applied to repair damage.
        - Establish a quality assurance standard requiring post-construction testing of the electrical systems of new boats.
    - Install isolation transformer with mid-point of the secondary winding connected to a common equipotential node (Parise 2014).
    - Install fuses, circuit breakers, GFCI, and grounding system. Also, insulated wire is important (Bernstein 1991).
    - Require periodic inspection of shore-based electrical systems at all currently-regulated marinas/docks.
    - Consider legislating the periodic inspection of shore-based electrical systems at all private marinas/docks.
    - Inform private marina/dock owners of the hazards of ESD and the benefits of electrical inspection by qualified persons.
    - Eliminate electricity in boats (e.g., row boats, small sail boats) and at marinas/docks.
    - Limit power supply and appliances on boats and at marinas/docks.
    - Reduce/eliminate electrically conductive boat components (e.g., hulls, ladders, propellers, anchor chain, drive).
    - Insulate electrical components on boats and at marinas/docks (e.g., motors and wires).

5. Potential mitigation measures — controls on people:

- Prohibit swimming in any marina where AC shore power is supplied to the docks for any purpose.
- Prohibit swimming near any private dock where AC shore power is supplied to the docks for any purpose.
- Post ESD warnings at any dock with shore power connection.
- Post ESD warnings on any boat with sufficient electrical power source(s).
- Have manufacturers include ESD warnings in boats with sufficient power sources/power needs.
- Have the Coast Guard update its boater's guide to federal regulations and safe boating tip brochure to include ESD warnings and mitigation strategies (https://www.uscgboating.org/images/420.PDF).
- Create designated safe swimming areas away from marinas/docks with shore power connection.
- Educate insurers about ESD and mitigation options to help manage ESD risks.
- Identify power sources and requirements for boats when licensing/registering.
- Require permits to install electrical connections at marinas/docks.
- Institute regulations/penalties for noncompliance.
- Conduct periodic inspections for boats and marinas/docks, including inspections after incidents occur.
- Provide public safety communications.

6. Data collection needs:

- Create a category in data collection databases to include injury and deaths attributable to ESD.
- Collect data on the number of boats with electric motors/equipment with sufficient power sources / connections such that ESD could occur (e.g., presence of 30 mA current or 2 V/ft electric field).
- Collect data on stray voltage on boats.
- Collect data on stray voltage at marinas/docks.
- Collect data on the number of boats (new boats and existing boats), considering their power source.
- Collect data on the number of marinas/docks (commercial and private marinas/docks), considering the number of slips at marinas/docks.
- Collect data from injury databases that are set up to be used for fatal injuries suffered in the water.

7. Further research needs:

- Conduct further research to better characterize the decay in voltage/voltage gradient as distance to a fault source increases.
- Conduct quantitative risk assessments after collecting data (e.g., data on number of boats and number of marinas/docks).
- Conduct further research to better understand the limitation of power supply and appliances on boats and at marinas/docks.
- Conduct further research by field tests to better characterize the effect of suggested mitigation plans:
  - Periodically tests boats for AC leakage.
  - Periodically test boats for integrity of the grounding system.
  - Install a residual current device in the shore power supply of a boat's electrical system.
  - Require proper bonding (grounding) system for all underwater metal when considering AC power supply to boats.

- o Install interrupters / isolation devices (e.g., isolation transformers, fuses, circuit breakers, GFCI).
- o Evaluate legal protections for the site (e.g., warning signs).

8. Key unknowns:

- Shape of land under the water can make a difference in the measurement of electrical current strength (Ayyub, 2004).
- Baseline measurements of electric current hazard levels in the water, taking into account proximity to boats, number of boats, and location of boats, etc.

Based on the state of knowledge of ESD hazards, risks, and potential mitigation options, as well as the gaps in knowledge, it was only possible to develop a range of potential mitigation measures but not to recommend specific measures or sets of measures. Because of this, and coupled with the fact that there is a wide range of interested and affected parties (stakeholders), it is suggested that specific risk mitigation strategies be developed within various regulatory and market environments as described by the socio-technical system (STS) approach and illustrated in the Figure 3.2:

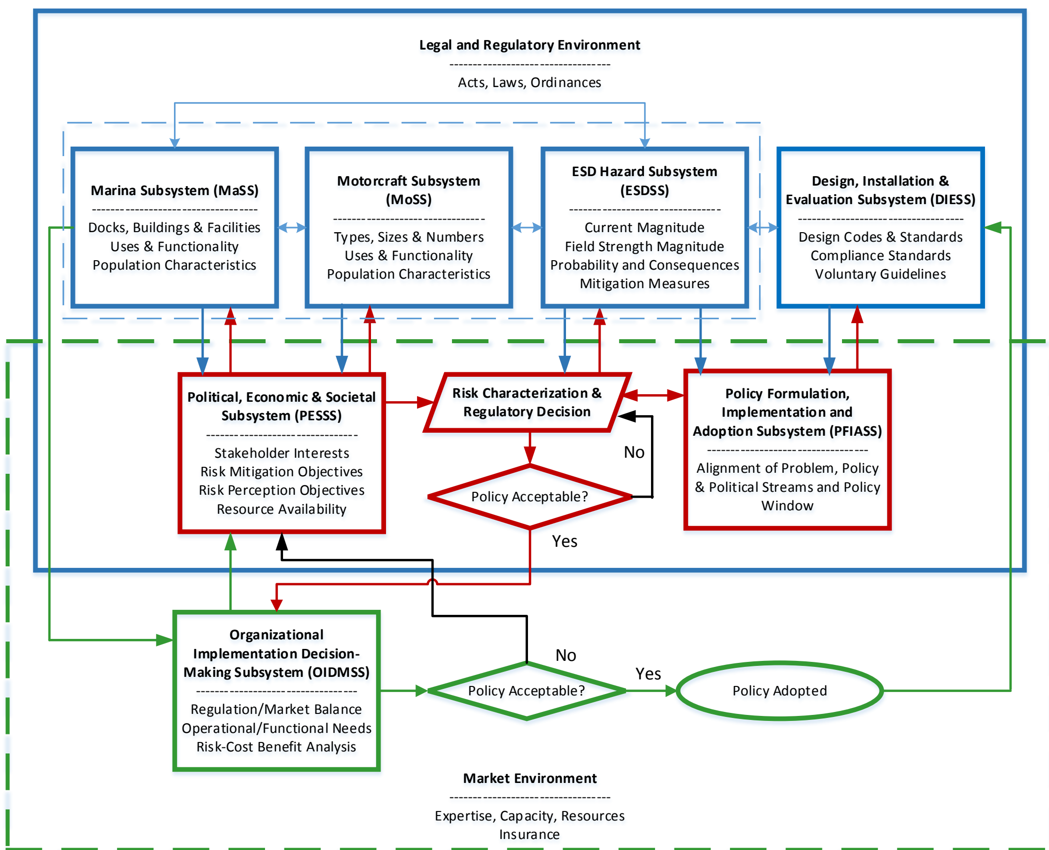

Figure 3.2 Marina-Motorcraft Regulatory System as a Socio-Technical System

The STS approach considers regulatory, market, human and technology issues in the characterization and management of risk through regulation, technology, market, and voluntary measures. It brings together key stakeholders, along with the available data, knowledge of available control technology, and knowledge of the market to more comprehensively characterize risks and establish effective mitigation strategies. By developing mitigation strategies within an STS framework, widespread acceptance can be gained.

Going forward, to enhance quantitative risk assessment, more data are needed, and those data will need to be translated, through calculation, into specific types of variables and parameters (components of the what could go wrong, how likely, and potential consequences) that will be needed by the selected risk estimation approach within the STS / risk characterization process. Needed data, as outlined above, can be extracted from literature, surveys and expert judgment. More quantitative cost-benefit and risk-cost-benefit analyses can then be conducted.

It is suggested that initially, focus on developing inspection protocol, conducting some targeted measurements in and around boats, marinas and docks, and developing quantity data from the literature (e.g., how many boats with electrical systems, how many marinas, boaters, …, cost of mitigation measures, estimates of mitigation effectiveness, etc), can help enhance the picture. Expert judgement can be used to develop better quantitative risk estimates, as well as cost and effectiveness of possible mitigation measures. Together, this will provide a more comprehensive picture of the problem and pathways to solutions.

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1.0 INTRODUCTION

Electric Shock Drowning (ESD) can directly electrocute a swimmer in the water or cause a level of paralysis that ultimately results in drowning. Reports in the mainstream media indicate ESD is a concern in and around public and private marinas, boatyards, and floating buildings. In 2015, the Fire Protection Research Foundation (FPRF) facilitated a workshop aimed at identifying research that is needed to better characterize ESD hazards and risks and to identify strategies to mitigate the potential for ESD in the vicinity of marinas, boatyards, and floating buildings (FPRF 2015). As part of and subsequent to this FPRF workshop, it was determined that while progress was being made to understand the causes of and potential mitigation strategies for ESD, the problem has not been resolved and needs to be further addressed.

1.1 BACKGROUND

Data on ESD are sparse. There are many reasons for this, including lack of a national surveillance system, such as NFIRS for fire incidents, and lack of reporting secondary causes (e.g., electrical shock as leading to drowning) where drowning is recorded as cause of death. Furthermore, electricity-related near-drowning episodes are rarely reported as such due to lack of a detailed description of the incident, poor documentation on medical records, or because the patients do not seek medical attention. Electricity-related drowning is difficult to identify because physical evidence of electricity-induced burns may not be readily apparent (BMA 2004; Ayyub et al. 2016). Nonetheless, data compiled from media articles and anecdotal reports illustrates that 10 ESDs can occur in a year (Shafer and Rifkin 2016), and since data are not tracked, the number could be higher. While relatively small in number, the frequency of ESD has been sufficient to highlight the concern and seek means to manage the risk in a comprehensive manner.

The 2015 FPRF workshop identified three distinct realms of activity that arguably have equal share of the overall issue: marinas, motorcraft, and infrastructure. As defined in the workshop report (FPRF 2015), the term *marinas* is intended to include boatyards and all facilities that are expressly designed to support motorcraft. The term *motorcraft* is intended to include boats and other water-borne vessels that provide water-based transport and come and go into and out of marinas. The term *infrastructure* is intended to include all the normal electrical service found in the built environment that supports the marinas. Control, use, and regulation of electricity varies by realm, as illustrated in Table 1.1.

Table 1.1 Realms of Activity

	Marinas	Motorcraft	Infrastructure
Source of electricity	Electrical equipment that is generally in fixed locations within marinas	Electrical equipment that is mobile and can move from location to location	Electrical equipment that is generally in fixed locations from grid to marina
End-use operator	Permanently located and well-defined	Owner/operator who is transient	Permanently located and well-defined
AHJ	Often local code official	Coast Guard or insurance	Often local code official

Consideration of these three realms of activity helps to understand the importance and complex interrelationship of the electrical equipment involved. In addition, the FPRF workshop attendees identified three areas of risk management focus: (i) technical, (ii) awareness, and (iii) regulatory. In the end, it was determined that ESD should be addressed using a comprehensive risk focus rather than a focus on only technical or other narrow singular solutions. The complex interactions of the realms and the multi-prong risk management approach highlight ESD as a socio-technical system. This concept will help guide development of an effective risk management solution, as discussed in Section 3.

1.2 RESEARCH GOAL

As stated in the Request for Proposals (RFP), the overall goal of this project is to provide a comprehensive risk assessment and associated action plan to prevent, mitigate, and/or eliminate the harmful effects of ESD in the vicinity of marinas, boatyards, and floating buildings. The objectives of this project are as follows:

- Summarize previous applicable literature, projects, and activities in support of the goal of this project
- Define the risk assessment elements for this application, including risk metrics and acceptability criteria
- Identify, summarize, and categorize the hazards and hazardous scenarios of impact
- Evaluate the risks through estimation of frequency and consequence
- Recommend an action plan to manage the risk, including measures to eliminate, prevent, and/or mitigate the risks
- Recommend a methodology for evaluating the potential effectiveness of the action plan that addresses the effectiveness of the plan elements versus the cost to implement them

1.3 REQUIRED PROJECT TASKS

The following is a list of required project tasks, as detailed in the RFP.

- Literature Review
- Define Risk Assessment Elements
- Hazard Identification
- Risk Evaluation
- Action Plan
- Evaluation Measures
- Final Report

While this effort touches upon each of these areas, deviations from the task descriptions stated in the RFP were proposed and accepted by the FPRF. In brief, the deviations largely relate to limiting the scope of the risk assessment and evaluation, given the paucity of data, and focusing more on describing the risk environment, developing a framework for future quantitative risk assessment as data become available, and outlining strategies for risk mitigation more so than detailed action plans. The following reflects the outcomes of this effort.

2.0 LITERATURE REVIEW

A comprehensive literature review is important to understand what is known about the problem, where critical gaps exist, and therefore where further attention is warranted. For this effort, we followed the approach for a literature review as outlined in Figure 2.1 in research paper (Pautasso 2013).

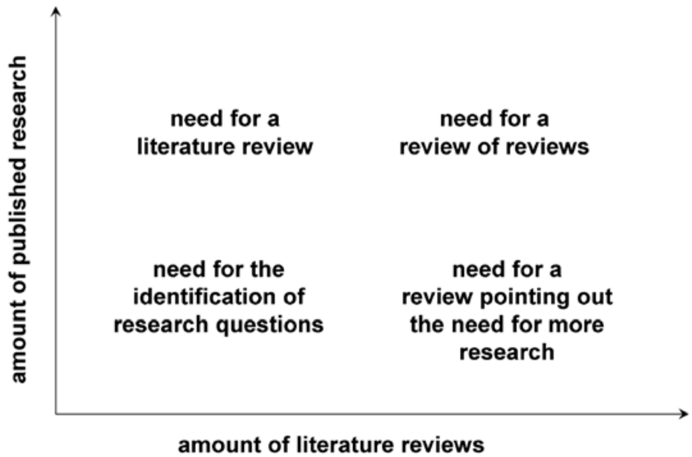

Figure 2.1. A Conceptual Diagram of the Need for Different Types of Literature Reviews Depending on the Amount of Published Research Papers and Literature Reviews (labelled Figure 1 in Pautasso 2013)

Reviewing literature requires the ability to identify and find relevant material, synthesize information from various sources, employ critical thinking, and analyze material — evaluate, summarize, and cite (Budgen and Brereton 2006). Ideally, one aims to find as much relevant literature as possible to characterize the problem and to help guide the path towards solutions. Pautasso (2013) outlines two types of literature review: mini or full. The primary difference is the depth of reading and analysis. As an initial step, several of the documents highlighted in the 2015 FPRF workshop on ESD were reviewed. Web searches were then conducted on: ESD, hazards and risks associated with ESD, risk assessment for ESD, and related search terms. In addition to documents identified during such searches, references listed within key documents were reviewed as well. The bibliography in Annex A contains the list of documents that were identified.

During the literature review for this project, the amount of published research directly related to the ESD project was found to be limited. The articles and reports identified can generally be classified by two major topics: literature related to electricity and electrical shock hazards, and literature related to risk assessment, communication and management. In addition, a few reports and articles directly relevant to ESD were identified. In the end, a total of 31 documents were reviewed in detail: 14 papers about electricity, 10 documents for warning signs, and 7 research papers for enforcements and regulatory impact. The results of the review are applied to this project, and specific comments related to the applicability to the project are stated at the end of every literature review. The detailed literature review is provided in Annex B.

3.0 RISK ASSESSMENT ELEMENTS

The aim of this task was to review and select an appropriate framework for risk characterizing and assessing and managing risk. This involved consideration of the various component parts and framework typologies in the context of ESD and its realms and regulatory relationships. As a starting point, it was decided to frame the ESD realms and regulatory relationships in terms of a socio-technical system.

3.1 SOCIO-TECHNICAL SYSTEM (STS) CONCEPT

As noted in Section 1 above, the 2015 FPRF workshop on ESD in the marina environment identified three distinct realms of activity that arguably have equal share of the overall issue: marinas, motorcraft, and infrastructure (FPRF 2015). It was noted that consideration of these three realms of activity helps one to understand the importance and complex interrelationship of the electrical equipment involved. It can also be observed that these complex interactions can be reflected as a socio-technical system (STS).

In brief, STS theory and concepts emerged from studies of organizations and the roles of social and technological components and the realization that they are integrally linked (Trist and Murray 1993). It has been shown that a STS framework provides a useful model for describing the actors and interactions in the building regulatory system, as illustrated in Figure 3.1 (Meacham and van Straalen 2017).

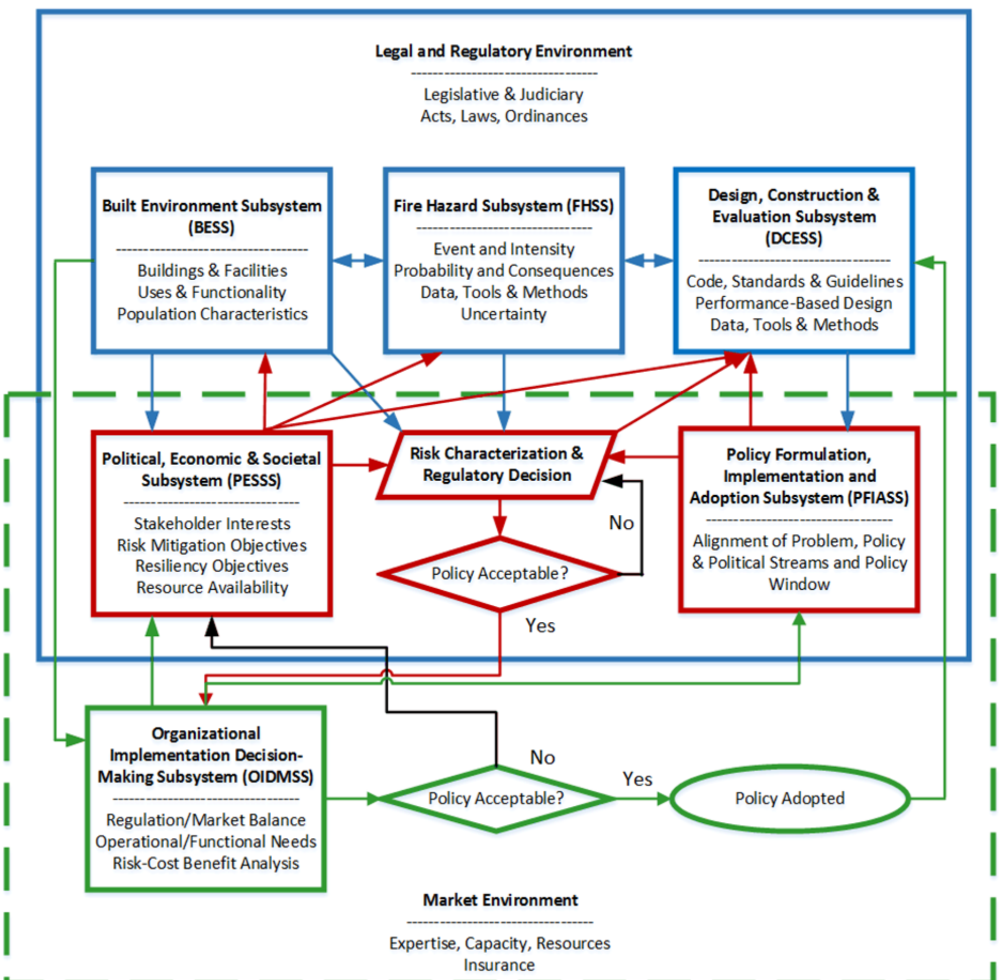

Figure 3.1 Building Regulatory System as a Socio-technical System. (Meacham and van Straalen 2017)

In the STS building regulatory framework there are two operational environments — "legal and regulatory" and "market" — and an "interactions" environment within which decisions are made. Within each environment are subsystems associated with technology: Built Environment (BESS), Fire Hazard (FHSS), and Design, Construction and Evaluation (DCESS); with policy/decision-making: Political, Economic and Societal (PESSS) and Policy Formulation, Implementation and Adoption (PFIASS); and with the market: Organizational Implementation Decision-Making (OIDMSS).

Figure 3.1 illustrates the high-level interactions between subsystems. The BESS, FHSS and DCESS interact with each other to describe/define the hazards, assessment approaches, and mitigation options. The selection of regulated levels of performance, and tools and methods of analysis recognized for compliance with the regulations, are developed and agreed on in the PESSS, PFIASS, and risk characterization and decision environment. The policy suggestions are vetted and balanced with market options in the OIDMSS. The subsystems themselves are also socio-technical systems. Standards developed in the private sector may or may not become part of the regulatory environment, because they can be used on a voluntary basis. Placement of standards within the DCESS reflects the role they play within the regulatory environment.

It is suggested that by making a few modifications, the STS framework can be useful when considering the marina-motorcraft environment and the complex interactions, including hazards, risks, regulation, and market interactions. This is illustrated in Figure 3.2.

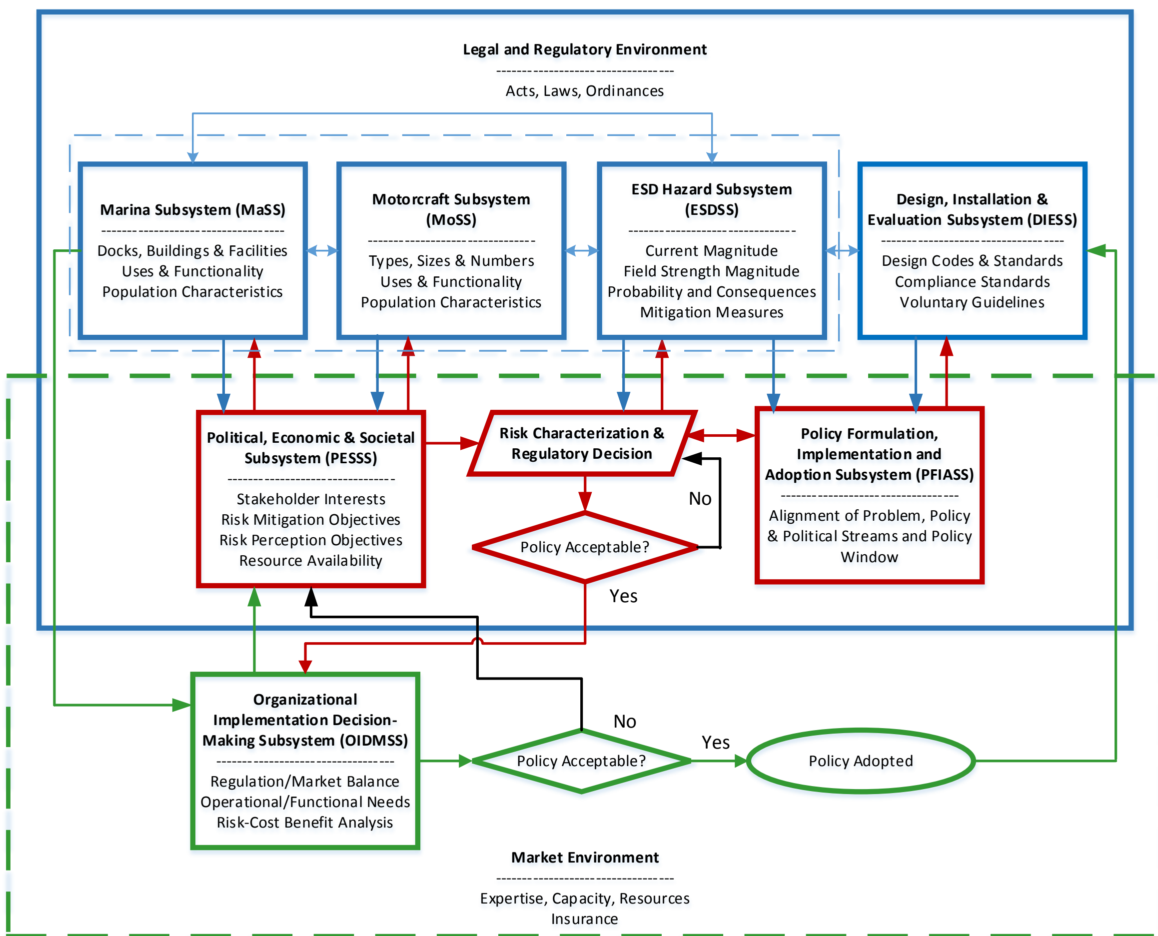

Figure 3.2 Marina-Motorcraft Regulatory System as a Socio-Technical System.

Within this STS framework for ESD, the Marina (MaSS), Motorcraft (MoSS) and ESD Hazard (ESDHSS) subsystems reflect the realms and interactions that place the potentially lethal combination of people, electricity, and water together, in and around motorcraft and marinas. The hazards and risks are functions of the electrical equipment and services in these realms/subsystems. The hazards and levels of risk are influenced and can be influenced by design, installation, and evaluation (inspection/compliance) regulations and activities, which in turn are functions of the stakeholder interests and actions (PESSS) and policy decisions (PFIASS). Decisions on tolerable risk (hazard) levels, and how they are reflected in regulation, are made within the risk characterization and regulatory decision frame, which influences the regulatory mechanisms (DIESS). These mechanisms are balanced within the market environment (OIDMSS) where instruments such as insurance can be used along with regulation to achieve an overall level of tolerable risk and safety.

We propose this structure to help entities aiming to develop risk management strategies understand better the relationships and influences that need to be considered. For example, tolerable risk is a function of public perception of risk and resource availability to mitigate the risk (PESSS). Characterization of the risk requires this understanding, as well as the interaction of the electrical infrastructure within the marina and motorcraft realms (MaSS, MoSS and ESDSS). Regulations to address the risk (hazards) to a tolerable level need to be formulated in balance with perceptions (PESSS) and market instruments and constraints, such as cost to achieve desired benefits (OISMSS). At the core is adequately characterizing the risk.

3.2 RISK CHARACTERIZATION

As used here, risk characterization is an analytic-deliberative process through which information relevant to the risk problem is gathered, analyzed, and where appropriate, quantified. Then in the context of potentially impacted and affected stakeholders, decisions are made about the tolerability of the risk and the approaches to avoiding, mitigating, or eliminating the risk (see for example, Stern and Fineberg 1996; Meacham 2004; Meacham and van Straalen 2017).

To adequately address a risk problem, a broad understanding of the relevant losses, harms, or consequences to the interested or affected parties is required. It is very important, therefore, that the process has an appropriately diverse participation or representation of the spectrum of interested and affected parties, of decision-makers, and of specialists in appropriate areas of science, engineering, and risk analysis at each step. The analytic-deliberative risk characterization is illustrated in Figure 3.3.

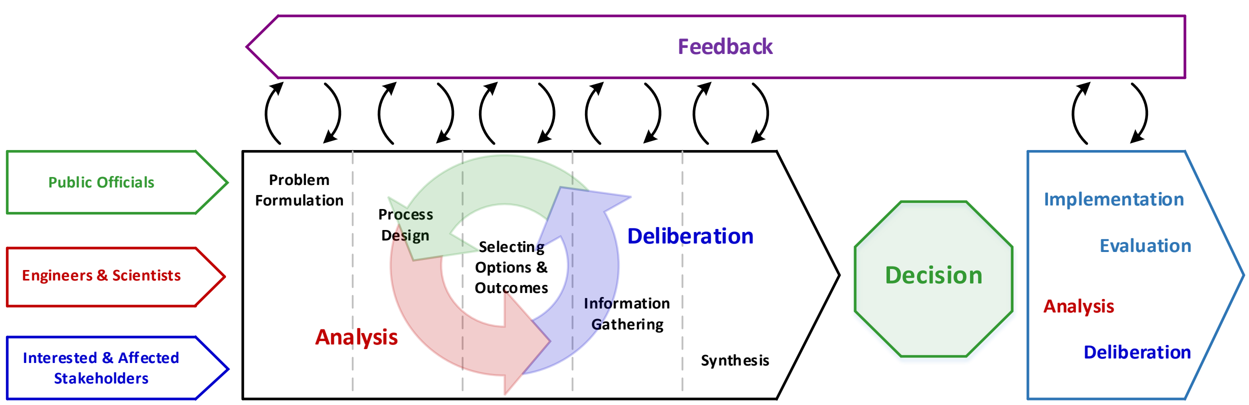

Figure 3.3 Analytic-Deliberative Risk Characterization Process. (Adapted from Stern and Fineberg 1996)

When applied to regulatory development, the risk characterization typically requires several iterations, as new information and data become available and as participants gain better understanding and raise more issues. One of the most important factors in risk characterization is to ensure that adequate scientific and technical information is available to support the decision. This function occurs primarily in step one of the diagnosis stage: diagnose the kind of risk and state of knowledge. To help focus this effort, various diagnostic questions should be asked about the hazards and the risks, including the following:

- Who is exposed?
- Which groups are exposed?
- What is posing the risk?
- What is the nature of the harm?
- What qualities of the hazard might affect judgments about the risk?
- Where is the hazard experience?
- Where and how do hazards overlap?
- How adequate are the databases on the risks?
- How much scientific consensus exists about how to analyze the risks?
- How much scientific consensus is there likely to be about risk estimates?
- How much consensus is there among the affected parties about the nature of the risk?
- Are there omissions from the analysis that are important for decisions?

The aim is to develop agreement on what the components of the risk problem are, including who is at risk, from what hazards, in what way(s), and how best to assess and represent the risk.

3.3 RISK ASSESSMENT AND CHARACTERIZATION TOOLS

There are numerous tools that can be applied for hazard and risk assessment and characterization, such as reflected in the *SFPE Handbook of Fire Protection Engineering* (e.g., see SFPE HB, 5th ed., Chapter 75, 2015). These tools are aimed at helping to answer the following questions: what can go wrong, how likely are they to go wrong, and what is the impact (consequences) of them going wrong (Kaplan and Garrick 1981). What can go wrong is the hazard assessment component. How likely are they to occur is the frequency or probability component. What is the impact is the consequence analysis component. For brevity, we focus on three tools: fault tree analysis (FTA), event tree analysis (ETA), and decision trees.

FTA is essentially a “reverse thinking” or “top down” deductive technique that focuses on one particular event that could (or did) occur (typically an accident) and provides a structure for evaluating the potential causes of the event (e.g., given failure

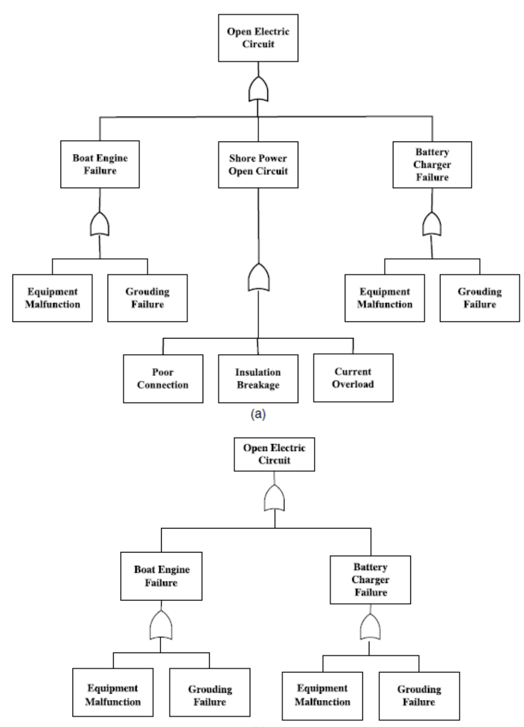

Figure 3.4 Fault Tree for ESD. (Ayyub et al. 2016)

X, what could have been the cause). It does this by providing a structure, in the form of a graphic representation of a logic model, that an analyst uses to display various events, conditions, actions, and outcomes. The output of an FTA is a set of combinations of root or initiating events that could lead to (or could have lead to) a failure and may include component, equipment, system, operating and/or human actions, failures, or errors (see Figure 3.4). Although FTA may be a qualitative tool as used in hazard assessment, it can be used as a quantitative risk assessment tool if probabilities or frequencies are assigned to the various initiating or root causes. Fault tree analysis (FTA) can be used to predict the probability or frequency of an event's outcome by combining the probabilities or frequencies of initiating events using logic gates (primarily AND gates and OR gates). Use of an AND gate implies that all branches leading into the upper event must happen for the event to occur.

Whereas FTA begins with a failure and provides a structure to look for potential causes, event tree analysis (ETA) provides a structure for postulating an initiating event and analyzing the potential outcomes. The principal tool is a decision tree (as used in decision analysis) with branches for success or failure (yes or no or other binomial output). The basic approach is to identify an initiating event, identify systems or strategies intended to mitigate the event, and ask the "success or failure" question for each system or strategy, building the tree in the process. As with FTA, ETA is primarily a qualitative tool as used in hazard assessment but is often used as a quantitative risk assessment tool by assigning probabilities, much the way probabilities are used in a decision tree.

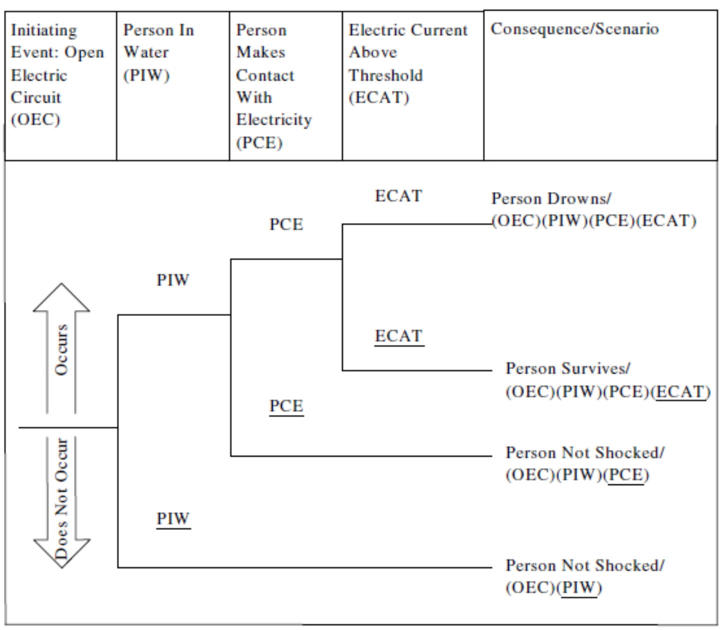

Figure 3.5 Event Tree for ESD. (Ayyub et al. 2016)

An exemplar event tree is shown in Figure 3.5. Event trees are often used in scenario-based risk analysis, where each branch of the tree is a scenario. Given a starting probability for event occurrence, and the likelihood of each subsequent event or mitigating action, the probability of the scenario can be estimated. Coupled with consequence analysis for that event, the probability and consequence of the scenario can be combined to result in an estimate of risk.

In many cases, FTA is used to determine the success/failure probabilities of the safety measures within a scenario. This combination of FTA and ETA is widely used in occupational health and safety, chemical process safety, nuclear power safety and related areas to identify and assess risks of concern. However, this approach is highly dependent on the availability of data for the estimation of risk, and when data are sparse, the risk estimates can be quite small. While on the surface this is good, a downside is that small risks can be deemed negligible, and no action is taken to further mitigate the risk.

In some cases, application of a more generalized decision tree can be helpful. A decision tree can be used to identify choices or options for mitigating a risk situation, but without the quantification component. The Fire Safety Concepts Tree as embodied in NFPA 550 is an example. NFPA 550 starts with a top-level objective, such as provide safety to life from fire, and steps the decision-maker through the process of identifying means to prevent fire or manage the impact of fire. A similar structure can be applied to ESD. This is discussed in more detail in section 3.4.

3.4 RISK MANAGEMENT

Once a risk is well-characterized and understood, one can manage the risk. There are four fundamental risk management strategies: avoid, accept, mitigate, or transfer. Avoidance requires action to remove the hazard, or the target that may become impacted by the hazard. Mitigation is reduction of the risk by managing the hazard or the exposed. Transfer is use of insurance or related mechanisms to reduce or manage the expected loss without necessarily reducing the risk. Acceptance is a decision that some level of risk is tolerable or acceptable and that other options are not worth further pursuit, since the costs may outweigh the benefits, or other economic, technical or social factors may influence the decision.

A comprehensive risk management strategy also considers mechanisms to monitor and review risks over time and the importance of communicating risks to interested and affected parties, in particular any levels of tolerable or acceptable risk. A generally accepted framework for risk management is illustrated in Figure 3.6. This risk management framework is embodied in ISO 31000 (ISO 2009) and its predecessor AS/NZS 4360 (AS/NZS 2004).

Establishing the context relates to defining the risk problem. The steps of identifying, analyzing, and evaluating risks (inside the red box) are components often considered as being traditional risk assessment. Treating the risk is where the accept, avoid, mitigate, or transfer decisions are made, with monitoring and communicating being important and necessary bookends. One will notice the risk characterization process as including/requiring consideration of these same elements. Regulation can be considered a global risk management strategy in that it makes use of avoidance, mitigation, and acceptance mechanisms. Risk evaluation, management, and communication will be further explored in the next phase of this effort.

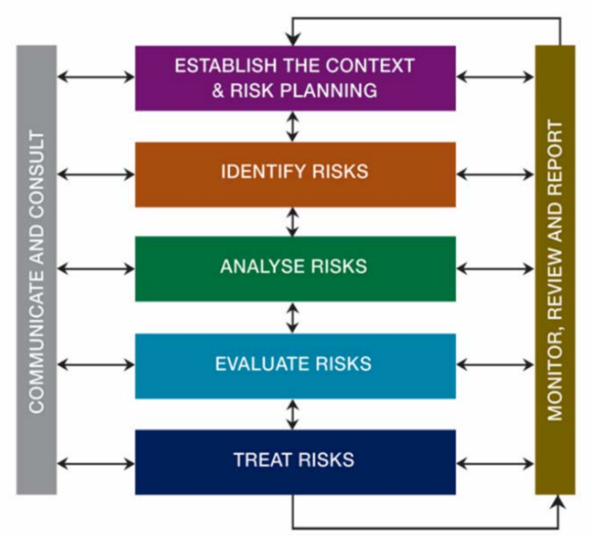

Figure 3.6 Risk Management Framework. (AS/NZS 2004)

3.5 RISK REDUCTION ALARP

There are many regulatory tools and concepts that are useful in helping to reflect tolerable levels of risk as part of risk management. The concept of As Low As Reasonably Practicable (ALARP) is one such approach. The ALARP concept reflects the reality that (a) it is nearly impossible to reduce risk to zero (other than avoiding the activity or hazard completely, which is in many cases not practicable), and (b) reducing the risk (hazard) can be so costly as to outweigh any benefit. ALARP can be used for individual or societal risk and can be quantitatively or qualitatively expressed, as shown in Figure 3.7 (http://www.hse.gov.uk/risk/theory/alarpglance.htm).

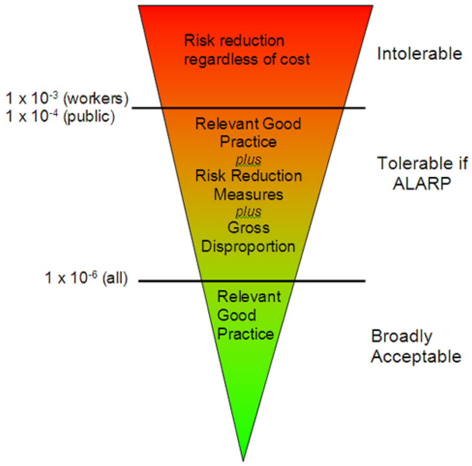

Figure 3.7(a) Quantitative Risk Representation.

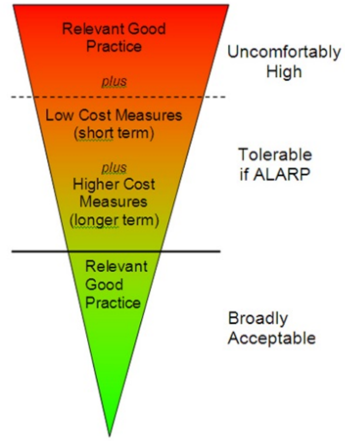

Figure 3.7(b) Societal Risk Representation.

A simple example is a car. Driving a car is inherently risky. Being a good driver can only control so much: faulty equipment, poor weather conditions, and other drivers can influence the risk. As for equipment, very safe cars are available, and safer cars can be built (e.g., tanks). However, these are very costly. As such, society generally tolerates the risk of accidents but enforces measures to minimize the risk as much as is reasonably practicable through regulation (e.g., speed limits, testing, licensing), safety measures (e.g., air bags, passive restraint systems), and education. Discussion on ALARP can be found on the UK Health and Safety Executive website (http://www.hse.gov.uk/risk/theory/alarpglance.htm), among other sources. The concept is widely applied in occupational health and safety and could be a mechanism for ESD risk reduction regulation or guidance as well.

3.6 DECISION TREE

In general, a decision tree is a method for representing the possible outcomes following a succession of events, combining points where the ensuing path is subject to choice and points where it is not (Watts and Hall 2015). In general, a decision tree presents one with an "or" decision (i.e., choice A or choice B). A particular form of a decision tree known well in fire safety engineering is the Fire Safety Concepts Tree (FSCT) (NFPA 550 2017), which includes both "or" conditions as well as "and" conditions.

As defined by Watts (2008), the FSCT is a graphical representation of the deliberations and professional judgments (decisions) of the NFPA Technical Committee on Systems Concepts for Fire Protection in Structures and represents one way in which building fire safety can be viewed. The FSCT starts with a fire safety objective (e.g., prevent loss of life due to fire) and divides it into two primary branches: "prevent fire ignition" and "manage fire impact," the concept being that one or the other must be accomplished to meet the fire safety objectives. In the FSCT, a (+) symbol represents an "or" function (i.e., A or B may be required) and a (•) represents an "and" function (i.e., A and B are required).

One can use the tree as a guide to evaluate potential fire impacts in those cases where a building fails to meet the criteria of one or more branches (e.g., if ignition is not prevented, one can evaluate the ability of the building's systems to manage the fire impact). One can also modify the fire safety concepts tree into the form of an event tree or a decision tree for risk analysis. A portion of the fire concepts tree is provided in Figure 3.8 (NFPA 550 2017; SFPE 2015). The FSCT is helpful in that it presents all mitigation options (choices) for fire protection measures in a single diagram. The FSCT can also be used as a basis for developing event trees.

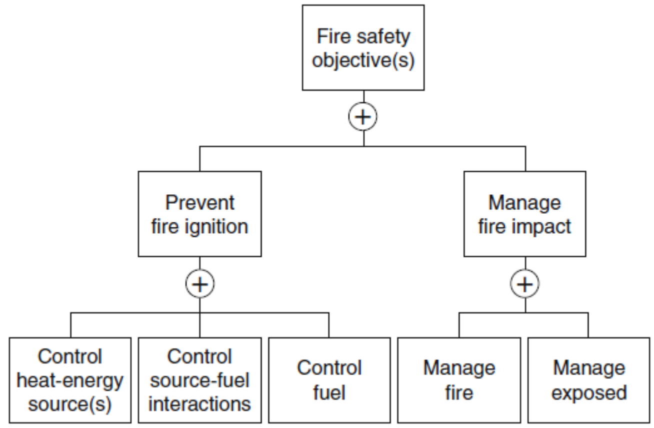

Figure 3.8 Portion of FSCT. (NFPA 550 2017)

3.7 RISK ENVIRONMENTS AND RISK FACTORS

In considering the information developed to date, including the previous work by the FPRF (2015), Ayyub et al. (2004; 2016), and otherwise as resulting from the literature review, it was decided to focus on three environments in which ESD could occur: person-boat-water, person-dock-water, and person-boat-dock-water, graphically represented in Figure 3.9. These represent the environments in which ESD can occur and, therefore, help to shape the pathways of exposure to electricity (e.g., person in contact with electrical wire while in the water near a dock) and the options to mitigate that exposure. The risk factors are then largely related to electricity, water, and people coming together, as illustrated in Figure 3.10. The factors can be physical infrastructure related (e.g., exposed electrical service), motorcraft related (e.g., metal hull boat with electric motor), or person related (e.g., young, old, awake, asleep, drunk, incapacitated).

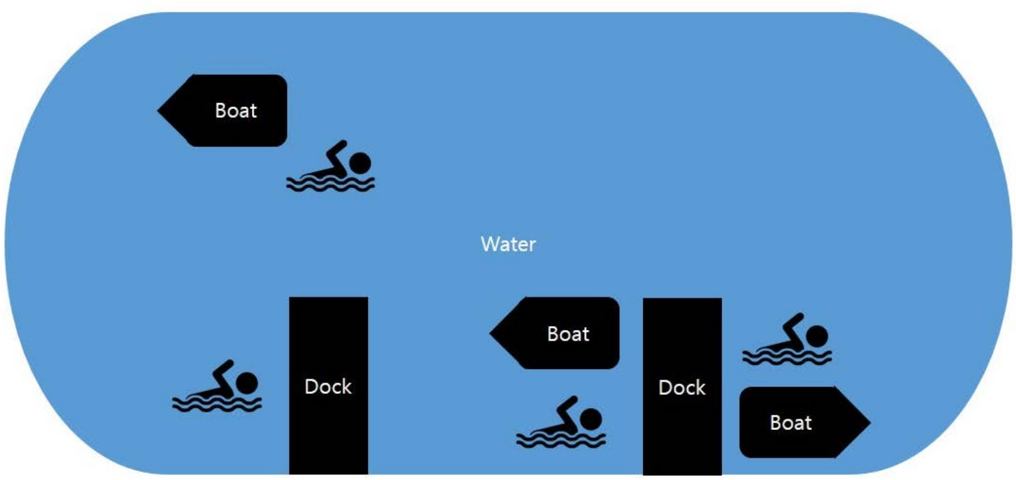

Figure 3.9 Risk Environments.

Sets of representative risk factors includes those illustrated in Figures 3.10(a), (b), and (c):

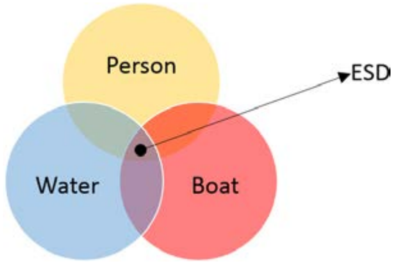

Figure 3.10(a) Environment 1.

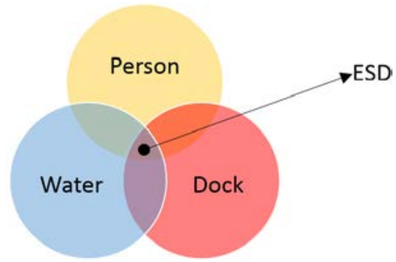

Figure 3.10(b) Environment 2.

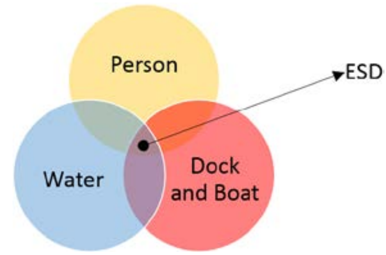

Figure 3.10(c) Environment 3.

This approach also helps one to identify scenarios of concern, such as the following (Ayyub et al. 2016):

1. Boat located offshore, person in fresh water: In fresh water, the hazard for swimmers near a boat with 120 V appliance leakage can be substantial. The swimmer might bridge the gap between any energized metal part of the boat and a good ground.
2. Boat located offshore, person partially in fresh water and partially on boat: When a swimmer initially feels the electrical current and does not realize what is happening, the swimmer may instinctively swim toward the boat instead of away from it. This can be a fatal mistake.
3. Boat located at dock, person partially in fresh water and partially on boat: Drowning may occur due to an electric shock received while a person was entering a boat from the water.
4. Boat located at dock, person partially in fresh water and partially on dock: Drowning may occur due to an electric shock received while a person was entering a boat from the water.
5. Boat located at dock, person in fresh water: Boat located at dock with 120 V appliance leakage into shallow freshwater. A swimmer bridges the gap between an energized metal part of the boat and a good ground. A potential of only a couple of volts causes the swimmer to lose muscular control and not be able to swim clear. It is not necessary to have a potential capable of inducing ventricular fibrillation.

Those scenarios are developed based on considerations of exposure that are likely to exist. Figure 3.11 indicates the attributes and states of electric-current induced drowning scenarios (Ayyub et al. 2016).

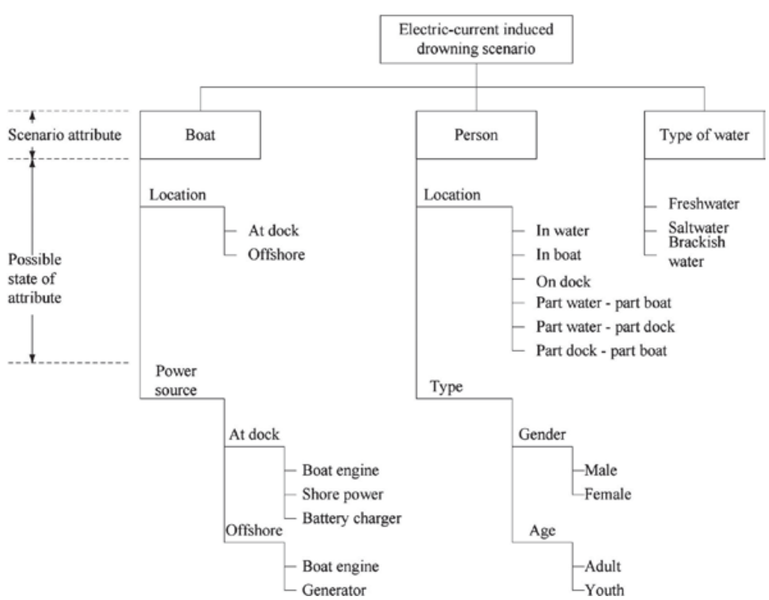

Figure 3.11 Attributes and States of Electric-Current-Induced Drowning Scenarios. (Ayyub et al., 2016)

Considering the three environments that have been identified and the attributes of ESD scenarios identified by Ayyub et al. (2016), it is suggested that the preceding five scenarios are of primary concern. Scenarios 1 and 2 are relevant to environment 1, and scenarios 3, 4, and 5 are relevant to environment 3. Ayyub et al. (2016) did not address environment 2, so new scenarios are needed for that. Together, this approach serves as a starting point for the ESD Concepts Tree as discussed in Section 3.8.

To quantitatively estimate risk, one must be able to estimate frequency (probability) as well as consequences. As discussed in Section 3.3, this requires estimates such as frequency or probability of a person's exposure to an unacceptable electrical current or field while in the water near a boat or a dock. This requires a significant amount of data on the combinations of factors that must align to result in an unacceptable outcome.

While research can be conducted to develop such data, one should also consider the magnitude of the problem, and the extent to which the data are available, and whether effective mitigation can be implemented. Data availability is addressed here. Mitigation effectiveness will be explored in more detail in the next phase of work.

From the literature review, there appears to be a lack of data for many of the necessary aspects of quantitative risk assessment:

1. Reliability and failure data on electrical infrastructure are unknown.
2. Reliability and failure data of electrical systems on motorcraft are unknown.
3. Effectiveness of regulations and enforcement mechanisms for control of electrical infrastructure are unknown.
4. The ability to control the actions of people is highly variable (e.g., prohibiting alcohol consumption, getting people to follow rules related to swimming restrictions).

In addition, the overall societal risk, as based on the reported (presumed) annual deaths and near misses due to ESD, is quite low, as illustrated in Figures 3.12, 3.13, and 3.14 (detailed data provided in Annex B).

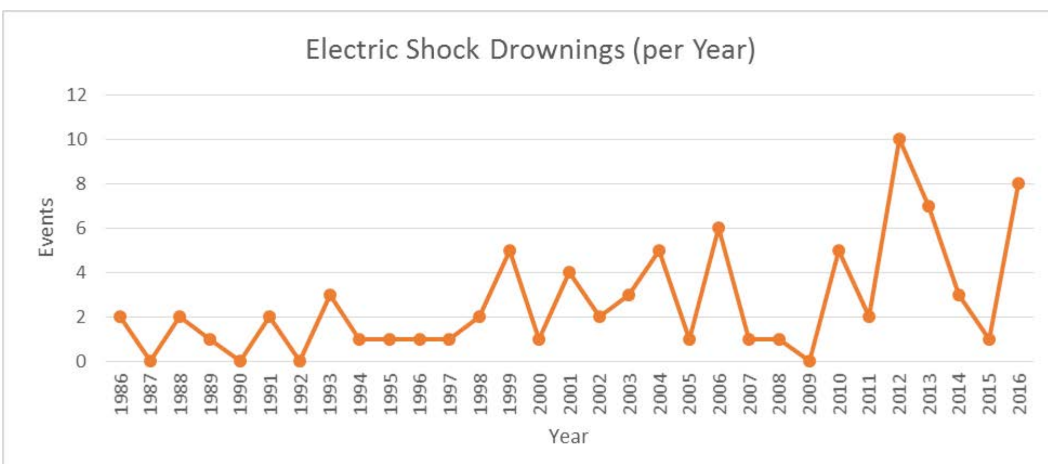

Figure 3.12 Annual ESD from Literature. (Reflects Shafer and Rifkin 2017)

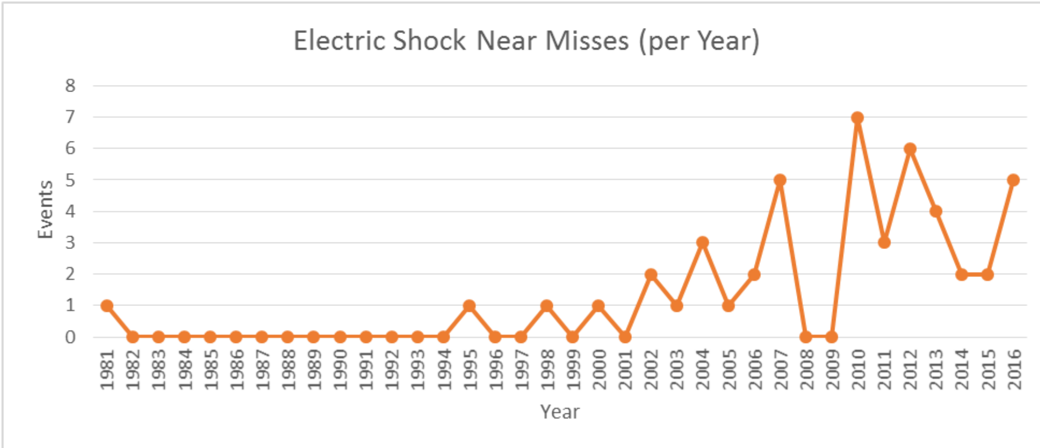

Figure 3.13 Annual ESD Near Misses from Literature. (Reflects Shafer and Rifkin 2017)

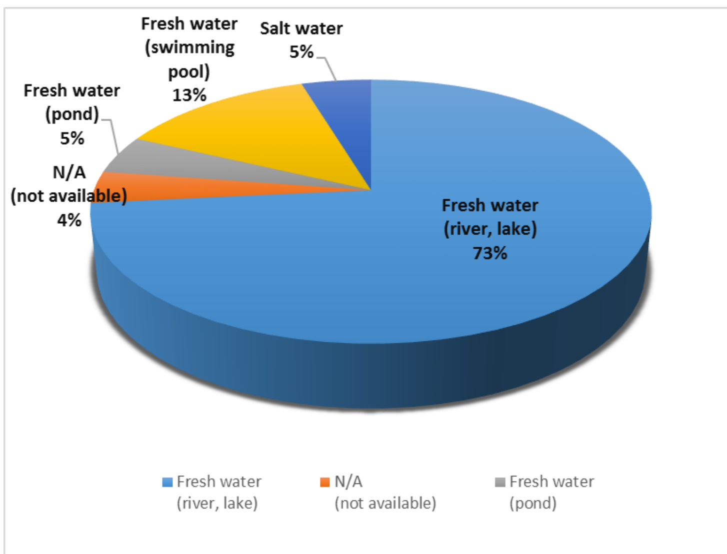

Figure 3.14 Percentage of ESD by Water Source. (Reflects Shafer and Rifkin 2017)

While lack of data alone is not a reason for not pursuing ESD mitigation and risk management, it may make the risk quantification and communication more challenging.

3.8 RECOMMENDATION FOR ESD RISK FRAMEWORK: DECISION TREE FOR ESD

Considering the various environments of focus, the risk factors, and the various approaches to identify and manage risk, use of an ESD Concepts Tree (ESDCT), much like the FSCT, is suggested as a tool for identifying scenarios of concern and mitigation options for consideration. The ESDCT approach is suggested for several reasons:

1. A quantitative risk assessment requires sufficient data on event frequency (or probability) to develop good risk estimates. In the case of ESD, frequency data are lacking, as are reliability data for infrastructure components.

2. Should a quantitative risk approach be desired, the framework developed by Ayyub et al. (2016) could be applied, as data become available. This may need to be enhanced with additional scenarios and issues of concern, as identified in this work.
3. The ESDCT approach can work in concert with the ETA and FTA approach suggested by Ayyub et al. (2016) to move toward a quantitative risk approach in the future.
4. The ESDCT approach is designed to be applicable in all three environments of concern. It can also be extended to work in related environments (e.g., brackish water as well as fresh).
5. The ESDCT is designed to go into more detail on exposures and mitigation options than the approach by Ayyub et al. (2016) to facilitate better decision making.

3.8.1 Structure of the ESD Concepts Tree

The ESD concepts tree (ESDCT) shows relationships of ESD prevention and management and its impact. As with the FSCT, the ESDCT uses logic gates to show a hierarchical relationship of ESD decisions with “or” and “and” gates. An “or” gate is represented by a circle with a plus sign in it, and an “and” gate is represented by a circle with a dot in the middle. Figure 3.15 illustrates the top level of an ESD concept tree with selected lower-tiered gates. The top box of the ESD concept tree is labeled “Prevent ESD” and indicates the object of the tree. Strategies for achieving the objective are divided into two categories: “Prevent exposure to electricity” and “Manage exposure impact.” These strategies are connected through an “or” gate to the objective. It means that “Prevent ESD” can be accomplished with “Prevent exposure to electricity” or “Manage exposure impact.” Because perfect prevention or management is impossible to achieve — and despite the connecting “or” gate — both must be applied together to enhance the level of safety. Figures 3.15, 3.16, 3.17, and 3.18 illustrate the ESD concept trees developed.

3.8.2 Use of the ESDCT

The ESDCT can be applied to all three environments: person-boat-water, person-dock-water, and person-boat-dock-water. Starting with the selection of a target environment, prevention of exposure to electricity or management of exposure impact is considered. The ESDCT then guides the decision maker through options associated with prevention or management.

The use of the ESDCT can be illustrated by examining how to prevent exposure in the case of Scenario 1, as discussed previously. Scenario 1 is considered a critical scenario by Ayyub et al. (2016) and is described as a boat located offshore, in fresh water, with a person involved. This example fits Environment 1 as described above [see Figure 3.10(a)]. Application of one branch of the ESDCT for this scenario is illustrated in Figure 3.16(a).

On the left side of the “Prevent exposure to electricity” branch are two strategies: “Prevent/prohibit electrical system” and “Prevent/prohibit human exposure.” In this example, both strategies can be applied. In the branch “Prevent/prohibit electrical system,” three strategies are illustrated with their specific mitigation strategies. Since the example is relevant to Environment 1, “No electricity at dock” is not applicable (no dock), but “No electric motor” or “No battery” should be considered as potential options for the boat. Since the gate is an “or” gate, the strategy of “Prohibit swimming” below “Prevent/prohibit human exposure” also should also be considered.

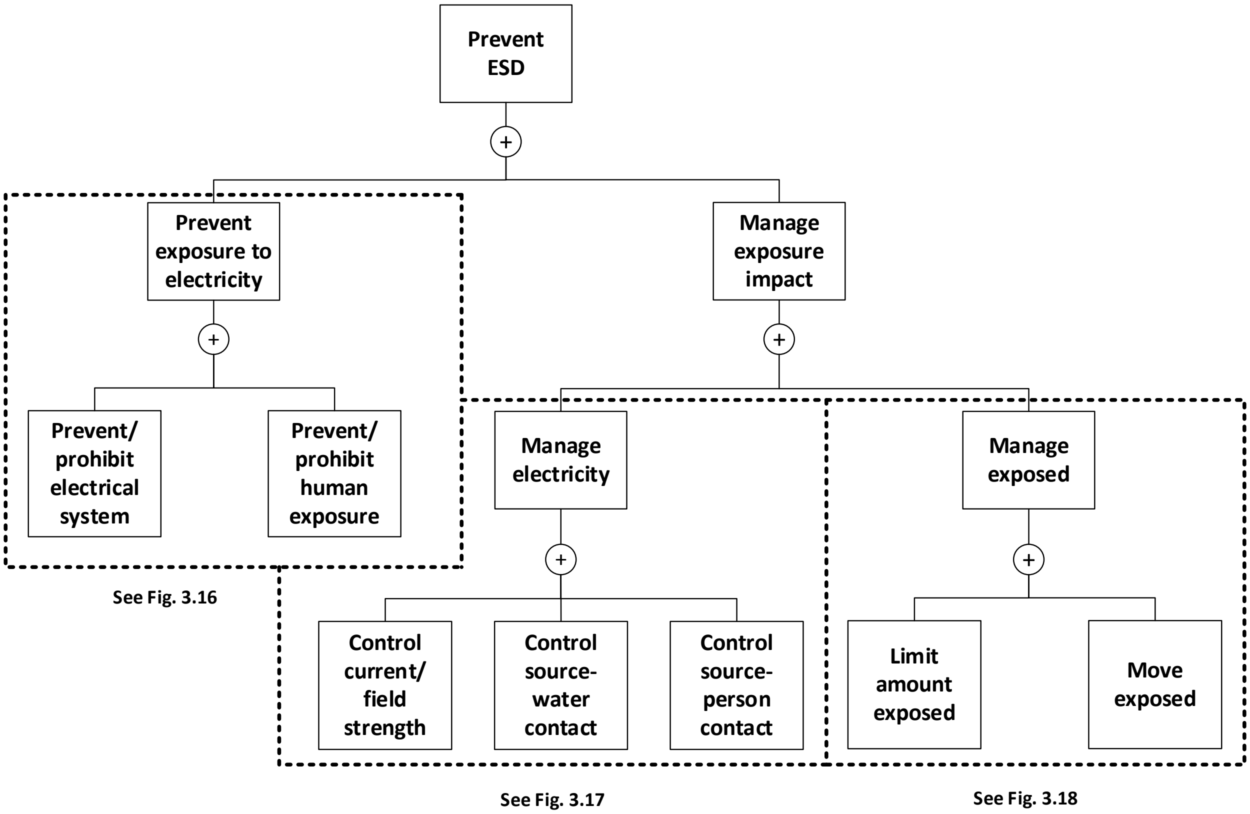

Figure 3.15 Top Level of ESD Concept Tree with Selected Lower-Tiered Gates.

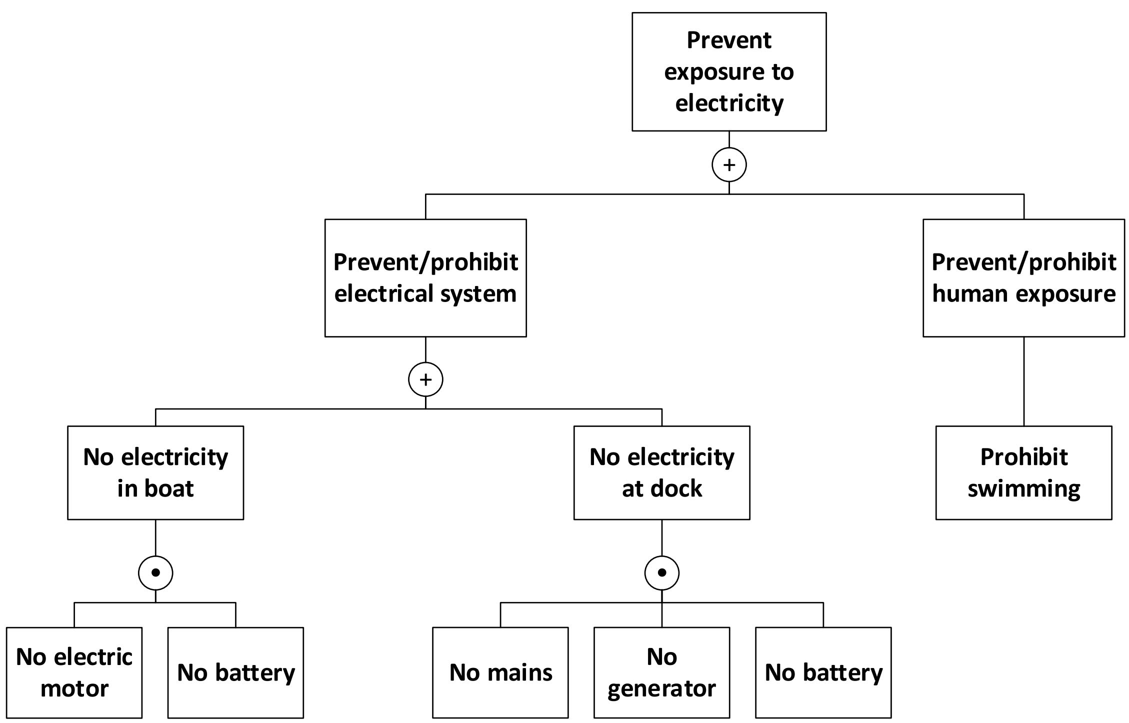

Figure 3.16 Prevent Exposure Branch of ESDCT.

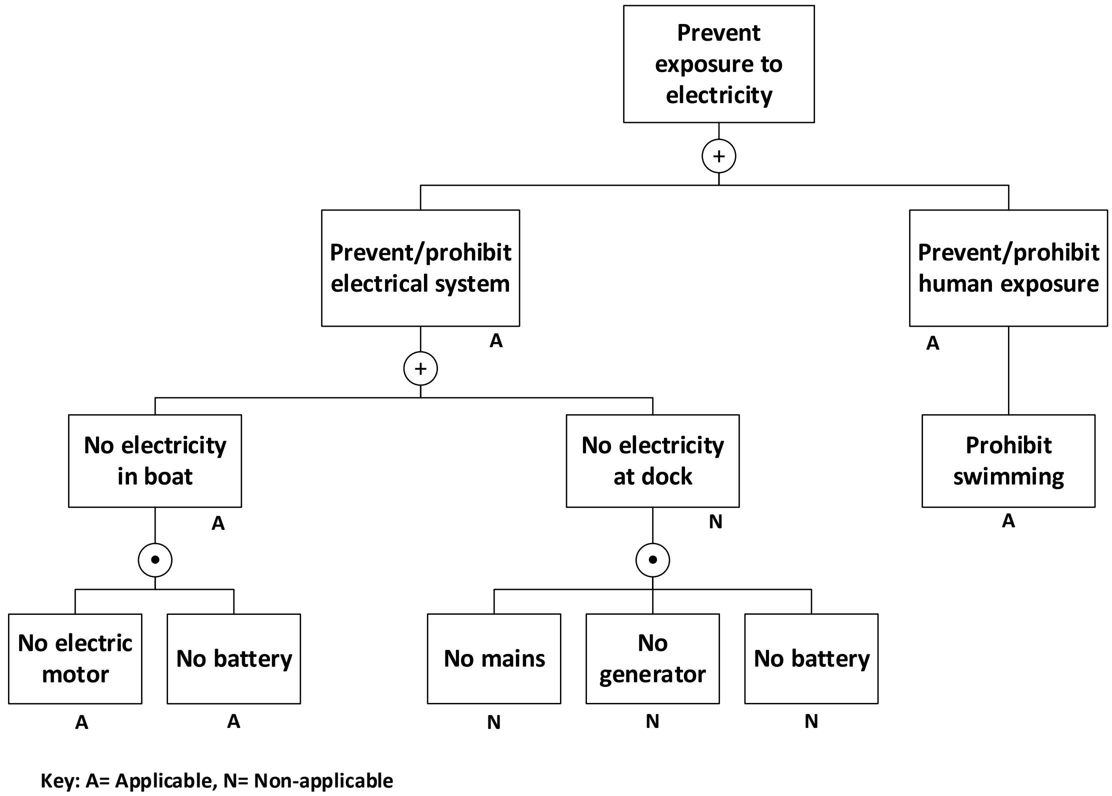

Figure 3.16(a) Prevent Exposure to Electricity in Environment 1.

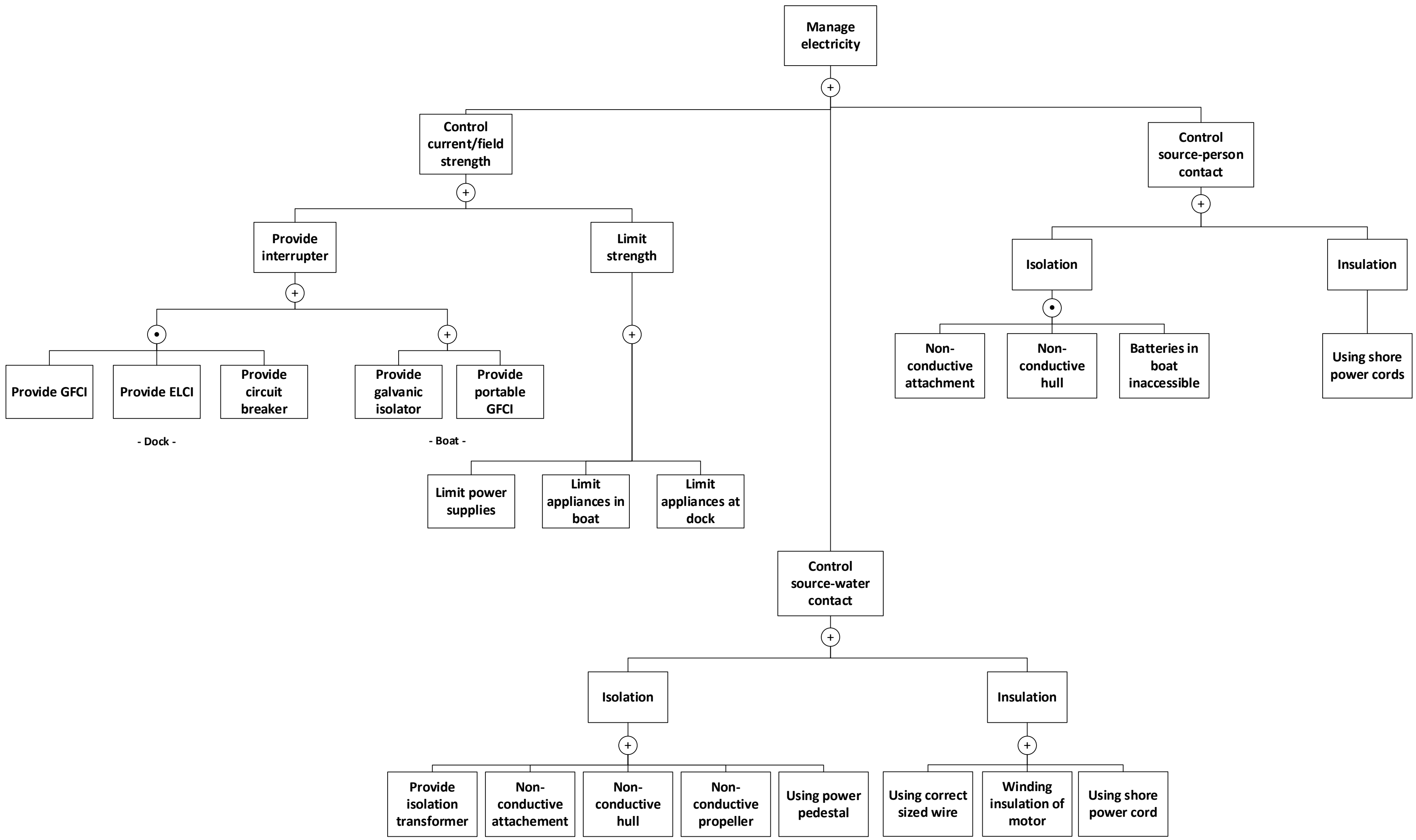

Figure 3.17 Manage Electricity Branch of ESDCT.

In Figure 3.17, ten mitigation options are listed. The explanation for those options are as follows:

Ground Fault Circuit Interrupter (GFCI)
A GFCI prevents shock and electrocution. It operates by quickly shutting off power to the circuit if the electricity flowing into the circuit differs by even a slight amount from that returning. This device trips electrical circuits when a ground fault or leakage current is detected.

Portable GFCI
A portable GFCI does not require special knowledge for installation, and it adds flexibility by protecting outlets that are not GFCIs. A portable GFCI can be used on a temporary basis and should be tested whenever it is used.

Equipment Leakage Circuit Interrupter (ELCI)
An ELCI measures the magnetic field generated by current flow within electrical wires. If an imbalance of current flow is detected, it immediately shuts off electricity to the switches. It can be installed on the boat's shore-cord inlet, and when the leakage current reaches 30 mA, the ELCI will shut off shore power to the boat.

Circuit breaker
Circuit breakers are designed to detect faulty electrical conditions. They operate within electrical systems and interrupt current flow.

Shore power cord
A shore power cord (also called a *marine power cord*) is designed specifically for use near water to provide shore-side electrical power to a boat when its main and auxiliary engines are turned off. Unlike shore power cables, cord ends often fail sooner from internal corrosion.

Power pedestal
A power pedestal (also called a *dockside electrical system*) is a power box designed with corrosion-resistant materials to provide electricity safely on the dock.

Galvanic isolator
Galvanic corrosion occurs when two dissimilar metals are immersed in electrolyte, and the metals are connected by direct contact or by the shore power cord. Generally, installing a galvanic isolator is the most common way to interrupt the circuit safely. A galvanic isolator is connected between a boat's ground and the shore power cord's ground. It allows significant current to pass out of the boat to the shore power ground.

Isolation transformer
An isolation transformer transfers electricity from the shore to the boat and back again using the magnetic field generated by the electrical current. It does not transfer electricity through shore wires physically touching the boat's wires. Compared with other devices like the ELCI, the isolation transformer can correct the power issue without shutting off the power on the boat.

Correct size of wire
When the current flows in wire, heat is produced. In general, wire for shore-side use is rated for 90˚C. Using the correct size of wire is important to avoid failure of insulation and burning.

Winding insulation of motor

To protect the motor against external factors such as high temperature, it is important to measure the winding insulation resistance. It is necessary to insulate components such as the enamel coating on the magnet wire, conduit box, and so forth.

The “Manage exposed” branch of the ESDCT is shown in Figure 3.18.

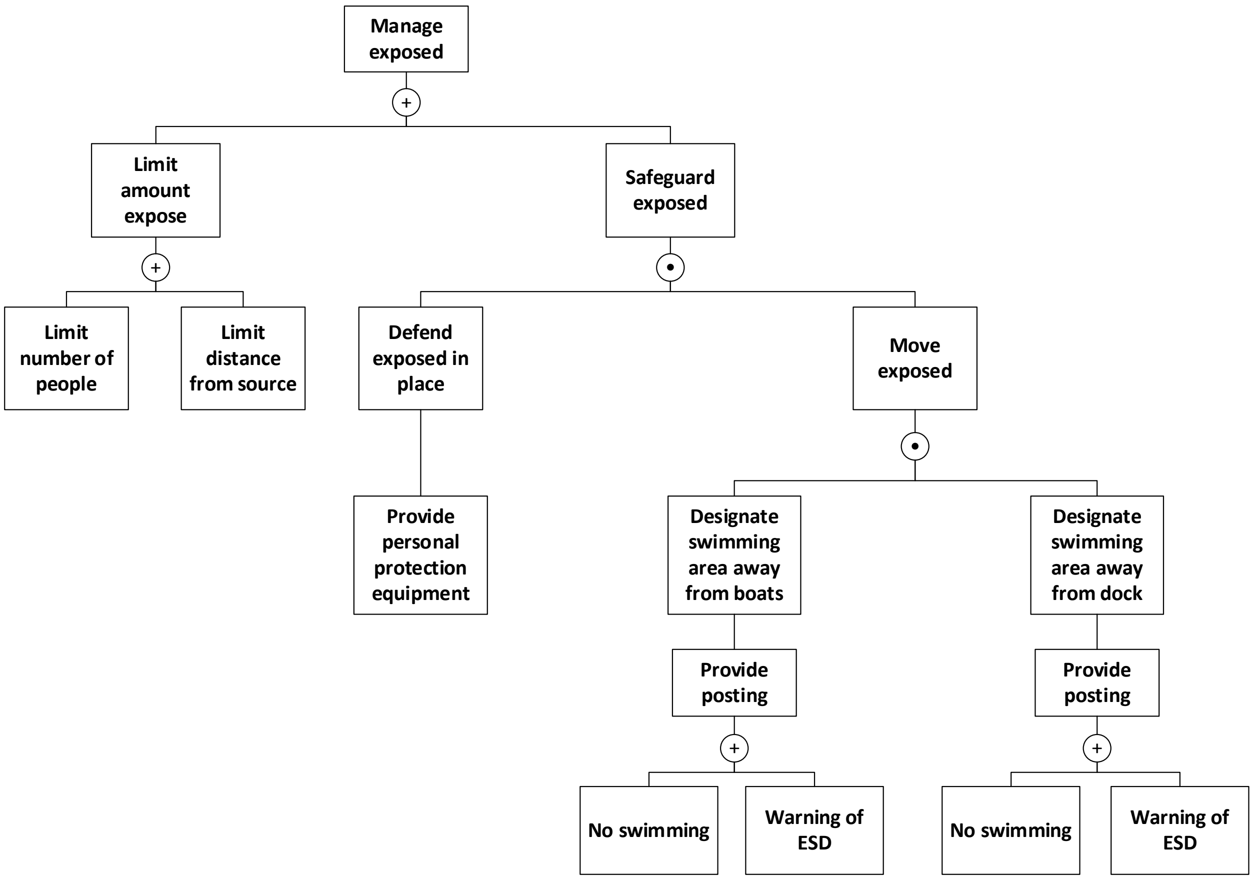

Figure 3.18 Manage Exposed Branch of ESDCT.

As with the FSCT, the ESDCT aims to provide a full set of conditions that impact the potential for ESD along with potential mitigation options. However, the ESDCT does not present the decision maker with a solution, no more than the FSCT does for fire. Further analysis is still required, and several decisions will still need to be made.

For example, for each potential mitigation option, there are technical, policy, financial, and behavioral implications. Prohibiting metal hull boats with electric motors may not be possible due to the transient nature of the user and environment. Preventing someone from drinking alcohol while on a boat or dock near electrical services may not be possible. Posting for no swimming near a dock may be difficult to enforce. Providing appropriate electrical safety controls on boats may be difficult to regulate. Finding the appropriate balance for sufficient power for boats at docks, while staying below hazardous current levels (e.g., 30 mA), may not be practicable. Nonetheless, application of the ESDCT can present a range of options, to which further analysis can be applied, and decisions can be made within the STS framework described previously (i.e., balancing risk, stakeholder objectives, policies, and regulatory and market mechanisms).

4.0 HAZARD IDENTIFICATION

This section focuses on hazards of concern, which need to be addressed as part of the risk management efforts. A hazard is understood to be a condition or physical situation with a potential for harm. To identify and quantify the hazard, we must understand the target, the nature of the hazard and how it impacts the target (vulnerability to the hazard), and under what conditions the hazard can create the impacts (exposure pathways) of concern. As a starting point for this effort, we defined the target to be people, the hazard to be electrical current or field, the sources of which might be submerged power terminals, incorrect wiring/ground faults, failsafe failure, equipment failure, operator negligence or other (to be determined), and the impact to be vulnerability to the current with respect to different physiological aspects, given the pathways of exposure resulting from various combinations on land- and water-based connections.

To begin, we cite the work of Ayyub et al. (2016) who characterized the health effects of electric currents, the relationship between hazard magnitude and impact (up to and including death, as measured in mA of 60-Hz AC current), the pathways of exposure, and a range of hazard scenarios. As noted by Ayyub et al. (2016), the response of the human body to electric shock depends on a number of factors, including source of applied voltage, waveform and frequency, current nature (i.e., AC or DC) and magnitude, equivalent impedance of both the surrounding medium and the victim, pathway taken by the shocking current as it travels through the victim's body, location and area of contact, and shock duration.

4.1 HAZARDS AND CONSEQUENCES TO PEOPLE

4.1.1 PHYSIOLOGICAL ISSUES

The most common physiological effects on the body by increasing current magnitude are perception, muscular contraction, unconsciousness, fibrillation of the heart, respiratory nerve blockage, and burning (Geddes, Baker 1971). The effects of electricity on the human body are affected by diverse variables such as magnitude of the current, electric fields, shock duration, weight of the body, and type of water.

4.1.2 IEEE STANDARD 80

IEEE Standard 80 introduces a method for calculating tolerable body current limit based on research of dangerous electric currents (Dalziel 1946). In Dalziel's studies, equations 4.1 and 4.2 assume electric current that 99.5 percent of all people can safely withstand, without ventricular fibrillation. Those equations for allowable current through the body, I_B, are provided as a function of both weight of the body and shock duration as follows:

$$k = \sqrt{S_B} \qquad \text{(Equation 4.1)}$$

$$I_B = \frac{k}{\sqrt{t_s}} \qquad \text{(Equation 4.2)}$$

Where, k is a constant 0.116 for 50 kg, 0.157 for 70 kg of body weight, S_B is an empirical constant 0.0135 for 50 kg, 0.0246 for 70 kg of body weight, and t represents the shock duration. Equation (2) is not valid for very short or long durations since the test has limitations for time duration with a range of between 0.03 and 3.0 seconds.

4.1.3 MAGNITUDE OF THE CURRENT

Current is defined as the amount of electricity (electrons or ions) flowing per time (second). The magnitude of electric current that flows through the body determines diverse effects of an electric shock. Table 4.1 (Kouwenhoven 1968) describes the general relationship between current magnitude and human body reaction by increasing current magnitude. The table illustrates that current magnitude between 9 mA and 30 mA is referred to as the "let-go range." Because the American Boat & Yacht Council (ABYC) suggested 30 mA of AC as the highest acceptable current to prevent ESD, we adopted 30 mA as a threshold for the project.

Table 4.1 Effects of Electric Current in the Human Body (Kouwenhoven 1968)

Current (mA)	Reaction
< 1	Generally not perceptible
1	Faint tingle
5	Slight shock felt; not painful but disturbing. Average individual can let go. Strong involuntary reactions can lead to other injuries.
6-25 (women)	Painful shock, loss of muscular control*
9-30 (men)	The freezing current or "let-go' range. * Individual cannot let go, but can be thrown away from the circuit if extensor muscles are stimulated.
50-150	Extreme pain, respiratory arrest, severe muscular contractions. Death is possible.
1,000-4,300	Rhythmic pumping action of the heart ceases. Muscular contraction and nerve damage occur; death likely.
10,000	Cardiac arrest, severe burns; death probable

* If the extensor muscles are excited by the shock, the person may be thrown away from the power source.

4.1.4 ELECTRIC FIELD

Electric field (so called potential gradient) refers to a region in which an electric charge experiences a force usually because of a distribution of other charges. It is equivalent to a potential gradient along the field and is measured in volts per meter or volts per foot (Law and Rennie 2015). When the energized conductor is water, the electric field should be considered as well as current. In other words, current is required to make the electric field in the water depending on the resistivity of the water. Research studies, including a suggested electric shock hazard of underwater swimming pool lighting fixtures (Smoot and Bentel 1964), confirmed that 2.12 V/ft and 2.68 V/ft can cause loss of muscular control of the legs. Based on this research, 2 V/ft of electric field is used as a threshold in the project.

4.1.5 BODY MASS

A person can feel an electric shock when they complete a circuit. In the circuit, the body is generally expressed as a single resistor or a network of resistors. People with small frames provide less resistance, and those with large frames provide more. Several studies, including a reevaluation of lethal electric currents (Dalziel 1968), confirmed that the magnitude of current is a function of body weight, and the minimum magnitude of current to cause fibrillation is approximately proportional to the weight of the body. Figure 4.1 illustrates the relation of fibrillating current to body weight for various animals such as sheep, calves, pigs, and dogs for a 3.0 second duration shock.

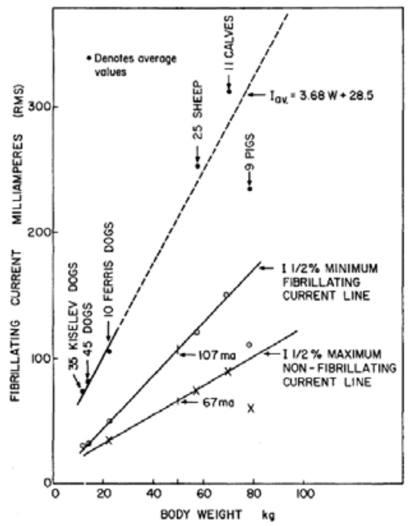

Figure 4.1 Fibrillating Current versus Body Weight for Various Animals for a 3-second Duration Shock (Dalziel, C. F., 1968)

4.1.6 SHOCK DURATION

As noted in Figure 4.2, shock duration is a variable as are body weight and current magnitude. Based on studies (Dalziel 1968), within the range of body weight of the large animals considered, the relationship between fibrillating current and shock duration is independent of body weight. The study also found that the relationship between the magnitude of fibrillating current and shock duration with certain body weights is approximately inversely proportional. Figure 4.2 illustrates fibrillating current versus shock duration for 50 kg and 70 kg of body weight.

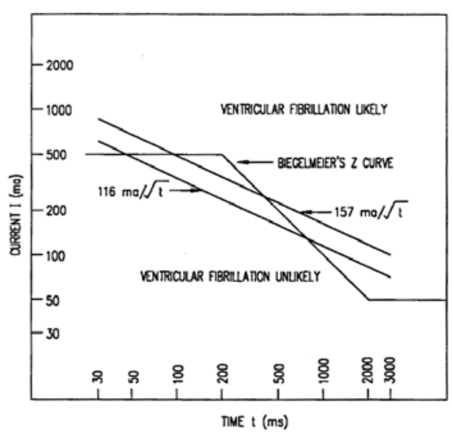

Figure 4.2 Fibrillating Current Versus Shock Duration (Dalziel, C. F., 1968)

4.1.7 TYPE OF WATER

The magnitude of the current depends on the resistivity of the water. Research studies (American Boat & Yacht Council, Inc. 2014) confirmed the importance of water salinity regarding ESD. The risk of ESD increases as water salinity decreases. Water can be freshwater or saltwater. Saltwater is more conductive than freshwater; the resistivity of saltwater is 20 ohm-cm compared to 1400 ohm-cm for freshwater. ESD can occur more readily when a person is in freshwater because human body is closer to saltwater than freshwater. Also, according to statistics data on electric shock drownings (Shafer and Rifkin 2017), the number of incidents in freshwater is far higher than in saltwater (see Annex C).

5.0 RISK EVALUATION

Risk evaluation is defined as the process of comparing the level of risk against risk criteria (AS/NZS 4360:2004). In many cases, a simplified approach such as a hazard matrix or a risk matrix is accepted by interested and affected parties, as the concept may be familiar. This approach should include a maximum consequence for each type of loss (e.g., life safety, property). Each maximum consequence should be ranking very low, low, moderate, high, and very high. The risk matrix approach could be effective because it is widely accepted by affected parties as previously mentioned.

5.1 RISK MATRIX FOR ESD

A risk matrix is developed by considering the ESDCT. In the previous section, the ESDCT was developed by considering the various environments of focus, the risk factors, and the various approaches to identify and manage risk. It is suggested as a tool for identifying scenarios of concern and mitigation options for consideration. Three environments were defined: person-water-boat, person-water-dock, and person-water-dock-boat. The matrix includes regulated components: new boats, existing boats, commercial marina/dock, and private marinas/docks. The matrix reflects the strategies in ESDCT, and it shows the estimation of the strategies by ranking the consequences. In the matrix, the relative effectiveness of mitigation measures is ranked by comparing two reasons why the strategy could have an impact on reducing the risk and two reasons why the strategy might not have an impact on reducing the risk. Relative cost-effectiveness is also ranked by considering different regulated components, market price, and so forth. Finally, by comparing the relative effectiveness of mitigation measures and relative cost-effectiveness, relative impact on reducing overall risk is determined.

5.1.1 RISK MATRIX FOR BOATS

Boats must be classified as new boats and existing boats. Since the number of existing boats is far higher than number of new boats, it affects the estimation of relative cost-effectiveness and relative impact on reducing overall risk. In addition, ranking the relative impact on reducing overall risk for new boats is determined by considering short-term and long-term since initial gains could be small until turnover of boats in use. Table 5.1 is the risk matrix for new boats, and Table 5.2 is the risk matrix for existing boats.

Table 5.1 Risk Matrix for New Boats

<table>
<tr><th colspan="7">New Boats</th></tr>
<tr><th colspan="2">Strategy</th><th>Why the strategy could have an impact on reducing the risk</th><th>Why the strategy might not have an impact on reducing the risk</th><th>Relative effectiveness of mitigation measure</th><th>Relative cost-effectiveness</th><th>Relative impact on reducing overall risk</th></tr>
<tr><td colspan="2">No source of electricity in boat (e.g., row boat, small sail boat)</td><td>The frequency and consequences would be zero because there is no source of electricity in the boat.</td><td>The number of boats with no electricity could be small compared to the overall number of boats.</td><td>Very high[1]</td><td>Very high[2]</td><td>Low[3, 4]</td></tr>
<tr><td colspan="2">Limit power supply and appliances on boat</td><td>It reduces frequency of exposure to unacceptable current levels, and reduces consequences to the person if exposed to the power source.</td><td>The number of boats for which the power supply is modified after purchase could affect the frequency and consequences.</td><td>High</td><td>High[5]</td><td>Short-term: low[4, 6]

Long-term: moderate[4, 6]</td></tr>
<tr><td>Isolate electrical source(s) from person/water contact</td><td>Nonconductive hull</td><td>It reduces frequency of exposure and severity of consequences by keeping people from coming in contact with electricity through the hull.</td><td>There could be another source of leakage current other than the hull but near the hull.</td><td>High</td><td>Moderate-high[7, 8]</td><td>Short-term: low-moderate[4, 6]

Long-term: moderate-high[4, 6]</td></tr>
</table>

[1] Eliminate electricity.
[2] The cost would be very low compared with electric boats.
[3] It is not practical to eliminate all electricity in all boats.
[4] The number of new boats is far lower than the number of existing boats, so initial gains are small until a turnover of boats in use occurs.
[5] More cost comparisons are needed for eliminating electricity in boats.
[6] It depends on boat owners not making changes after purchase.
[7] It depends on the market price of components.
[8] The number of boats with wooden hulls is smaller than the number of boats with fiberglass hulls.

New Boats						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	Nonconductive attachments (e.g., ladder, anchor chain)	It reduces frequency of exposure and severity of consequences associated with contact with conductive attachments.	There could be another source of leakage current other than attachments but near attachments.	Moderate-high[9]	Moderate-high[7]	Short-term: low[4, 6] Long-term: moderate[4, 6]
	Nonconductive propeller, drive, etc.	It reduces frequency of exposure and severity of consequences associated with contact with a conductive propeller.	If a nonconductive propeller is close enough, a person could bridge to the electrical source in the boat.	Moderate[9]	Low-moderate[7]	Short-term: low[4, 6] Long-term: moderate[4 ,6]
	Batteries in boat inaccessible	It reduces frequency of exposure and severity of consequences associated with contact with batteries.	Could be moved batteries or otherwise defeat attempt to isolate source from person.	Moderate	Moderate-high[7]	Short-term: low[4, 6] Long-term: moderate[4, 6]
	Provide interrupter (e.g., portable GFCI, galvanic isolator)	It reduces frequency of exposure and severity of consequences associated with contact with energized material by shutting off the power source.	The interrupter could malfunction or be absent.	High	Moderate[7]	Short-term: moderate[4, 6] Long-term: high[4, 6]

[9] Effectiveness can also increase with a nonconductive hull.

New Boats						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
Insulate electrical sources from person/water contact	Winding insulation of motor	It reduces frequency of exposure and severity of consequences.	The insulation could fail and the high temperature could accelerate corrosion.	Moderate[10]	Moderate-high[7]	Short-term: low[4,6] Long-term: moderate[4,6]
	Using correct-sized wire in boat electrical system	It reduces frequency of exposure and severity of consequences by keeping people from coming in contact.	The insulation could fail and the high temperature could accelerate corrosion.	High[10]	Moderate[7]	Short-term: moderate[4,6] Long-term: high[4,6]
Provide warnings	"No swimming" warning in boat	It reduces frequency of exposure to unacceptable levels of electricity in the water by prohibiting swimming near the boat.	The warning might be ignored since some research shows some people do not heed signs/warnings.	Moderate[11]	High	Low-moderate[12]
	ESD warning in boat	It reduces frequency of exposure to unacceptable levels of electricity in the water by providing warning of ESD directly.	The warning might be ignored since some research shows some people do not heed signs/warnings.	High[11]	High	Moderate-high[12]
Education	For boat owners	It reduces frequency of exposure and severity of consequences by educating about electrical systems of their boats and ESD.	Boat owners might not put learnings into effect.	Moderate	Moderate	Low-moderate

[10]It depends on the time until the insulation fails and the high temperature accelerates corrosion.
[11] Effectiveness can also increase with education, regulations/penalties regarding noncompliance, and public safety communications.
[12] It depends on number of people complying with warnings.

New Boats						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	For swimmers	It reduces frequency of exposure to unacceptable levels of electricity by educating swimmers about ESD before they enter the water.	Swimmers might not put learnings into effect.	High	Moderate-high	High[13]
	For qualified inspectors	It reduces frequency of exposure and severity of consequences by educating the professional inspector about defective electrical system issues relating to ESD.	Inspectors might not put learnings into effect.	High	Moderate-high	Low-moderate[14]
Inspection	By agency (e.g., Coast Guard)	It reduces frequency of exposure and severity of consequences by inspection for compliance with institutional strategies.	Professional knowledge of electricity might be deficient compared with electrical engineers.	High	Low-moderate	Moderate
	By qualified inspectors	It reduces frequency of exposure and severity of consequences by inspecting the overall electrical system professionally.	Human error could affect frequency and consequences.	High	Low-moderate	Low-moderate[15]

[13] Educating swimmers has relatively higher impact than educating boat owners or inspectors, because swimmers are directly affected by ESD.
[14] Depends on percentage of regulated area.
[15] There may be some limitations due to jurisdictional concerns.

New Boats					
Strategy	**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
License/register boats (with identification of power sources and requirements)	It reduces frequency of exposure and consequences by enabling control of the overall strategy by making people aware of requirements for their boats.	The number of people operating boats without licenses or registrations could affect frequency and consequences.	High	Moderate	Moderate
Regulations/penalties regarding noncompliance	It reduces frequency of exposure and consequences by enabling control of the overall strategy by making people aware.	People might evade the regulation.	High	Moderate-high	Moderate-high
Public safety communications (e.g., providing awareness campaigns)	It reduces frequency of exposure and severity of consequences by broadcasting information regarding ESD.	If few people care about safety communications, it would affect frequency and consequences.	High	Low-moderate	Moderate-high[16]

[16] Unlike education, public communication targets diverse groups, not just a specific group.

Table 5.2 Risk Matrix for Existing Boats

Existing Boats						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measures**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
No source of electricity in boat (e.g., row boat, small sail boat)		The frequency and consequences would be zero since it eliminates the source of electricity in boats.	The number of boats with no electricity could be small compared to the overall number of boats.	Very high[1]	Very high (Boats with no electricity) Very low[2] (Boat with electricity)	Low[3]
Limit power supply and appliances on boat		It reduces the frequency of exposure to unacceptable current levels, and reduce consequences to the person if exposed to the power source.	The number of boats that modify the power supply after purchase could affect the frequency and consequences.	High	Low-moderate[2]	Moderate[3]
Isolate electrical source(s) from person/water contact	Nonconductive hull	It reduce frequency of exposure and severity of consequences by keeping people from coming in contact with electricity through the hull.	There could be another source of leakage current other than the hull but near the hull	High	Low[2, 4]	Low[3]
	Nonconductive attachments (e.g., ladder, anchor chain)	It reduces frequency of exposure and severity of consequences associated with contact with	There could be another source of leakage current other than attachments but near attachments.	Moderate-high[5]	Low-moderate[2, 4]	Low[3] (If not modified) Moderate-high[3] (If many boats modified)

[1] Eliminate electricity.
[2] It is not likely that many existing boats would be retrofitted.
[3] The number of existing boats is far higher than the number of new boats.
[4] It depends on the market price of components.
[5] Effectiveness can also increase with nonconductive hulls.

Existing Boats						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measures**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
		conductive attachments.				
	Nonconductive propeller, drive, etc.	It reduces frequency of exposure and severity of consequences associated with contact with conductive propeller.	If the nonconductive propeller is close enough, a person could bridge to the electrical source in the boat.	Moderate[5]	Low-moderate[2, 4]	Low[3] (If not modified) Moderate-high[3] (If many boats modified)
	Batteries in boat inaccessible	It reduces frequency of exposure and severity of consequences associated with contact with batteries.	Could be moved batteries or otherwise defeat attempt to isolate source from person.	Moderate	Moderate[2, 4]	Low[3] (If not modified) Moderate-high[3] (If many boats modified)
	Provide interrupter (e.g., portable GFCI, galvanic isolator)	It reduces frequency of exposure and severity of consequences associated with contact with energized material by shutting off the power source.	The interrupter could malfunction or be absent.	High	Low[2, 4]	Moderate-high[3]
Insulate electrical sources from person/water contact	Winding insulation of motor	It reduces frequency of exposure to unacceptable current by keeping people from coming in contact with electricity but no	The insulation could fail and high temperature could and accelerate corrosion.	Moderate[6]	Low[2, 4]	Low[3] (If not modified) Moderate-high[3] (If many boats modified)

[6] It depends on the time until the insulation fails and high temperature accelerates corrosion.

Existing Boats						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measures**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
		change of consequences.				
	Using correct-sized wire in boat electrical system	It reduces frequency of exposure and severity of consequences by keeping people from coming in contact with electrical sources.	The insulation could fail and high temperature could accelerate corrosion.	High[6]	Low[2, 4]	Low[3] (If not modified) Moderate-high[3] (If many boats modified)
Providing Warnings	"No swimming" warning in boat	It reduces frequency of exposure to unacceptable levels of electricity in the water by providing a safe distance from the boat.	People might ignore the warning since some research shows some people do not heed signs/warnings.	Moderate[7]	High	Low-moderate[8]
	Warning in boat of ESD	It reduces frequency of exposure to unacceptable levels of electricity in the water by providing direct warning of ESD.	People might ignore the warning since some research shows some people do not heed signs/warnings.	High[7]	High	Moderate-high[8]
Education	For boat owners	It reduces frequency of exposure and severity of consequences by educating about the electrical system of their boats and ESD.	If boat owners do not put learnings into effect, it could affect frequency and consequences.	Moderate	Moderate	Low-Moderate

[7] Effectiveness can also increase with education, regulation/penalties for noncompliance, and public safety communications.
[8] It depends on the number of people complying with the warnings.

Existing Boats						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measures**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	For swimmers	It reduces frequency of exposure to unacceptable levels of electricity by educating swimmers directly about ESD before they enter the water.	If swimmers do not put learnings into effect, it could affect frequency and consequences.	High	Moderate-high	High[9]
	For qualified inspectors	It reduces frequency of exposure and severity of consequences by educating the professional inspector about defective electrical system issues relating to ESD.	If inspectors do not put learnings into effect, it could affect frequency and consequences.	High	Moderate-High	Low-Moderate[10]
Inspection	By agency (e.g., Coast Guard)	It reduces frequency of exposure and severity of consequences by inspecting for compliance with institutional strategies.	Professional knowledge of electricity might be deficient compared with electrical engineers.	High	Low-Moderate	Moderate
	By qualified inspectors	It reduces frequency and consequences of exposure to unacceptable levels of electricity by inspecting the overall	Human error could affect frequency and consequences.	High	Low-moderate	Low-moderate[11]

[9] Educating swimmers would have relatively higher impact than educating boat owners or inspectors, because swimmers are directly affected by ESD.
[10] It depends on the percentage of regulated area.
[11] There may be some limitations due to jurisdictional concerns.

Existing Boats					
Strategy	**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measures**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	electrical system professionally.				
Licensing/registering boats (with identification of power sources and requirements)	It reduces frequency and consequences by enabling control of the overall strategy by making people aware of requirements for their boats.	The number of people operating boats without licenses or registrations could affect frequency and consequences.	High	Moderate	Moderate
Regulations/penalties regarding noncompliance	It reduces frequency and consequences by enabling control of the overall strategy by making people aware.	If people evade the regulation, it could affect frequency and consequences.	High	Moderate-high	Moderate-high
Public safety communications (e.g., providing awareness campaign)	It reduces frequency of exposure and severity of consequences by broadcasting information regarding ESD.	If few people care about safety communications, it could affect frequency and consequences.	High	Low-moderate	Moderate-high[12]

[12] Unlike education, public communication targets diverse groups, not just a specific group.

5.1.2 Risk Matrix for Marinas/Docks

The regulated components for marinas/docks are broken out into two classifications: commercial marinas/docks (Table 5.3) and private marinas/docks (Table 5.4). Unlike commercial marinas/docks, the private dock is difficult to inspect, control, and regulate. Also, the size of docks must be considered in terms of the number of slips. These differences affect the relative impact on reducing overall risk at the dock.

Table 5.3 Risk Matrix for Commercial Marinas / Docks

<table>
<tr><th colspan="7">Commercial Marinas/Docks</th></tr>
<tr><th colspan="2">Strategy</th><th>Why the strategy could have an impact on reducing the risk</th><th>Why the strategy might not have an impact on reducing the risk</th><th>Relative effectiveness of mitigation measure</th><th>Relative cost-effectiveness</th><th>Relative impact on reducing overall risk</th></tr>
<tr><td colspan="2">Prohibit sources of electricity at the dock (e.g., no mains, no generator, no battery)</td><td>The frequency and consequences would be zero because it eliminates the source of electricity at marinas / docks.</td><td>This strategy is not practical for the commercial marina/dock.</td><td>Very high[1]</td><td>Low-moderate</td><td>Low[2]</td></tr>
<tr><td colspan="2">Limit power supply and appliances at the dock</td><td>It reduces frequency of exposure and severity of consequences to the person if exposed to the power source.</td><td>Could be the number of electrical systems at dock modify the power supply after construction.</td><td>High</td><td>Moderate</td><td>Moderate-high[3, 4]</td></tr>
<tr><td rowspan="2">Isolate electrical source(s) from person/water contact</td><td>Provide isolation transformer at dock</td><td>It reduces frequency of exposure and severity of consequences associated with contact with conductive materials at dock.</td><td>There could be a malfunction of controlling power issue.</td><td>Moderate-high[5]</td><td>Short-term: low[6]:
Long-term: high[6]</td><td>Moderate-high[3, 4]</td></tr>
<tr><td>Use power pedestal</td><td>It reduces frequency of exposure and severity of consequences associated with contact with conductive materials at dock.</td><td>A power pedestal might contain defective parts.</td><td>Moderate[7]</td><td>Moderate-high[6]</td><td>Low-Moderate[3, 4]</td></tr>
</table>

[1] Eliminate electricity.
[2] It is not practical to eliminate electricity at a commercial marina/dock.
[3] It depends on dock owners not making changes after construction.
[4] It depends on the number of electrical systems at the dock.
[5] An isolation transformer does not shut off the power; therefore, its effectiveness would be lower than providing an interrupter.
[6] It depends on the market price.
[7] It depends on the time until the insulation fails and high temperature accelerates corrosion.

Commercial Marinas/Docks						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	Provide interrupter (e.g., GFCI, ELCI, circuit breaker)	It reduces frequency of exposure and severity of consequences by shutting off the power.	The interrupter might malfunction or being absent.	High	Moderate[6]	Moderate-high[3, 4]
Insulate electrical sources from person/water contact	Use shore power cord	It reduces frequency of exposure and severity of consequences associated with contact with energized material.	The insulation could fail and high temperature could accelerate corrosion.	Moderate-high[7]	Moderate-high[6]	Moderate[3, 4]
Designate swimming area away from docks and designated boating waterways		The frequency and consequences would be zero because it eliminates the source of electricity from the swimming area.	There could be an unexpected accident (e.g., using prohibited electrical items, boating off waterways).	Very high[8]	High	Moderate-high[9]
Provide warnings	"No swimming" warning at dock	It reduces frequency of exposure to unacceptable levels of electricity in the water by indicating a safe distance from the dock.	People might ignore the warning since some research shows some people do not heed signs/warnings.	Moderate-high[8]	Moderate-high[10]	Moderate[11]

[8] Effectiveness could increase with education, regulation/penalties for noncompliance, and public safety communications.
[9] It depends on the number of people complying with the signs.
[10] It depends on the size of marinas/docks and the number of signs.
[11] It depends on the number of people complying with the warnings.

Commercial Marinas/Docks						
Strategy		Why the strategy could have an impact on reducing the risk	Why the strategy might not have an impact on reducing the risk	Relative effectiveness of mitigation measure	Relative cost-effectiveness	Relative impact on reducing overall risk
	ESD warning dock	It reduces frequency of exposure to unacceptable levels of electricity in the water by providing direct warning of ESD.	People might ignore the warning since some research shows some people do not heed signs/warnings.	High[8]	Moderate-High[10]	Moderate-High[11]
Education	For dock/marina owners	It reduces frequency of exposure and severity of consequences by educating about the electrical system at the dock and ESD.	Owners might not put learnings into effect.	Moderate	Moderate	Low-moderate
	For employees (e.g., operator, supervisor)	It reduces frequency of exposure to unacceptable levels of electricity and reduce consequences by educating about electrical system of dock.	Boat owners might not put learnings into effect.	Moderate	Moderate-high	Moderate-high
	For swimmers	It reduces frequency of exposure to unacceptable levels of electricity by educating swimmers directly about ESD before they enter the water.	Swimmers might not put learnings into effect.	High	Moderate-high	High[12]
	For qualified inspectors	It reduces frequency of exposure and severity of consequences by educating professional	Inspectors might not put learnings into effect.	High	Moderate-high	Moderate-high[13]

[12] Educating swimmers would have a relatively higher impact than educating marina owners, employees, because swimmers are more directly affected by ESD.
[13] It depends on the percentage of regulated area.

Commercial Marinas/Docks						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
		inspectors about defective electrical system issues relating to ESD.				
Inspection	By agency (e.g., Coast Guard)	It reduces frequency of exposure and severity of consequences by requiring inspection for compliance with institutional strategies.	Professional knowledge of electricity might be deficient compared with electrical engineers.	High	Low-moderate	Moderate
	By qualified inspectors	It reduces frequency and severity of consequences by requiring professional inspection of the overall electrical system.	Human error could affect frequency and consequences.	High	Low-moderate	Moderate-high[14]
Permits to install electrical connections		It reduces frequency of exposure and severity of consequences by enabling control of overall strategy by requiring people to obtain permits before installing electrical connections.	People might evade the regulations.	High	Moderate	Moderate-high (If required)
Regulations/penalties for noncompliance		It reduces frequency of exposure and severity of consequences by enabling control of overall strategy by instituting regulations	People might evade the regulations.	High	Moderate-high	Moderate-high

[14] There may be limitations due to jurisdictional concerns.

Commercial Marinas/Docks					
Strategy	**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	and penalties for noncompliance.				
Public safety communications	It reduces frequency of exposure and severity of consequences by broadcasting information about ESD.	If few people care about safety communications, it could affect frequency and consequences.	High	Low-moderate	Moderate-high[15]

[15] Unlike education, public communication targets diverse groups, not just a specific group.

Table 5.3 Risk Matrix for Private Marinas / Docks

Private Marinas/Docks						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
Prohibit all sources of electricity at dock (e.g., no mains, no generator, no battery)		The frequency and consequences would be zero because it eliminates the source of electricity at marinas / docks.	The strategy is not practical for private marinas/docks.	Very high[1]	Low-moderate	Moderate-high[2, 3]
Limit power supply and appliances at dock		It reduces frequency of exposure and severity of consequences to the person if exposed to the power source.	Could be number of electrical systems at dock that modify the power supply after construction.	High	Moderate	Moderate-high[3, 4]
Isolate electrical source(s) from person/water contact	Provide isolation transformer at dock	It reduces frequency of exposure and severity of consequences of contact with conductive materials at the dock.	There could be a malfunction of controlling power issue.	Moderate-high[5]	Short-term: low[6]: Long-term: high[6]	Moderate-high[3, 4, 7]
	Use power pedestal	It reduces frequency of exposure and severity of consequences associated with contact with conductive materials at the dock.	The power pedestal could contain defective parts.	Moderate[8]	Moderate-high[6]	Low-moderate[3, 4, 7]

[1] Eliminate electricity.
[2] It is not practical to eliminate electricity at all private marinas/docks but relatively more practical than commercial marinas/docks.
[3] It is difficult to inspect, control, and regulate private marinas/docks.
[4] It depends on the number of electrical systems at the dock.
[5] The transformer does not shut off the power; therefore, it would be less effective than an interrupter.
[6] It depends on the market price.
[7] It would be expensive for private marina/dock owners.
[8] It depends on the time until the insulation fails and the high temperature accelerates corrosion.

Private Marinas/Docks						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	Provide interrupter (e.g., GFCI, ELCI, and circuit breaker)	It reduces frequency of exposure and severity of consequences by shutting off the power.	The interrupter could malfunction or be absent.	High[4]	Moderate[6]	Moderate-high[3, 4, 7]
Insulate electrical sources from person/water contact	Use shore power cord	It reduces frequency of exposure and severity of consequences associated with contact with energized material.	The insulation could fail and high temperature could accelerate corrosion.	Moderate-high	Moderate-high[6]	Moderate[3, 4, 7]
Designate swimming area away from docks and designated boating waterways		The frequency and consequences would be zero because it eliminates the source of electricity from the swimming area.	There could be an unexpected accident (e.g., using prohibited electrical items, boating off waterways).	Very high[9]	High	Moderate-high[3, 10]
Provide warnings	"No swimming" warning at dock	It reduces frequency of exposure to unacceptable levels of electricity in the water by indicating a safe distance from the dock.	People might ignore warnings since some research shows some people do not heed signs/warnings.	Moderate-high	Moderate-high[11]	Moderate-high[3, 12]

[9] Effectiveness can increase with education, regulation/penalties regarding noncompliance, and public safety communications.
[10] It depends on the number of people complying with signs.
[11] It depends on the size of marinas/docks and the number of signs.
[12] It depends on the number of people complying with the warnings.

Private Marinas/Docks						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
	ESD warning at dock	It reduces frequency of exposure to unacceptable levels of electricity in the water by providing a direct warning about ESD.	People might ignore the warnings since some research shows some people do not heed signs/warnings.	High	Moderate-high[11]	Moderate-high[3, 12]
Education	For dock/marina owners	It reduces frequency of exposure and severity of consequences by providing education about electrical systems at the dock and ESD.	Dock owners might not put learnings into effect.	Moderate	Moderate	Low-moderate
	For employees (e.g., operator, supervisor)	It reduces frequency of exposure to unacceptable levels of electricity and reduce consequences by educating about electrical system of dock more professionally than boat owners regarding ESD.	Boat owners might not put learnings into effect.	Moderate	Moderate-high	Low[13]
	For swimmers	It reduces frequency of exposure to unacceptable levels of electricity by educating swimmers directly about ESD	Swimmers might not put learnings into effect.	High	Moderate-high	Moderate-high[14]

[13] It is not practical for private marina/dock owners to employ people.
[14] Educating swimmers would have a relatively higher impact than educating marina owners, employees, and inspectors, because swimmers are more directly affected by ESD.

Private Marinas/Docks						
Strategy		**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
		before they enter the water.				
	For qualified inspectors	It reduces frequency of exposure and severity of consequences by educating professional inspectors about defective electrical system issues relating to ESD.	Inspectors might not put learnings into effect.	High	Moderate-high	Low
Inspection	By agency (e.g., Coast Guard)	It reduces frequency of exposure and severity of consequences by inspecting for compliance with institutional strategies.	Professional knowledge of electricity might be deficient compared with electrical engineers.	High	Low-moderate	Low[3]
	By qualified inspectors	It reduces frequency of exposure and severity of consequences by inspecting the overall electrical system professionally.	Human error could affect frequency and consequences.	High	Low-moderate	Low[3, 15]
Permits to install electrical connections		It reduces frequency and consequences by enabling control of the overall strategy by requiring people to obtain permits to install electrical connections.	People might evade the regulations.	High	Moderate	Moderate-High[3] (If required)

[15] There may be some limitations due to jurisdictional concerns.

Private Marinas/Docks					
Strategy	**Why the strategy could have an impact on reducing the risk**	**Why the strategy might not have an impact on reducing the risk**	**Relative effectiveness of mitigation measure**	**Relative cost-effectiveness**	**Relative impact on reducing overall risk**
Regulations/penalties for noncompliance	It reduces frequency of exposure and severity of consequences by enabling control of the overall strategy by imposing penalties for noncompliance.	People might evade the regulations.	High	Moderate-high	Low-moderate[3]
Public safety communications	It reduces frequency of exposure and severity of consequences by broadcasting information about ESD.	If few people care about safety communications, it could affect frequency and consequences.	High	Low-moderate	Low[16]

[16] Unlike education, public communication targets diverse groups, not just a specific group.

5.1.3 Estimation of Strategies (Controls on Electricity)

Some strategies from ESDCT are suggested, and they are estimated with some assumptions and reasons. The strategy of "No source of electricity" can reduce frequency and consequences to zero, because it eliminates the source of electricity in boats and at docks. However, the number of boats with no electricity could be small compared to the total number of boats. Also, this strategy is not practical for commercial and private marinas/docks. Although pros and cons exist, relative effectiveness can be measured as very high for boats (new and existing) and for marinas/docks (commercial and private). Relative cost-effectiveness would be very high for new boats and very high for existing boats with no electricity (e.g., row boat, small sail boat), but very low for existing boats with electricity, because it is not likely many boats would be retrofitted. Relative cost-effectiveness would be low-moderate for both commercial and private marinas/docks. Considering the number of new boats and existing boats, relative impact on overall risk would be low for both new boats and existing boats but for different reasons: eliminating electricity in every new boat is not practical, and there are too many existing boats. Relative impact is estimated as low for commercial docks, since it is not practical to eliminate electricity, and moderate-high for private docks since it is more practical than commercial docks.

Limiting power supply and appliance on boats and at docks is another strategy that reduces frequency of exposure to unacceptable current levels, and consequences to the person exposed to the power source. However, the relative cost-effectiveness of modifying the power supply and appliances can be ranked as high for new boats, low-moderate for existing boats (since it is not likely many existing boats would be retrofitted), and moderate for commercial and private docks. Relative impact on reducing overall risk for new boats could be ranked as low for the short-term and moderate for the long-term since it depends on boat owners not making changes after purchase, and initial gains would be small until turnover of boats in use occurs. For existing boats, the relative impact is estimated as moderate, considering the number of existing boats. In addition, it is estimated as moderate-high for both commercial and private docks but for different reasons. Whereas the relative impact depends on the number of electrical systems at commercial docks, it is difficult to determine whether or not private dock owners applied the strategy.

For boats, using nonconductive hulls (e.g., wooden hulls, fiberglass hulls), attachments (e.g., ladders, anchor chains), and propellers, and making boat batteries inaccessible and providing interrupters (e.g., portable GFCI, galvanic isolators) are suggested as strategies to isolate an electrical source from person/water contact.. Relative effectiveness can be estimated as high for nonconductive hulls, moderate-high for nonconductive attachments, moderate for nonconductive propellers, moderate for inaccessible boat batteries, and high for interrupters. For non-conductive hulls, relative cost-effectiveness is ranked as m-high for new boats, since the number of boats with wooden hulls is smaller than the number of boats with fiberglass hulls (considering market tendencies), and low for existing boats, because it is not likely that large numbers of existing boats would be retrofitted. For new boats, relative impact is low-moderate for the short-term, moderate-high for the long-term considering the number of new boats. It also depends on boat owners not making changes after purchase. For existing boats, relative impact is ranked as low considering the number of existing boats.

The strategy of using nonconductive attachments for new boats is determined to be moderate-high for relative cost-effectiveness, depending on market price, and low-m for existing boats when compared with the number of new boats. Relative impact for new boats is low for the short-term and moderate for the long-term, considering the initial gains. The relative impact for existing boats is low if existing boats are not modified and moderate-high if many existing boats have been modified, due to the number of existing boats.

Using nonconductive propellers for new and existing boats can be estimated as low-moderate for relative cost-effectiveness based on market price, and relative impact for new boats is low for the short-term and moderate for the long-term, considering the number of boats and boat owners' future behavior. Comparing with new boats, the relative impact for existing boats is low if existing boats have not been modified and moderate-high if many existing boats have been modified, because the number of existing boats far exceeds the number of new boats.

The strategy of making boat batteries inaccessible ranks as moderate-high for relative cost-effectiveness for new boats compared with using nonconductive materials. The relative impact is low for the short-term and moderate for the long-term. The relative impact of using nonconductive propellers and attachments and making boat batteries inaccessible is the same, but the impact is lower than using nonconductive hulls, since the probability of touching those parts is lower than the probability of touching the hull. For existing boats, the relative cost-effectiveness of making boat batteries inaccessible is moderate is lower than the relative effectiveness for new boats, due to the number of existing boats. The relative impact is low if existing boats have not been modified and moderate-high if many existing boats have been modified.

Providing interrupters is another option for reducing risk. The relative cost-effectiveness is moderate for new boats and low for existing boats because of the number of existing boats. Relative impact for new boats is moderate for the short-term and high for the long-term, considering the boat owner's behavior after purchase and initial gains of the strategy. For existing boats, the relative impact is estimated as moderate-high, considering the number of existing boats.

Winding insulation of motors and correct-sized wire for boat electrical systems are also suggested as strategies to isolate electrical sources from person/water contact. However, these strategies might not reduce the risk of insulation failure and the subsequent acceleration of corrosion by high temperature. The relative effectiveness of these mitigation measures for both new boats and existing boats is moderate for motor insulation and high for correct-sized wire, since the rate of corrosion in exposed wire is higher than in motors, although motors produce higher temperatures. For new boats, relative cost-effectiveness of motor winding insulation could be moderate-high but moderate for correct-sized wire, considering market price. For motor, the relative impact is Low for the short-term, and Moderate for the long-term that are lower relative impact than using correct sized wire since the effect of wire regarding ESD is higher than motor. In contrast, existing boat needs far more cost than new boats because of number of boats, so the relative cost effectiveness is Low for motor and wire. Although motor and wire are determined as Low (if not modified) and Moderate-High (if many boats modified) for relative impact on reducing overall risk, using correct sized wire in boat electrical system could be higher than winding insulation of motor.

As strategies to isolate electrical sources from person/water contact for marinas/docks, providing an isolation transformer at the dock, using a power pedestal, and providing an interrupter (e.g., GFCI, ELCI, circuit breaker) are suggested. Based on ESDCT, using a shore power cord is another strategy to isolate electrical sources from person/water contact. Providing isolation transformers at dock can reduce the frequency of exposure and severity of consequences associated with contact with conductive materials at the dock but malfunction of controlling power issue could affect the risk. Because the relative effectiveness of this strategy for both commercial and private docks could be lower than limiting power supply and appliances at docks, it is ranked as moderate-high. Also, an isolation transformer does not shut off the power, so its effectiveness would be lower than an interrupter. The relative cost-effectiveness is low for the short-term and high for the long-term for both commercial and private docks because of the benefits of transformers compared with interrupters. The relative impact on reducing overall risk is moderate-high for both but for different reasons: for commercial docks, the size of the dock must be considered; for private docks, inspection, controlling, and regulation must be considered.

Using a power pedestal at the dock can also reduce the frequency of exposure and severity of consequences, but mitigation effectiveness would be decreased if any parts are defective. Compared with an isolation transformer, the relative effectiveness could be moderate (lower than an isolation transformer). Also, relative cost-effectiveness is moderate-high, depending on market price. Although relative impact is determined as low-moderate for both commercial and private docks, the size of the dock must be considered for commercial docks and the difficulties of inspection and regulation must be considered for private docks.

Providing interrupters can reduce the frequency of exposure and severity of consequences by shutting off the power, but malfunction or absence of the interrupter could affect effectiveness. Compared with an isolation transformer, the relative effectiveness could be higher because interrupters shut off the power rather than control electricity. However, relative cost-effectiveness could be higher than transformers because of their characteristics (needed to be replaced), and, therefore, it is ranked as moderate. Relative impact on reducing risk is determined as moderate-high for both commercial and private docks.

Using a shore power cord reduces the frequency of exposure and severity of consequences associated with contact with energized material, but failure of the insulation and subsequent acceleration of corrosion by high temperature could affect its relative effectiveness. For that reason, its relative effectiveness as a mitigation measure is ranked as moderate-high compared with using a power pedestal (exposure of wire occurs more often with a shore power cord than with a power pedestal). Relative cost-effectiveness is determined as moderate-high, depending on the market price of wire. Compared with using a power pedestal, the relative impact of using a shore power cord on reducing overall risk could be higher because of its greater effectiveness.

5.1.4 Estimation of Strategies (Controls on People)

In addition to strategies for electrical systems in boats or at docks, designating swimming areas away from docks and designated boating waterways, posting warnings, educating stakeholders, instituting inspections and mandatory licensing/registering of boats (with identification of power sources and requirements), requiring permission to install electrical connections, instituting regulations and penalties for noncompliance, and broadcasting public safety communications are also suggested as strategies.

Unlike strategies for electrical systems, the relative effectiveness, cost-effectiveness, and impact of mitigation measures on reducing risk could be same for new boats and existing boats. In contrast, the strategies in this section could differ between commercial marinas/docks and private marinas/docks.

A “no swimming” warning posted in a boat is estimated as moderate for relative effectiveness, high for relative cost-effectiveness, and low-moderate for relative impact. Compared with this, a warning posted in boat of ESD has higher relative effectiveness, because this warning alerts people of ESD more directly than a “no swimming” warning. Both are low cost to provide, so relative cost-effectiveness for both could be high. Considering relative effectiveness, relative impact could be determined as low-moderate for providing a “no swimming” warning and Moderate-High for providing a warning of ESD.

Providing a “no swimming” warning at both commercial and private docks is estimated as moderate-high for both relative effectiveness and relative cost-effectiveness. The cost-effectiveness is determined by the size of the dock and the number of warnings. Because private docks could be ranked higher than commercial docks, the relative impact on reducing overall risk could be moderate for commercial docks and moderate-high for private docks. As with boats, the relative effectiveness of an ESD warning could be higher than a “no swimming” warning. Relative cost-effectiveness and relative impact are determined as moderate-high for both commercial and private docks, but they could differ depending on the size of the dock and the number of signs.

For marinas/docks, designating a swimming area away from docks and designated boating waterways is a suggested strategy. Because this strategy reduces the frequency and consequences to zero, the relative effectiveness can be estimated as very high, although an unexpected accident could diminish the effectiveness. The relative cost-effectiveness could be estimated as moderate-high, and the relative impact could be estimated as moderate for both commercial and private docks. The relative impact of providing warnings and designating swimming areas could be estimated, considering that those strategies depend on the number of people who comply with signs and warnings.

Education for owners, swimmers, employees (at marinas/docks only), and qualified inspectors is suggested, because this strategy can reduce frequency and consequences. For boats and docks, education for owners ranked as moderate for relative effectiveness, moderate for relative cost-effectiveness, and low-moderate for relative impact. Education for employees (at marinas/docks only) could be less costly than educating owners, because employees do not require professional knowledge about electrical systems in boats or at docks. With such relative cost-effectiveness, the relative impact for commercial docks could be determined as moderate-high, a higher rank than that for education for owners. In contrast, the relative impact for private dock is estimated as low since it is not practical to employ people at private docks. Educating swimmers directly regarding ESD is ranked as high for relative effectiveness and moderate-high for relative cost-effectiveness for new boats, existing boats, commercial docks, and private docks. However, it is difficult to inspect, control, and regulate the private dock so the relative impact is estimated as moderate-high compared with others ranked as high. For new and existing boats, educating qualified inspectors is ranked as high for relative effectiveness, moderate-high for relative cost-effectiveness, and low-moderate for relative impact. Compared with education for swimmers, the relative impact of education for qualified inspectors depends on the percentage of regulated area, so it is determined as low-moderate for boats. The same strategy for docks is determined as high for relative effectiveness and moderate-high for relative cost-effectiveness. In case of commercial docks, the relative impact is estimated as moderate-high. Because of the difficulties of inspection, control, and regulation, the relative impact for private docks is lower than for commercial docks.

Inspection by agencies (e.g., Coast Guard) for new and existing boats for compliance with institutional strategies can reduce the frequency of exposure and severity of consequences. Defective knowledge of electricity on the part of inspectors could affect frequency and consequences, but the relative effectiveness could be estimated as high. Because it is costlier than education, the relative cost-effectiveness could be low-moderate. The relative impact could be higher than inspection by qualified inspectors (inspection of institutional strategies would be more effective), so it could be ranked as moderate. For marinas/docks, relative effectiveness could be also estimated as high and relative cost-effectiveness could be low-moderate as with boats. Since the private dock is difficult to regulate, the relative impact on reducing over risk could be ranked as low when compared with commercial docks ranked as moderate. Inspection also could be conducted by qualified inspectors. For boats, relative effectiveness is high, and relative cost-effectiveness could be low-moderate. Relative impact on reducing over risk could be ranked as low-moderate since inspection by qualified inspectors has some limitation due to jurisdictional concerns compared with inspections by agency. For both commercial and private docks, relative effectiveness could be high, and relative cost-effectiveness could be ranked as low-moderate. Compared with the relative impact of inspection by agency, the relative impact on reducing overall risk could be determined as moderate-high for commercial docks and low for private docks. The relative impact for qualified inspectors could be higher than that for agencies since the inspectors have relatively more professional knowledge than agencies for commercial docks. In contrast, the relative impact for private docks is ranked as low, because private docks are difficult to inspect, regulate, and control.

Mandating that boats be licensed/registered and provide identification of power sources and requirements is a strategy that can reduce frequency and consequences, because would enable control of the overall strategies by making people aware of requirements for their boats. Although the number of people operating boats without licenses or registrations could affect the frequency and consequences, the relative effectiveness of this mitigation method could be estimated as high. In addition, relative cost-effectiveness could be moderate since it would require some cost to implement. Relative impact on reducing overall risk could be ranked as moderate. For dock, requiring permission to install electrical connections is suggested as a strategy. If people evade the regulation, it could affect frequency and consequences, but it could be estimated as high for relative effectiveness. The relative cost-effectiveness could be moderate because it requires some cost to apply this strategy. Also, relative impact on reducing overall risk could be ranked as moderate-high (if required) for both commercial and private marinas/docks.

Instituting regulations and penalties for noncompliance is suggested as a strategy for boats and docks. It can reduce frequency and consequences by making people more aware. Also, this strategy can enable control of the overall strategy. For boats and docks, the relative effectiveness of this mitigation measure is estimated as high, and relative cost-effectiveness could be ranked as moderate-high. Relative impact on reducing overall risk for boats and commercial docks could be ranked Moderate-High. For private docks, the relative impact is ranked as low-moderate because private docks are difficult to regulate.

Public safety communication (e.g., providing awareness campaign) can reduce frequency of exposure and severity of consequences by broadcasting information about ESD. For new boats, existing boats, commercial marinas/docks, and private marinas/docks, the relative effectiveness is determined as high, and the relative cost-effectiveness is estimated as low-moderate. The relative impact on reducing overall risk for boats and commercial docks is ranked as m-high. Generally, public safety communications are costlier than other strategies such as education, because they target diverse groups, not just specific groups. Therefore, relative cost-effectiveness could be lower than education. In addition, the relative impact on reducing overall risk for private docks is lower than commercial docks because private docks are difficult to control and regulate.

6.0 ACTION PLAN STRATEGIES

In the risk assessment process, an action plan should be included for developing options and actions to enhance opportunities and reduce threats to project objectives (ANSI/PMI 2008). In the previous section, a detailed action plan to manage the risk was recommended, including measures to eliminate, prevent, and/or mitigate the risk. It is possible to apply the ESDCT and the risk matrix to all sizes and types of commercial and private marinas/docks and to all new and existing boats in the three environments: person-water-boat, person-water-dock, and person-water-dock and boat.

6.1 RISK COMMUNICATION / EDUCATION STRATEGIES

Risk communication is the process of informing people about potential hazards to their person, property, or community (EPA). In other words, it is the interactive process of exchange of information and opinion involving multiple messages about the risk management (AS/NZS 2004). In this project, providing warnings and education are suggested as the risk communication strategies. The basic communication model is illustrated in Figure 6.1.

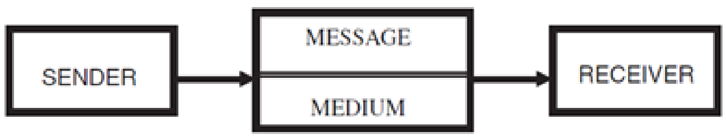

Figure 6.1 Basic Communication Model (Laughery 2006)

In Figure 6.1, the *Sender* could be a designer, originator, and sender of the warning message. *Medium* indicates how the message is presented or displayed. *Message* can be defined as the content of the warning. *Receiver* is the target audience of the warning.

Warning signs are intended to influence people's behavior in ways that will improve safety (Laughery 1999). Three things are necessary for a warning sign to be successful: it should capture attention and be understood, it should agree with existing attitudes and beliefs or be adequately persuasive to evoke a change toward agreement, and it must motivate the user to comply (Wogalter 1996). It is necessary to understand how accidents occur and how warning signs affect accidents. From the literature review, Figures 6.2 and 6.3 explain these processes clearly. Inadequate safety knowledge, inadequate safety awareness, and inadequate safety habits lead to unsafe acts and unsafe conditions, and together, these factors could result in an accident. However, if these factors are addressed with warning signs, the frequency and consequences of accidents could be decreased.

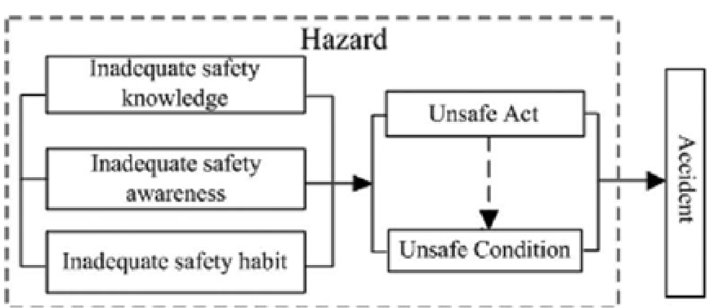

Figure 6.2 Common Causes of Accidents (Laughery 2006)

Figure 6.3 The Principle of Warning Signs to Prevent Accidents (Laughery 2006)

When creating warning signs, the gender and familiarity effects should be considered. The work of Goldhaber and deTurck (1989) confirmed that males may process less information from warning signs than females (Goldhaber 1988). In addition, it is confirmed that as people become more familiar with a product by using it, they are less likely to notice the product has a warning message and perceive less risk associated with using the product (Godfrey et all., 1983).

Various risk communication / warning signage strategies are available, for use in different environments, by different stakeholders. Representative examples include:

- Marina / Dock Owners and Operators
  - Posting "no swimming – electric shock hazard" signage in marinas where electrical cables / connections are present
  - Posting "no swimming – electric shock hazard" signage at individual docks with electrical connections
  - Posting "designated swimming area" signage within a marina, away from boats and sources of electricity
  - Posting "designated swimming area" signage away from docks with electrical connections
- Motorcraft Manufacturers
  - Posting "caution – electrical shock" warnings in motorcraft with electrical systems
  - Posting "no swimming with 10 feet of boat – electrical shock drowning hazard" in motorcraft with electrical systems and conductive components
  - Providing safety tips in Owners Manuals regarding ESD hazards on and around boats and docks
- Relevant NGOs and Government Organizations (e.g., US Coast Guard)
  - Providing information about ESD hazards on and around boats and docks, and how to reduce or avoid them, in safe boating guidance documents
  - Develop public awareness / safety campaigns with messaging about ESD and how to reduce or avoid the hazards

Providing education and training is also a viable strategy. Potential targets for education and training, based on ESD hazard and risk documents, include boat owners, swimmers, employees of commercial docks/marinas, and electrical inspectors. To increase the likelihood of successful messaging and education programs, they should be conducted in conjunction with each other, as well as with enforcement programs (e.g., inspections and compliance enforcement).

6.2 REGULATORY / GUIDANCE STRATEGIES

In addition to strategies regarding warning signs, public safety campaigns, and education about ESD hazards, development of regulations (codes, standards) and voluntary guidance documents, which address ESD hazard (via mitigation or avoidance), can be helpful.

There already exist standards and codes that address ESD in one way or another, albeit not directly. These include:

(1) American Boat & Yacht Council (ABYC):

- ABYC A-28, *Galvanic Isolators*
- ABYC A-31, *Battery Chargers and Inverters*
- ABYC E-11, *AC & DC Electrical Systems on Boats*
- ABYC T-5, *Safety Signs and Labels*
- ABYC T-24, *Owner/Operator's Manuals*

(2) Title 33, Code of Federal Regulations, Subchapter S, Parts 173–199, "Boating Safety."

(3) Underwriters Laboratories (UL):

- UL 1168, *Standard for Recreational Boats*
- UL 1199, *Standard for Recreational Boats Less Than 20 Feet in Length*
- UL 1426, *Standard for Electrical Cables for Boats*

(4) National Fire Protection Association (NFPA):

- *NFPA 70®, National Electrical Code®,* Article 555
- NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft*
- NFPA 303, *Fire Protection Standard for Marinas and Boatyards* (Note: the requirements for marinas and boatyards in NFPA 303 are not applicable to private, noncommercial docking facilities constructed or occupied for the use of the owner or residents of the associated single-family dwelling.)

(5) Institute of Electrical and Electronics Engineers (IEEE):

- IEEE 45, *Recommended Practice for Electric Installations on Shipboard*
- IEEE 80, *Guide for Safety in AC Substation Grounding*

More detailed information for these codes and standards is given in Annex E. going forward, it is recommended that these documents be reviewed, and where deemed appropriate, updated to address ESD risk mitigation and avoidance in greater depth. This is best done by the groups and associated subject matter experts.

6.3 STRATEGIES FOR MANUFACTURERS

Manufacturers of motorcraft can play a significant role in reducing the potential for ESD by controlling the presence or transmission of electricity via the motorcraft and its attachments. At one end of the spectrum is simply to remove sources of electricity. This is clearly not an option for all motorcraft, but does represent one category of boats. When electricity, electrical systems, and electrical appliances are required, then a variety or strategies to limit current strength, limit field strength, insulate and isolate may be available.

Representative strategies for manufacturers are suggested in Table 5.1 Risk Matrix for New Boats. These include technology and material options, as well as messaging, as outlined above. There is of course cost implications to any mitigation measures, which need to be considered. Also, it is recognized that a more in depth assessment of the mitigation measures and the benefit-cost issues need to be conducted. However, these reflect a reasonable first step.

When reviewing the matrix, it should be noted that the relative impact on reducing overall risk will be increased by applying the strategies during manufacturing of all new boats, although the number of new boats will be far lower than the number of existing boats. As such, the relative impact of this strategy should be viewed from a long-term perspective.

6.4 PUBLIC SAFETY / AWARENESS COMMUNICATIONS

Public safety / awareness communications and campaigns are tools that aim to make the public aware of issues, and as necessary, safety options (avoidance, mitigation). The fire protection community is well aware of public safety and awareness campaigns, such as ‘change your clock, change the battery in your smoke detector’ and ‘stop, drop and roll’ as developed and supported by NFPA, and the fire service in general.

There exists significant research within communication science that has examined characteristics of messages that enhance individual risk perceptions, attitudes, and behavior, reflects how messages are received regarding public health, disasters and more (e.g., see Dillard and Pfau 2002; Heath and Palenchar 2000; Niederdeppe et al. 2008). While the literature is diverse, and the guidance wide-ranging, some elements for consideration include (Niederdeppe et al. 2008):

- A message can frame issues as being caused by internal factors (within control of the individual), external factors (beyond the control of the individual), or some combination of the two.
- Message frames influence how people think about who is responsible for causing problems, who is responsible for addressing these problems, and ultimately what policies (if any) should be implemented.
- Narratives (stories) are a fundamental way that human beings interact and exchange information.
- Narratives can help overcome resistance to persuasion by reducing counterarguments, facilitating message recall and comprehension, and providing opportunities for observational learning through identification with characters.

Going forward, various stakeholder groups should consider developing public safety / awareness campaigns, which consider what different actors can do to avoid or mitigate ESD risks (e.g., targeting the public to avoid swimming in areas with live electrical systems near or in the water; targeting marina / dock owners to check and ensure safety of electrical installations; etc.). Ideally, the stakeholder groups will work together for consistent messaging, effectively forming advocacy coalitions (e.g., see Sabatier and Jenkins-Smith, 1993). In addition, the advocacy coalition and their collaborative messaging can become a powerful force for influencing public policy (laws, regulations).

6.4 INSPECTION STRATEGIES

It is understood that motorcraft, marinas and docks will necessarily have electrical systems. The challenge is that if they are not properly installed and maintained, stray voltage and currents could result, which could then lead to electrical shock and to ESD. To help address this concern, inspections of land-based and motorcraft-based electrical systems by qualified inspectors should be conducted. To be effective, the inspections need to be conducted correctly, specifically as related to the systems and hazards, and at regular intervals.

Review of the literature suggests that most ESD accidents are difficult to inspect post-incident. For example, a recent accident in Put-in-Bay, Ohio, was reviewed by inspectors who reported that they found everything to be in proper working order by checking the shore-power wiring on the dock. However, several factors are not clear from the reports, including (as noted by Project Technical Panel member Ed Lethert):

- Who did the inspection?
- Is the person who inspected the boat qualified in marine electrical systems?
- Where did the inspector check? Docks? Boat? Adjacent boats?
- What exactly did they check?
- What are the detailed results of each check?
- What equipment was used to perform each check?
- Under what conditions was each check performed?
- Does the marina have any benchmark data to show what "okay" means?

To help reduce the potential for future ESD tragedies, the specific causes must be determined. It is suggested that inspection must be conducted by following a recognized standard or checklists be used. One example is the Electrical Wiring Design and Protection Self-Inspection Checklist available from the US Occupational Safety and Health Administration (http://www.isri.org/safety-best-practices/isri-safety/isri-safety-resources/osha-resources/osha-inspection-checklist#.WYx9slWGOot).

For the future, it is recommended that ESD-specific standards and checklists be developed to guide the inspection of land- and motorcraft-based electrical systems – pre- and post-ESD incidents – to help develop better data and reduce the likelihood of ESD occurrence.

7.0 DATA REQUIREMENTS AND FUTURE RESEARCH NEEDS

7.1 DATA REQUIREMENTS

In conducting this study, it was determined that only limited data exist for quantitatively estimating the risks associated with ESD. As a result, a qualitative risk assessment approach was developed, which focused on relative contributions to risk, and relative risk-effectiveness of potential mitigation measures. Going forward, if a more quantitative risk assessment and management approach is desired, additional data will be needed. The following overviews types of data which would be helpful, how one might assess the goodness of the data, potential sources of data, potential means to collect the data, and how the data could be used.

7.1.1 TYPES OF DATA

As discussed in Section 3, risk is a measure of what can go wrong, how likely it is to go wrong, and what the impacts (consequences) might be (Kaplan and Garrick 1981). With respect to ESD, what can go wrong relates to determining how electricity, people and water might come together. Hazard assessments, inspections of boats and electrical systems, and the like, will yield such data. How likely ESD is to occur is a function of the frequency or probability of the convergence of electricity, people and water. This requires data on such factors as number of boats with electrical systems, number of docks with shore-based electrical connections, presence of stray currents in such environments, number of people who may be impacted, and so for. The impact relates to an assessment of the consequences of electricity, people and water interaction, given certain current levels or field strengths, body mass and water salinity. Therefore, to build a database to help assess the ESD risk, data such as the following would be helpful:

- Databases of injury and deaths attributable to ESD
  - Would need to differentiate incapacitation by electricity and then drowning
  - Would need to track injury resulting from both electrical- and water-based sources
  - Coroners data
- Data regarding number of boats with electric motors / equipment of a capacity to induce ESD (new boats / existing boats)
  - How many boats have on-board power sources above 30mA limit
  - How many boats will have / could have connection to shore-based electrical power sources above 30 mA limit
- Data regarding location and usage of boats with electric motors / equipment of a capacity to induce ESD (new boats / existing boats)
  - Inland fresh water waterways
  - Inland fresh water lakes and ponds
  - Inter-coastal areas
  - Private docks
  - Public marinas / docks
- Data on stray voltage on boats (from where, how and what magnitude)
- Data on stray voltage at marinas / docks (from where, how and what magnitude)
- Data on current-limiting and ground fault devices on boats
- Data on current-limiting and ground fault protection at docks and marinas

7.1.2 Goodness of Data

Data can be obtained from diverse sources, including expert opinion, laboratory testing, published information, event data collection, and field data collection. However, there are varying degrees regarding the goodness of the data. In general, the goodness of data can be estimated by checking 16 data quality dimensions as indicated in Table 7.1 below (Pipino et al. 2016).

Table 7.1 Data Quality Dimensions (Pipino et al. 2016)

Dimensions	Definitions
Accessibility	The extent to which data is available, or easily and quickly retrievable
Appropriate Amount of Data	The extent to which the volume of data is appropriate for the task at hand
Believability	The extent to which data is regarded as true and credible
Completeness	The extent to which data is not missing and is of sufficient breadth and depth for the task at hand
Concise Representation	The extent to which data is compactly represented
Consistent Representation	The extent to which data is presented in the same format
Ease of Manipulation	The extent to which data is easy to manipulate and apply to different tasks
Free-of-Error	The extent to which data is correct and reliable
Interpretability	The extent to which data is in appropriate languages, symbols, and units, and the definitions are clear
Objectivity	The extent to which data is unbiased, unprejudiced, and impartial
Relevancy	The extent to which data is applicable and helpful for the task at hand
Reputation	The extent to which data is highly regarded in terms of its source or content
Security	The extent to which access to data is restricted appropriately to maintain its security
Timeliness	The extent to which the data is sufficiently up-to-date for the task at hand
Understandability	The extent to which data is easily comprehended
Value-Added	The extent to which data is beneficial and provides advantages from its use

While not all of the above are necessarily applicable to the ESD problem, the above can be used to develop guidelines for ESD data collection, which would result in quality datasets. The Guidelines might include such factors as: what types of inspections should be undertaken (motorcraft, docks, marinas), what specific data should be collected, how are currents / field strengths to be measured and reported, and so forth. Guidance could also potentially be developed for medical professionals investigating reported ESD incidents, or more broadly, drowning incidents, in which electricity could feasibly have been involved. It is suggested that an effort focused on data collection guidance would be beneficial.

7.1.3 Potential Source of Data

There are many potential sources of data to support the above suggested data collection activities. Some of the sources are outlined below. Future efforts might explore these and other sources in more detail.

The U.S. Coast Guard compiles and publishes statistics on reported recreational boating accidents every year as Recreational Boating Statistics (http://www.uscgboating.org/statistics/accident_statistics.php). The statistics are derived from accident reports that are filed by the owners / operators of recreational vessels involved in accidents. In addition, this annual report shows the recreational vessel registration by year, by length & means of propulsion, and by state. All fifty states, five U.S. territories and the District of Columbia submit accident report data to the Coast Guard for inclusion in the annual Boating Statistics publication. While these data can be helpful there are limitations. For example, means of propulsion are classified only as 'mechanically propelled' and 'not mechanically propelled.' This does not get to specifics about electrical systems and capacity. However, it might be suggested that such data (and other) be collected, compiled and published by the Coast Guard in the future.

The Centers for Disease Control and Prevention (CDC) provides statistical data of drownings and incident data. These data consist of fatal injury data, nonfatal injury data, violent deaths, cost of injury report, and fatal injury mapping from Web-based Injury Statistics Query and Reporting System (WISQARS™). It also provides information of unintentional drowning deaths in the United States from National Centers for Health Statistics (NCHS). However, it is not clear that electric shock, as a precipitator to drowning, is identified. A change here could be the source of better data on ESD injuries and fatalities in the future.

The National Marine Manufacturers Association (NMMA) compiles detailed data for boat registrations, boat engine, and accessory sales, expenditures, and the retail and pre-owned markets (https://www.nmma.org/statistics). Certain data, such as outboard engine sales trends, and powerboat sales trends, could be a potential source of data for future ESD studies. In Annex F, NMMA data from the top five boating states (e.g., Florida, Texas, California, North Carolina, and New York) are presented as an example of data provided. The NMMA may also be a future partner for identifying and collecting other data of importance.

The Association of Marina Industries (AMI) provides the information of revenues and expenses, and facility information such as number of slips, occupancy, and average size (https://marinaassociation.org/). It may be possible to extract data on number of docks and slips, at least for larger / public marinas. Data on small / private docks (e.g., lakeside homes) would not be included, and data on these would have to be collected from other means.

In addition to the sources of data identified above, it is possible to obtain the information for registration of boats from http://www.dmv.org/boat-registration.php. In addition, each state has their own law in terms of taking boating safety education and it is possible to search different politics of states in http://www.boat-ed.com.

The types of data which could be collected, as outlined above, are summarized in Table 7.2 below. It is suggested that it could be worthwhile to extend this type of data identification and collection activity into the future under follow-on projects.

Table 7.2 Potential Source of Data

Data Collection Needs	Existing Data	Potential Source	Notes
Injury and deaths attributable to ESD	Number of injury by electric shock in recreational boats	U.S. Department of Homeland Security & U.S. Coast Guard[1]	Data of injury and deaths shall be provided in terms of ESD
	Number of drownings by recreational vessel type		
	Number of deaths by type of operator boating instruction		
	Number of deaths from accidental drowning and submersion	Centers for Disease Control and Prevention (CDC)[2]	
	Number of deaths from water, air and space, and other and unspecified transport accidents		
Number of boats with electric motors / equipment of a capacity to induce ESD	Number of recreational vessel registration by length and means of propulsion	U.S. Department of Homeland Security & U.S. Coast Guard[1] National Marine Manufacturer Association (NMMA)[3]	Number of vessels registered by means of propulsion shall be classified more specifically regarding electric boats
	Number of recreational vessel registration data by state		
Number of boats (new boats / existing boats)	Number of sales data	National Marine Manufacturer Association (NMMA)[3]	-
Number of marinas / docks	-	Association of Marina Industries (AMI)[4]	Number of marinas / docks shall be provided by types (e.g., commercial and private)
Electrical systems	-	-	Data from inspections
Stray Voltage	-	-	Measurement from inspections

[1] "2016 Recreational Boating Statistics", U.S. Department of Homeland Security, U.S. Coast Guard, Office of Auxiliary and Boating Safety, 22 May 2017, COMMANDANT PUBLICATION P16754.30. https://www.uscgboating.org/library/accident-statistics/Recreational-Boating-Statistics-2016.pdf

[2] "National Vital Statistics Reports", by Kenneth D. Kochanek, M.A., Sherry L. Murphy, B.S., Jiaquan Xu, M.D., and Betzaida Tejada-Vara, M.S., Division of Vital Statistics, U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, Centers for Disease Control and Prevention, National Center for Health Statistics, National Vital Statistics System. Vol 65, Number 4. https://www.cdc.gov/nchs/data/nvsr/nvsr65/nvsr65_04.pdf

[3] "U.S. Recreational Boating Statistical Abstract" National Marine Manufacturers Association (NMMA), 231 S. Lasalle Street, Suite 2050, Chicago, IL, 60604, Phone: (312)946-6200. https://www.nmma.org/statistics/publications/statistical-abstract

[4] "2016 Marina Trends Survey Report", Association of Marina Industries, 50 Water ST, Warren, RI, 02885, Phone: (866) 367-6622. https://marinaassociation.org/publications/ami-resources/2016-marina-trends-survey-report

7.2 FUTURE RESEARCH / DATA COLLECTION

As noted above, data can be collected by reviewing published statics on boating accidents, types of motorcraft, numbers of marinas, docks and the like. However, many of these sources do not include specific information required to assess ESD potential in detail. To address this, data collection via field investigations, inspections, and related mechanisms is possible.

7.2.1 FIELD INVESTIGATION

Field investigation is a form of data collection involving obtaining information from a sample of the relevant environments. While in general, the more data the better, even small samples can help fill knowledge gaps. For example, FPRF Project Technical Panel member Dr. John Hall Jr. suggested that with a relatively small sample, say from 5 to 10 marinas, the following data and measurements could be obtained:

- Base line measurements of electric hazard levels in the water, possibly taking account of proximity to boats, number and location of boats, etc.
    - Track down the sources to see how often hazards are due to shore cords with insulation damage or makeshift repairs
- Using experimental design and / or before / after design to see how the measurements of current hazards change based on implementation of individual strategies.
    - Periodically test boats for AC leakage
    - Periodically test boats for integrity of grounding system
    - Install a residual current device in the shore power supply of a boat’s electrical system
    - Require that all underwater metals be connected to the shore bonding (grounding) conductor if AC shore power is being supplied to the boat
    - All the other “install” ideas (e.g., adequate electronic devices, isolation transformers with certain properties, fuses, circuit breakers, GFCI, grounding systems
- Estimate the effectiveness of posted warnings or prohibitions on swimming practices

Such data would provide insight into actual situations, thereby enhancing knowledge and datasets.

7.2.2 REGULATORY INSPECTIONS / VOLUNTARY INSPECTIONS

In addition to field investigations, regulations could require electrical inspections of all electrical installations at docks and marinas, at least of a certain size. This, along with guidance for what specifically to look for, how to measure, record and report, would provide additional data.

In addition, local governments could embark on public awareness and data collection campaigns of a more voluntary nature. For example, much as the fire service in some communities gives away, and even installs, smoke alarms for some population groups, it may be possible for electrical inspectors to inspect electrical installations at private docks (e.g., at lakeside homes) and distribute ESD warnings and safe practice guides at the same time.

Also, given that some data on motorcraft are already collected by states as part of registrations, adding specific information for ESD, such as motor type, electrical power requirements, current limiting devices on motorcraft, and so forth, may be possible. These types of activities could be explored in the future.

7.2.3 LABORATORY EXPERIMENTS / MODELING

While examples of data collection, analysis and modeling have been identified (e.g., Smoot 1964; Dalziel 1968; Ayyub et al. 2016), it seems apparent that better characterization of actual hazard conditions and responses of people to electric shock, as related to the potential for ESD, would be beneficial. Examples of such data include.

- Conduct further research to better characterize the decay in voltage/voltage gradient as distance to a fault source increases.
- Conduct further research to better understand the limitations of power supply and appliances on boats and at marinas/docks.
- Conduct research to better understand and characterize current / field strength relationships, in and around water, as associated with body mass or other pertinent factors.
- Conduct research on materials and technologies to reduce electrical hazards that could lead to ESD in motorcraft and landside.
- Conduct research to better understand the effectiveness of warnings and public awareness activities on increasing public awareness, knowledge and protective actions related to ESD risks.

It is understood that such research requires investment, but opportunities could exist for partnering with different stakeholders in the market that have a role to play and benefits to reap (e.g., manufacturers, government, NGOs, industry, insurance).

7.3 HOW THE DATA COULD BE USED

Collecting good data is important. However, the importance is related to how the data might be used to help reduce the potential for ESD. As discussed earlier in the report, risk is a function of three factors: what could go wrong, how likely it is to go wrong, and what are the potential consequences. Data can be used to help in each area. In addition, data will also be helpful for risk communication and public safety awareness messaging.

7.3.1 WHAT COULD GO WRONG?

Data sets on ESD and injury related to electric shock in the areas of motocraft, marinas and docks will significantly help inform the magnitude of the problem. Changes to reporting on suspect ESD and related injuries could help this. Post-ESD investigations / inspections will help develop these data, which ultimately will be beneficial to developing quantitative risk estimates.

7.3.2 HOW LIKELY IS IT TO OCCUR?

Frequency of events will be difficult to assess. This is a function of having the convergence of electricity, people and water within one of the three environments (boats, docks, boats at docks). This may be difficult to come by. However, data sets on number and location of electrical systems (motorcraft, marinas and docks), capacity, mitigating measures (e.g., ground fault limiters), condition of conduit and cabling, number of boaters, numbers of people on boats, numbers of marinas, numbers of docks, etc., will all be helpful.

As noted above, some of these data may be available from published literature. Others will have to be collected. It may be needed that expert groups are used to initially develop estimates of these factors, which can be updated as data become available.

7.3.3 WHAT ARE THE POTENTIAL CONSEQUENCES?

Data on consequences seem to be rather well known. However, additional data on electric current / field strength level, mode of conduction, body mass and the like will help on estimating when ESD might occur.

7.3.4 Influences on Messaging

All of the data above will ultimately be helpful in risk communications, warnings and public safety awareness messaging. With knowledge about on number and location of electrical systems (motorcraft, marinas and docks), capacity, mitigating measures (e.g., ground fault limiters), condition of conduit and cabling, number of boaters, numbers of people on boats, numbers of marinas, numbers of docks, etc., one will be able to better inform messages, and to whom they should be targeted.

7.3.5 Future Development of Risk Quantification

Going forward, if more quantitative risk assessment is desired, the above data will need to be translated, through calculation, into specific types of variables and parameters (components of the what could go wrong, how likely, and potential consequences) that will be needed by the selected risk estimation approach. This may come from data in the literature, data developed through inspection and research, or by expert judgment.

Data are also needed on risk mitigation strategies: technologies, costs and ultimately, cost-benefit ratios. Data can be extracted from literature, surveys and expert judgment. More quantitative cost-benefit and risk-cost-benefit analyses can then be conducted.

It is suggested that initially, focus on developing inspection protocol, conducting some targeted measurements in and around boats, marinas and docks, and developing quantity data from the literature (e.g., how many boats with electrical systems, how many marinas, boaters, …, cost of mitigation measures, estimates of mitigation effectiveness, etc), can help enhance the picture. Expert judgement can be used to develop better quantitative risk estimates, as well as cost and effectiveness of possible mitigation measures. Together, this will provide a more comprehensive picture of the problem and pathways to solutions.

8.0 SUMMARY

A review of literature associated with electric shock drowning (ESD) has been conducted. The environments of concern for ESD as addressed in this work have been defined as the interactions of boats-people-water, docks-people-water, and boats-docks-people-water. Valuable information on ESD hazards, ESD impacts to people, means to assess ESD impacts, and potential ESD mitigation measures has been identified. In addition, data on potential ESD fatalities and near misses, and works of significance regarding assessment of ESD risks, are identified. In addition, various approaches to risk assessment and management have been explored, and frameworks for characterizing and presenting risks, and managing them within regulatory environments, have been identified.

Considering the various environments of focus, the risk factors, and the various approaches to identify and manage risk, an ESD Concepts Tree (ESDCT), much like the Fire Safety Concepts Tree (FSCT), has been developed as a tool for identifying scenarios of concern and mitigation options for consideration. The ESDCT approach is suggested for several reasons:

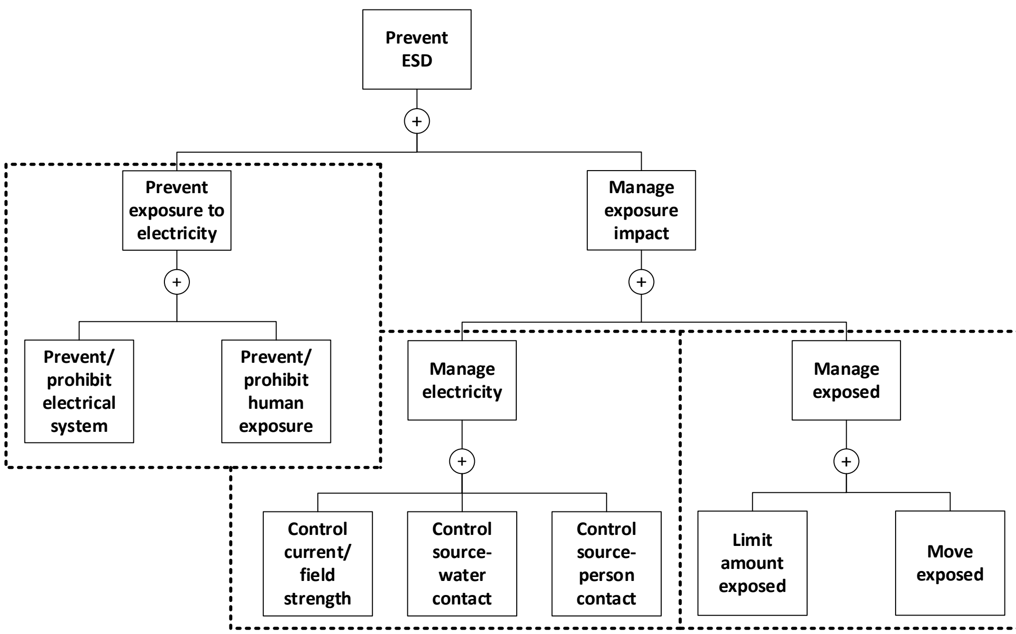

Figure 3.15 Top Level of ESD Concept Tree with Selected Lower-Tiered Gates.

1. A quantitative risk assessment requires sufficient data on event frequency (or probability) to develop good risk estimates. In the case of ESD, frequency data are lacking, as are reliability data for infrastructure components.

2. Should a quantitative risk approach be desired, the framework developed by Ayyub et al. (2016) could be applied, as data become available. This may need to be enhanced with additional scenarios and issues of concern, as identified in this work.

3. The ESDCT approach can work in concert with the ETA and FTA approach suggested by Ayyub et al. (2016), to move toward a quantitative risk approach in the future.

4. The ESDCT approach is designed to be applicable in all three environments of concern. It can also be extended to work in related environments (e.g., brackish water as well as fresh).

5. The ESDCT is designed to go into more detail on exposures and mitigation options than the approach by Ayyub et al. (2016), to facilitate better decision making.

While a reasonable amount of data and information was obtained regarding ESD hazards, risk assessment and risk management approaches, several shortcomings were also identified. Significant gaps exist regarding actual frequency of ESD events, as well as specific contributors to ESD injuries and deaths. Deaths may be recorded as drowning, and electrocution/electric shock may not be indicated as a contributor, even when suspected. Investigation of the causes of ESD are often incomplete, in part due to lack of training by investigators, especially with respect to electrical systems, or by not using suitably educated and trained personnel (e.g., electrical inspectors). In addition, data are lacking on the number of marinas and docks, particularly private ones (e.g., docks of individual homeowners), which in addition may not be subject to regulation, including of electrical systems. Furthermore, data on the number of boats that have electrical power sources are difficult to obtain. Not all states or local jurisdictions require registration of boats and/or recording of such data. There is also limited control/inspection of boats once in use, especially on smaller waterways, and outside of commercial or large private marinas, which may be subject to regulation.

Nonetheless, there are several options available for communicating ESD hazards and risks to various stakeholders, including boaters, swimmers, manufacturers, marina/dock owners, regulators and enforcers. Various strategies for communicating both ESD concerns and mitigation options have been developed. To help frame the relative risk associated with boats and marinas/docks, as well as relative effectiveness of mitigation strategies, a table has been developed that illustrates potential mitigation options, why they night or might not be effective, the relative cost-effectiveness, and a qualitative reflection on the overall impact on reducing ESD risk.

Based on the literature review and assessment of hazards, risks, mitigation options, and potential mitigating strategies, key findings include the following:

1. ESD hazard characterization — current strength and relationship to body mass and contact:
   - An electrical current of 30 mA is a reasonable threshold for precipitating ESD (Ayyub 2016).
   - The relationship between current magnitude and body mass is proportional (Dalziel 1968).
   - The relationship between current strength and shock duration is proportional (Dalziel 1968).
   - Equivalent touch or step voltage in terms of resistance of body is available (Lee 2011).

2. ESD hazard characterization — field strength and relationship to body mass and contact:
   - 2 V/ft of electric field can be used as a threshold (Smoot 1964).
   - Relationship between distance from energized materials and electric field strength is inversely proportional (Smoot 1964).

3. Sources and control of electricity:
   - Finding source of the stray, continuous, uncontrolled current flow is important.
     - One source of stray, uncontrolled current may be pole-mounted transformers (Zipse 1999).
     - Other sources include batteries, cables, motors, mains, generators, etc.
   - Fault conditions of concern include improperly wired appliances and electrical cores, electrical ground faults, exposed conductors in contact with the water, and failure of bonding system (Rifkin and Shafer 2008).

4. Potential mitigation measures — controls on electricity:

- The following are from Rifkin and Shafer (2008):
  - Install a residual current device (RCD) in the shore power supply of a boat's electrical system.
  - Require that all underwater metals be connected to the shore bonding (grounding) conductor if AC shore power is being supplied to the boat.
  - Periodically test boats for AC leakage into the water.
  - Periodically determine the integrity of a boat's bonding (grounding) system.
  - Replace any shore power cord with insulation damage or any cord with electrical tape applied to repair damage.
  - Establish a quality assurance standard requiring post-construction testing of the electrical systems of new boats.
- Install an isolation transformer with the mid-point of the secondary winding connected to a common equipotential node (Parise 2014).
- Install fuses, circuit breakers, GFCI, and a grounding system. Also, insulated wire is important (Bernstein 1991).
- Require periodic inspections of shore-based electrical systems at all currently regulated marinas/docks.
- Consider legislating the periodic inspection of shore-based electrical systems at all private marinas/docks.
- Inform private marina/dock owners of the hazards of ESD and the benefits of electrical inspections by qualified persons.
- Eliminate electricity in boats (e.g., row boat, small sail boat) and at marinas/docks.
- Limit power supply and appliances on boats and at marinas/docks.
- Reduce/eliminate electrically conductive boat components (e.g., hulls, ladders, propellers, anchor chain, drive).
- Insulate electrical components on boats and at marinas/docks (e.g., motors, wires).

5. Potential mitigation measures — controls on people:

- Prohibit swimming in any marina where AC shore power is being supplied to the docks for any purpose.
- Prohibit swimming near any private dock where AC shore power is being supplied to the docks for any purpose.
- Post ESD warnings at any dock with shore power connection.
- Post an ESD warning on any boat with sufficient electrical power source(s).
- Have manufacturers include ESD warnings in any boats with sufficient power sources/power needs.
- Have the Coast Guard update their "safe boating" brochure to include ESD warnings and mitigation strategies.
- Create designated safe swimming areas away from marinas/docks with shore power connection.
- Educate insurers about ESD and mitigation options, as a means to help manage ESD risks.
- License/register boats with identification of power sources and requirements.
- Require a permit to install electrical connections at marinas/docks.
- Institute regulations/penalties for noncompliance.

- Conduct periodic inspections of boats and marinas/docks (including post-incident inspections).
- Provide public safety communications.

6. Data collection needs:

- Create a category in data collection databases to include injury and deaths attributable to ESD.
- Collect data on the number of boats with electric motors/equipment with sufficient power sources / connections such that ESD could occur (e.g., presence of 30 mA current or 2 V/ft electric field).
- Collect data on stray voltage on boats.
- Collect data on stray voltage at marinas/docks.
- Collect data on the number of boats (new boats or existing boats) by considering their power source.
- Collect data on the number of marinas/docks (commercial or private marinas/docks) by considering the number of slips at the marinas/docks.
- Collect data from injury databases that are set up to be used for fatal injuries suffered in the water.

7. Further research needs:

- Conduct further research to better characterize the decay in voltage/voltage gradient as distance to a fault source increases.
- Conduct quantitative risk assessment after collecting data (e.g., data on number of boats and number of marinas/docks).
- Conduct further research to better understand the limitations of power supply and appliances on boats and at marinas/docks.
- Conduct further research by field test to better characterize the effect of mitigation plans suggested by this project:
    - Periodically tests boats for AC leakage.
    - Periodically test boats for integrity of the grounding system.
    - Install a residual current device in the shore power supply of a boat's electrical system.
    - Ensure proper bonding (grounding) system for all underwater metal, considering the AC power supply to the boat.
    - Install interrupters / isolation devices (e.g., isolation transformers, fuses, circuit breakers, GFCI).
    - Evaluate legal protections for the site (e.g., warning signs).

8. Key unknowns:

- Shape of land under the water can make a difference in measurement of electrical current strength (Ayyub 2004).
- Baseline measurements of electric current hazard levels in the water taking account of proximity to boats, number of boats, and location of boats, etc.

Based on the state of knowledge of ESD hazards, risks and potential mitigation options, as well as the gaps in knowledge, it was only possible to develop a range of potential mitigation measures but not to recommend specific measures or sets of measures. Because of this, and coupled with the fact that there is a wide range of interested and affected parties (stakeholders), it is suggested that specific risk mitigation strategies be developed within various regulatory and market environments as described by the socio-technical system (STS) approach and illustrated in the Figure 3.2:

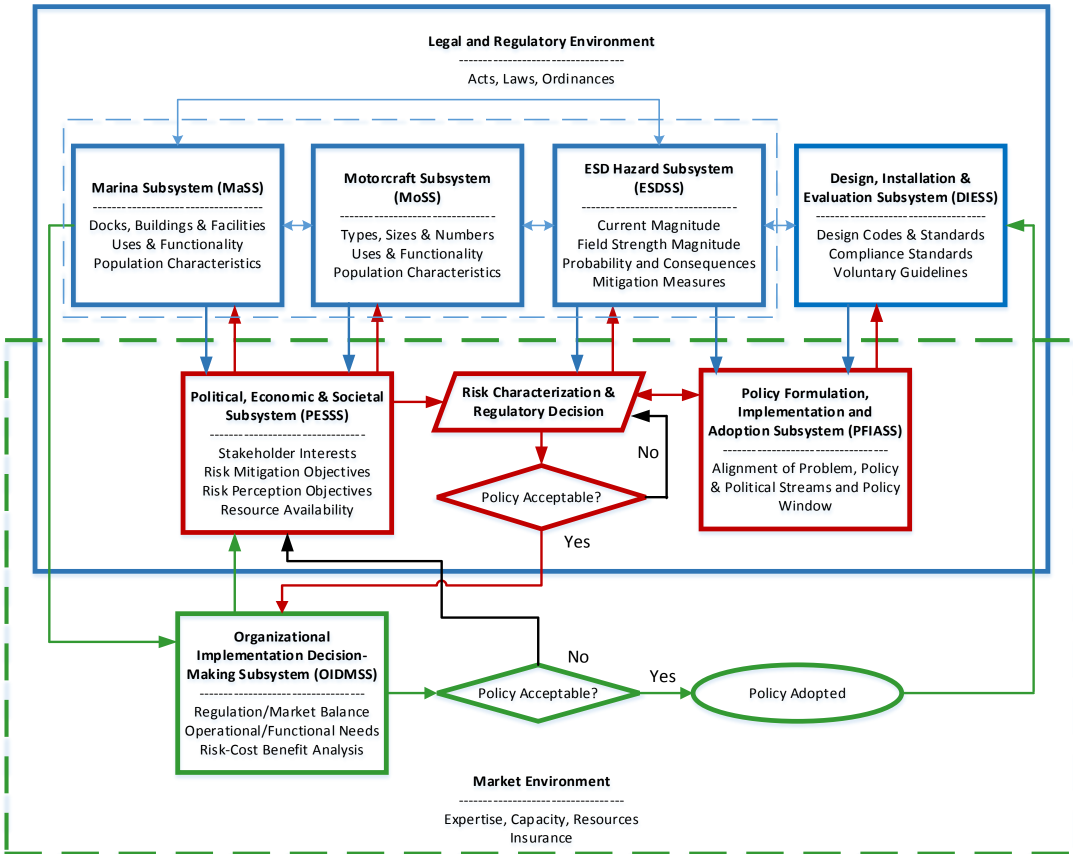

Figure 3.2 Marina-Motorcraft Regulatory System as a Socio-Technical System

The STS approach considers regulatory, market, human and technology issues in the characterization and management of risk through regulation, technology, market, and voluntary measures. It brings together key stakeholders, along with the available data, knowledge of available control technology, and knowledge of the market to more comprehensively characterize risks and establish effective mitigation strategies. By developing mitigation strategies within an STS framework, widespread acceptance can be gained.

Going forward, to enhance quantitative risk assessment, more data are needed, and those data will need to be translated, through calculation, into specific types of variables and parameters (components of the what could go wrong, how likely, and potential consequences) that will be needed by the selected risk estimation approach within the STS / risk characterization process. Needed data, as outlined above, can be extracted from literature, surveys and expert judgment. More quantitative cost-benefit and risk-cost-benefit analyses can then be conducted.

It is suggested that initially, focus on developing inspection protocol, conducting some targeted measurements in and around boats, marinas and docks, and developing quantity data from the literature (e.g., how many boats with electrical systems, how many marinas, boaters, …, cost of mitigation measures, estimates of mitigation effectiveness, etc.), can help enhance the picture. Expert judgement can be used to develop better quantitative risk estimates, as well as cost and effectiveness of possible mitigation measures. Together, this will provide a more comprehensive picture of the problem and pathways to solutions.

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Zipse, D.w. "Electrical shock hazard due to stray current." 1999 IEEE Industrial and Commercial Power Systems Technical Conference (Cat. No.99CH36371). doi:10.1109/icps.1999.787218

ANNEX B – LITERATURE REVIEWS

Risk Assessment Methodology for Electric-Current Induced Drowning Accidents

Source: Ayyub, Bilal M., T. S. Koko, Andrew Nyakaana Blair, and U. O. Akpan. "Risk Assessment Methodology for Electric-Current Induced Drowning Accidents." ASCE-ASME J. Risk and Uncert. in Engrg. Sys., Part B: Mech. Engrg. 2 (September 2016): 031004-1-31004-14. doi:10.1115/1.4032308.

Abstract:
This paper presents a methodology to identify hazards associated with electric-induced drowning and electric shocks for swimmers around docks, houseboats, and other boats in both freshwater and saltwater; assesses scenarios and risks associated with these hazards; and provides information needed to communicate results of the study to the public. The methodology consists of system definition, hazard identification, scenario assessment, risk assessment including likelihood and consequences in the form of health effects, and identification of potential hazard barriers and mitigations. Critical scenarios were identified and assessed according to weighting criteria, and the results were prioritized and used to define the parametric analysis ranges that needed to be performed using simulation. Event and fault trees (FTs) were developed for the critical scenarios. Shock safety criteria were defined by reviewing standards, such as the IEEE Standard for Shock Safety and the IEC Standard for Shock Safety. These results were used to determine critical voltage differential and current thresholds.

Highlights:
Table 3: Effects of 60-Hz AC current in the human body (hand-to-hand pathway)
Table 5: Threshold electric values for basic scenarios
Table 10: Summary matrix of scenarios versus all criteria
Fig. 7: Attributes and states of electric-current-induced drowning scenarios
Fig. 8: Event tree for electric-current-induced boating accident
Fig. 9 FT for electric-current-induced boating accident: (*a*) at dock and (*b*) offshore

Applicability to Project:
The research paper demonstrates methodology:
System definition
Hazard identification
Scenario assessment
Risk assessment, including likelihood and consequences in the form of health effects
Identification of potential hazard barriers and mitigations

Table 3 summarizes the general relationship between the applied current and corresponding human reactions for a 60-Hz current applied along a hand-to-hand path. Over the past 20 years, safe current thresholds have been revised based on improved data regarding body impedance and the influence of body-current pathways. (Dalziel, Charles F. "Electric Shock Hazards of Fresh Water Swimming Pools," 1999). At frequencies of 60 Hz, body impedance is largely resistive, and it can be modeled as a single resistor or a network of resistors. Seventeen scenarios are introduced based on the threshold electric field or current in Table 5.. Not all the scenarios are related to drowning, and only eight of the most critical scenarios are addressed. To identify accident scenarios and quantify risk, an event tree is used for electric-current-induced boating accidents as illustrated in Fig. 8 and Fig. 9. It can identify the various combinations of event successes and failures as a result of an initiating event to determine all possible scenarios. In addition, it suggests simple action plans to manage the risk, including measures to eliminate, prevent, and/or mitigate the risk. This paper aligns with our project and provides some of the data needed to achieve its main objectives.

Table 3 Effects of 60-Hz AC current in the human body (hand-to-hand pathway)

Current magnitude (mA)	Body reaction
<1	Generally imperceptible
1–3	Most subjects can feel a mild sensation
5	Maximum harmless current intensity
	GFCI setting
5–8	Subjects feel the sensation of shock but not generally painful
8–10	Typically painful sensation
	Muscular control is not lost and individual can still “let go”
	Strong involuntary reactions may lead to injury
10–25	This is called the freezing current or “no let go” range
	Painful shock, muscular control is lost
	Current may increase to fatal level
25–55	Breathing arrest may occur for shock durations >1 s
	Breathing usually resumes with respiratory assistance
55–250	Individual cannot “let go”
	Extreme pain and severe muscular contractions
	Induces respiratory arrest (heart fibrillation) within 1–4 s
	Death is possible
250–3000	Heart stops during shock
	Victim may be revived if current is removed quickly enough
500	May induce ventricular fibrillation for shock durations <0.1 s
1000–4300	Muscular contraction and nerve damage may occur
	Death is most likely
3000–10,000	Severe burns are typical
	Not fatal unless vital organs are burned
>10,000	Cardiac arrest
	Severe burns are likely
	Death is probable

GFCI: ground fault circuit interrupter.

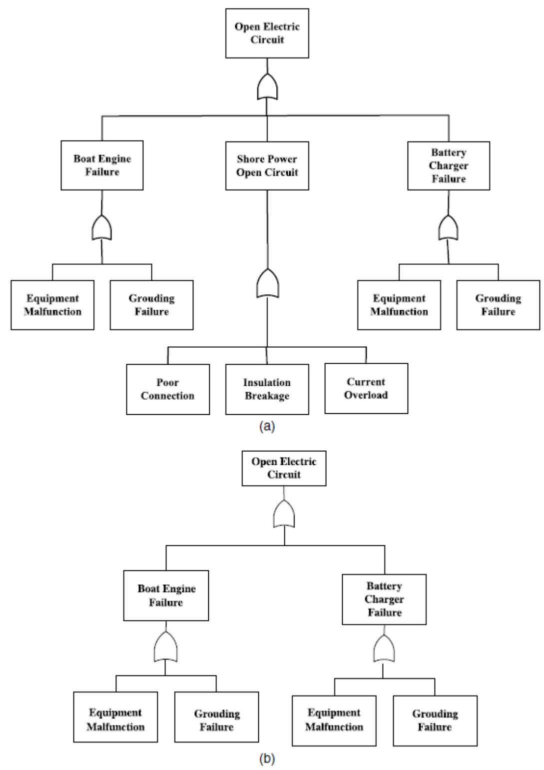


Fig. 9 FT for electric-current-induced boating accident: (*a*) at dock and (*b*) offshore

Table 10 Summary matrix of scenarios versus all criteria

	Severity (0.7)	Occurrence (0.15)	Detection (0.15)	Row total	Relative decimal value
BDPWF	0.12	0.14	0.04	0.11	0.11
BDPWS	0.07	0.14	0.04	0.08	0.08
BDPPWPBF	0.12	0.14	0.14	0.13	0.13
BDPPWPBS	0.03	0.14	0.14	0.06	0.06
BDPPWPDF	0.12	0.14	0.14	0.13	0.13
BDPPWPDS	0.03	0.14	0.14	0.06	0.06
BOPWF	0.19	0.04	0.04	0.15	0.15
BOPWS	0.08	0.04	0.04	0.07	0.07
BOPPWPBF	0.17	0.04	0.14	0.15	0.15
BOPPWPBS	0.06	0.04	0.14	0.07	0.07

Table 5 Threshold electric values for basic scenarios

Scenario	Location of boat	Location of person	Type of water	Threshold electric field or current
S1[a]	Dock	In water	Fresh	6.6 V/m (2 V/ft)
S2[a]	Dock	In water	Salt	6.6 V/m (2 V/ft)
S3	Dock	In boat	Fresh	10 mA
S4	Dock	In boat	Salt	10 mA
S5	Dock	On dock	Fresh or salt	10 mA
S6[a]	Dock	Part water–part boat	Fresh	6.6 V/m (2 V/ft)
S7[a]	Dock	Part water–part boat	Salt	6.6 V/m (2 V/ft)
S8[a]	Dock	Part water–part dock	Fresh	6.6 V/m (2 V/ft)
S9[a]	Dock	Part water–part dock	Salt	6.6 V/m (2 V/ft)
S10	Dock	Part dock–part boat	Fresh	10 mA
S11	Dock	Part dock–part boat	Salt	10 mA
S12[a]	Offshore	In water	Fresh	6.6 V/m (2 V/ft)
S13[a]	Offshore	In water	Salt	6.6 V/m (2 V/ft)
S14	Offshore	In boat	Fresh	10 mA
S15	Offshore	In boat	Salt	10 mA
S16[a]	Offshore	Part water–part boat	Fresh	6.6 V/m (2 V/ft)
S17[a]	Offshore	Part water–part boat	Salt	6.6 V/m (2 V/ft)

[a]Scenarios selected for further assessment.

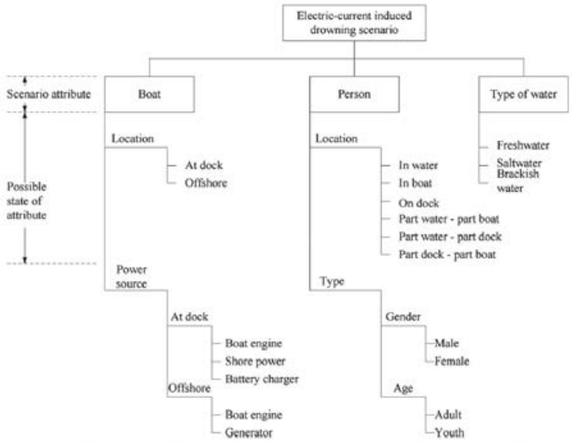


Fig. 7 Attributes and states of electric-current-induced drowning scenarios

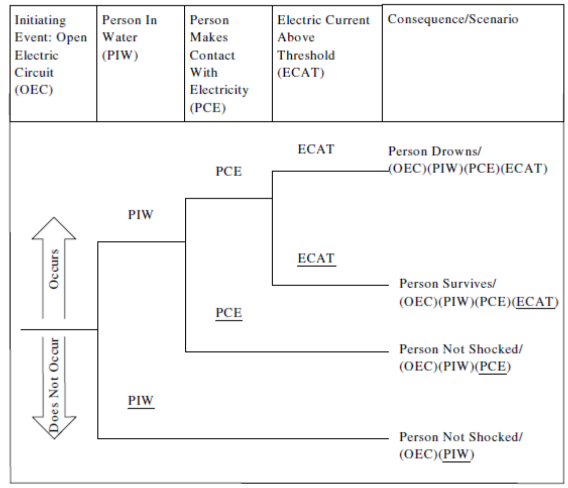


Fig. 8 Event tree for electric-current-induced boating accident

Electric-Current Induced Drowning Accidents: Scenarios, Risks, Mitigation Actions, and Communication

Source: Bilal M. Ayyub, T. S. Koko, Andrew Blair, Z. Tang, D.P. Brennan, U.O. Akpan, B.K Gallant and P.A. Rushton "Electric-Current Induced Drowning Accidents: Scenarios, Risks, Mitigation Actions, and Communication," U.S. Coast Guard, BMA02 ElectricShockDrowning-Version0 dated June 28, 2004

Highlights:
Basis of two shorter papers; 3 ESD objectives; Table 3-7; 17 Scenarios; risk communication

Applicability to Project:
The report "Electric-Current Induced Drowning Accidents: Scenarios, Risks, Mitigation Actions, and Communication" provides a problem description, definition of needs in this area, and risk analysis results, including risk communication. This is a comprehensive report, which served as the basis for the previously listed paper (Ayyub et al., 2016) and (Koko et al., 2016).

The study covers three main objectives:

1. Developing and demonstrating a methodology to identify hazards associated with electric-induced drowning and electric shocks for swimmers around docks, houseboats, and other boats in both freshwater and saltwater
2. Assessing scenarios and risks associated with these hazards
3. Developing information needed to communicate results of the study to the public

The authors developed 17 scenarios. Among the scenarios, seven scenarios are excluded since they may not occur drowning. Of the remaining ten scenarios, the following five most critical scenarios are identified by weighting criterion as illustrated in Table 3-7:

Table 3-7. Summary Matrix of Scenarios Versus all Criteria

	SEVERITY(.7)	OCCURRENCE(.15)	DETECTION(.15)	Row Total	Relative Decimal Value
BDPWF	.12	.14	.04	0.11	0.11
BDPWS	.07	.14	.04	0.08	0.08
BDPPWPBF	.12	.14	.14	0.13	0.13
BDPPWPBS	.03	.14	.14	0.06	0.06
BDPPWPDF	.12	.14	.14	0.13	0.13
BDPPWPDS	.03	.14	.14	0.06	0.06
BOPWF	.19	.04	.04	0.15	0.15
BOPWS	.08	.04	.04	0.07	0.07
BOPPWPBF	.17	.04	.14	0.15	0.15
BOPPWPBS	.06	.04	.14	0.07	0.07
				0.99	1.00

(1) Boat located offshore, person in fresh water
(2) Boat located offshore, person partially in fresh water and partially on boat
(3) Boat located at dock, person partially in fresh water and partially on boat
(4) Boat located at dock, person partially in freshwater and partially on dock
(5) Boat located at dock, person in fresh water

More details of the five the most critical scenarios above are discussed in our project to apply the ESD concept trees that we developed.

In the risk communication section of this research report, methods for prevention of electricity-induced accidents and risk mitigation for electricity in water are proposed. It is noticeable the useful information in this research paper to apply them developing ESDCT (e.g., how to prevent the electricity in different location of person from different source of hazard, how to protect people from electricity, and what are the checklists for boats and dock facilities). The report also suggested methods for risk mitigation for electricity in water as well as information about warnings regarding different kinds of environments. It also can be helpful information for the section of risk communication.

Electrical Shock Hazard Due to Stray Current

Source: Zipse, D.W. "Electrical shock hazard due to stray current." 1999 IEEE Industrial and Commercial Power Systems Technical Conference (Cat. No.99CH36371). doi:10.1109/icps.1999.787218.

Abstract:

The uncontrolled flow of continuous electric current over the earth, building steel, metallic piping, etc. has become a serious problem that lacks recognition by the greater part of the electrical industry. The resulting electric shocks appear to be of little concern to the majority of the electric utilities, electrical engineers or the public. However, with the advent of sensitive computers and electronic equipment, the problem will continue to grow. The electrical hazards associated with trailers, marinas and now ranges, and dryers being wired with only three wires has been recognized; this recognition has brought changes to the National Electrical Code. No longer can a single conductor serve as a neutral and ground. This logic must be extended to electrical services to residences, commercial establishments and industries to protect occupants from potentially hazardous electrical shocks.

Highlights:

Uncontrolled Flow of Continuous Electric Current; The Possible Sources of Current

Applicability to Project:

This paper introduces the hazard of uncontrolled flow of continuous electrical current. The uncontrolled flow of continuous electrical current is the flow of continuous electric current over the earth, building steel, metallic piping, etc., from multiple connections of the neutral conductor to earth or ground or from the interconnection of neutrals from different electrical systems that have multiple connections to earth or ground. Most electrical engineers are unaware that the primary neutral of a utility distribution transformer is directly connected to the secondary grounding system. To prevent the current from flowing over paths that could cause harm, the solution is to find the source of the stray, continuous, uncontrolled current flow. One source of stray, uncontrolled current is current coming from one or more of the other places served from the pole-mounted transformer. This source is considered in our project.

Methods of Calculating Electrical Body Impedance and Equipment for Measuring Leakage Current

Source: Smoot, A.W. and N. Mogan. "Methods of Calculating Electrical Body Impedance and Equipment For Measuring Leakage Currents." Electrical Shock Safety Criteria, 1985, 295-305. doi:10.1016/b978-0-08-025399-2.50029-1.

Abstract:
The impedance of the human body is represented by a five-component model, consisting of a resistor in series with two parallel combinations of a resistor and a capacitor. The values of the components can be calculated by equations as functions of the pathway and duration of the current through the body. On the basis of a literature review, suggested limits are given in order to prevent injuries from the physiological effects of the passage of electric current through the human body such as: inability to let go of the electrode, stoppage of breathing, ventricular fibrillation of the heart, electric burns and paralysis. This paper is limited to consideration of circuit voltage of not more than 250 V RMS.

Highlights:

Table 2: 60 Hz RMS Limits of Sinusoidal Currents for Protection from Ventricular Fibrillation

		Shock duration (T) (Seconds)		
Body Weight (kg)	Type of Person	Less than 0.0209	0.0209 to 1	Greater than 1
70	Men	I= 1245 mA	I= $83T^{-0.7}$ mA	I= 83 mA
55		I= 1125 mA	I= $75T^{-0.7}$ mA	I= 75 mA
43.8	Woman	I= 915 mA	I= $61T^{-0.7}$ mA	I= 61 mA
25		I= 585 mA	I= $39T^{-0.7}$ mA	I= 39 mA
8.4	Child	I= 300 mA	I= $20T^{-0.7}$ mA	I= 20 mA

Applicability to Project:
This paper presents the responsibility of making judgement of the safety of electric products. Compared with Ayyub (2016), they demonstrated acceptable current considering diverse body weights. Table 2 describes the sinusoidal current for protection from ventricular fibrillation at 60-Hz RMS. This table provides applicable criteria when we conduct risk analysis in terms of applying IEEE Std. 80.

A Method for Evaluating Electric Shock Hazards Based on Human Body Current

Source: Lee, Bok-Hee, Yang-Woo Yoo, and Jong-Hyuk Choi. "A Method for Evaluating Electric Shock Hazards Based on Human Body Current." Journal of the Korean Institute of Illuminating and Electrical Installation Engineers 25, no. 6 (2011): 108-14. doi:10.5207/jieie.2011.25.6.108.

Abstract:
In order to mitigate the possible hazards from electric shock due to the touch and step voltages, the high resistivity material such as gravel is often spread on the earth's surface in substations. When the grounding electrode is installed in two-layer soil structures, the surface layer soil resistivity is different with the resistivity of the soil contacted with the grounding electrodes. The design of large-sized grounding systems is fundamentally based on assuring safety from dangerous voltages within a grounding grid area. The performance of the grounding system is evaluated by tolerable touch and step voltages. Since the floor surface conditions near equipment to be grounded are changed after a grounding system has been constructed, it may be difficult to determine the tolerable touch and step voltage criteria. In this paper, to propose an accurate and convenient method for evaluating the protective performance of grounding systems, the propriety of the method for evaluating the current flowing through the human body around on a counterpoise buried in two-layer soils is presented. As a result, it is reasonable that the grounding system performance would be evaluated by measuring and analyzing the current flowing through the human body based on dangerous voltages such as the touch or step voltages and the contact resistance between the ground surface and feet.

Highlights: Grounding System Evaluation; IEEE Standard 80-2000

Applicability to Project:
This research paper aimed to understand the evaluation of the grounding system through tolerable touch and step voltages based on IEEE Std. 80-2000.

IEEE Std. 80-2000
$E_{touch} = I_B(R_B + 1.5\rho)$ $E_{step} = I_B(R_B + 6.0\rho)$ $I_B = \frac{k}{\sqrt{t_s}}$ $where;$ $E = Permissible\ total\ equivalent\ touch\ or\ step\ voltage$ $I_B = Current\ through\ the\ body$ $R_B = Resistance\ of\ the\ body$ $k = Constant, 0.116\ for\ 50\ kg\ of\ body\ weight, 0.157\ for\ 70\ kg\ of\ body\ weight$ $t_s = Shock\ duration$

IEEE Std. 80-2000 suggests methods for increasing the surface material resistivity, thereby increasing the permissible total equivalent voltage. In the field, inspectors evaluate the performance of the grounding system by only considering the permissible voltage. However, the paper states that by only considering permissible voltage, the change in current through the body by changing surface resistivity is not evaluated. The author suggests that current through the body should be evaluated rather than permissible voltage. This is the method applied in our Task 5 Action Plan, as outlined in our research proposal.

In-Water Shock Hazard Mitigation Strategies

Source: Electric shock drowning coauthored by David Rifkin and James Shafer, "In-Water Shock Hazard Mitigation Strategies," October 2008, ABYC report.

Abstract:
In FY 2003 & 2004 the American Boat & Yacht Council, ABYC, was awarded grants that studied the theory of AC electric shock in water. The purpose of these grants was to make a recommendation, after intense study, on how a person should react in the event of an encounter with an electrical situation. The laboratory based research that was conducted under these grants was concise, and repeatable in a lab situation. The problem arose when the lab set-up was to be tested in a real life situation; the parameters of the experiment could not be transferred to an environment with infinite variables (e.g. salinity, plant life, current, etc.). Currently this grant exists as a reference for future projects and has not been able to aid in the production of mitigation strategies for boats or people. In-water shock drownings are a reality and can be prevented by the use of off-the-shelf devices used in the correct manner and installations.

Highlights:
Ground Fault Circuit Interrupters (GFCI); NFPA 303, *Fire Protection Standard for Marinas and Boatyards*; Electrical Fault (i.e., "short circuit"); Tests

Applicability to Project:
This paper conducted the following tests: Basic, High Current, Isolated Ground, AC Leakage, Split Current, Broken Cable Insulation, Voltage, Current, Electric Field (voltage gradient) Relationship, and Dockside Accident Recreation. From these tests, the following seven results were found: It takes two faults to create a dangerous situation: an electrical fault to ground, and a break in the bonding (grounding) system back to the source.

If AC leakage current is kept to less than 100 milliamps, a dangerous condition should not result around boats connected to the shore power system. Current in the water varies linearly with voltage applied to an underwater metal. Voltage gradient varies linearly as current in the water is varied. A low-impedance bonding path will carry the majority of AC fault current back to the source (in freshwater). This will result in either a protective circuit action (to disrupt power to the fault) or significantly reduced touch voltages on metal surfaces (minimizing shock hazard). In saltwater, the water often offers a lower impedance than the bonding conductors themselves. In general, the smaller the surface area of the energized metal, the more dangerous it will be (for the same AC leakage current). Additionally, it takes a much higher level of AC leakage current to cause dangerous conditions as the surface area of the energized metals increases. In other words, a small, single stern drive fiberglass boat is potentially more dangerous than a large metal-hulled houseboat.

The lower the water conductivity, the greater will be the shock hazard for anyone in the water around boats using AC shore power. As the conductivity increases, the shock hazard diminishes. In the case of saltwater, there is little danger to anyone in the water. However, in saltwater fault current will be higher, representing an increased risk of onboard electrical fires.

From the results, it is possible to determine two general conditions that can cause accidents — fault conditions and environmental conditions.

Fault Conditions: Improperly wired appliances and electrical cores; Electrical ground faults and exposed conductors in contact with the water; and, Lack of or failure of the bonding system, which is designed to cause circuit protective action or reduce touch voltages to non-lethal levels in the event of an electrical fault

Environmental Conditions: Freshwater, saltwater, or brackish water

In addition, the paper made the following ten recommendations:

Install a residual current device (RCD) in the shore power supply of a boat's electrical system. This applies to all electrical systems that utilize shore power, including boats using transformers supplied by shore power. These RCD's respond to the imbalance of current between ungrounded and grounded conductors and cause a circuit protective action to quickly occur. Based on the data, this RCD should be set to trip at a maximum level of 100 milliamps (which would have prevented lethal voltage gradients for all scenarios in the Basic Testing series).

Require that all underwater metals be connected to the shore bonding (grounding) conductor if AC shore power is being supplied to the boat. This includes even those metals that are not part of the boat's electrical system since they still represent a potential fault current path back to the source through the water. This will protect anyone in the water in the event that any underwater metal becomes accidentally energized on the boat. This recommendation will also reduce the shock hazard for a boat's occupants. The ABYC standards concerning installation of transformers and battery chargers should be reviewed in light of this recommendation.

Periodically test boats for AC leakage into the water. While none of the boats tested during the study demonstrated any significant AC leakage current, field experience has revealed many boats leaking current at potentially dangerous levels. The examination of past accidents shows that one of the two conditions necessary for an accident to occur is an electrical fault to the grounding system (i.e., short circuit). Another way this manifests itself is as an improper connection between neutral and grounding (bonding) conductors on the boat. This connection always creates a parallel path for AC current to return to the source through the water. A periodic testing regimen could uncover faulty boats before an accident occurs. Incorporation of periodic AC leakage testing guidelines should be considered for ABYC and NFPA standards (specifically NFPA 303, *Fire Protection Standard for Marinas and Boatyards*).

Periodically determine the integrity of a boat's bonding (grounding) system. The second condition (the first being an electrical fault) necessary for an accident is a break in the bonding system between a boat's underwater metals and the supply bonding conductor. Periodic testing could reveal those boats with bonding system faults (e.g., broken bonding conductors, failed open circuited galvanic isolators, corroded or damaged receptacle connections) so that repairs can be made before an electrical fault occurs. Incorporation of periodic bonding system integrity testing guidelines should be considered for ABYC Standards along with expansion in NFPA 303 to include the boat itself as an electrical appliance connected to the shore power system.

Prohibit swimming in any marina where AC shore power is being supplied to the docks for any purpose. Posting of warnings should be considered for the protection of occupants of boats at a dock or marina facility. This could in the form of a physical sign posted at a dock or marina or a label near a boat's AC shore power main breaker. Consideration should be given to establishing "diving windows" in freshwater marinas using AC shore power, where all AC power could be secured at specified times to facilitate diving operations. Incorporation of swimming and posting guidelines should be considered for ABYC Standards and NFPA 303.

Replace any shore power cord with insulation damage or any cord with electrical tape applied to repair damage. The study showed that broken insulation can cause dangerous conditions if a shore cord is allowed to enter the water. Shore cord requirements are already included in NFPA 303. Consideration should be given to expanding requirements in the ABYC standards to include shore cord inspection and replacement criteria.

Revise the "Warning" NMMA brochure on Electrical Shock Hazards to include recommendations 3 through 6. Create a category in data collection databases to include injury and deaths attributable to electric shock drowning. This would expand visibility in this area and could prompt more research into improving boating and marina safety. Disseminate an abstract of this report, with recommendations, in the form of a brochure (similar to the NMMA pamphlet) to the US Corps of Engineers, State Boating Law Administrators, State Fish and Wildlife administrators, and other entities having jurisdiction of recreational salt and fresh water lakes and rivers (including law enforcement, and fire and rescue). Trade groups like the Association of Marina Industries, American Boat Builders and Repairers Association, and local marine trades associations should also be included in this dissemination.

Conduct a review of the National Marine Manufacturers Association (NMMA) checklist for inspecting for ABYC Standards compliance to ensure that all grounding (bonding) requirements established in the standards are included. This would serve to increase compliance in an area that directly impacts personal safety around boats. Establish a quality assurance standard requiring post-construction testing of the electrical systems of new boats. This testing could detect manufacturing defects in a boat's electrical system that could otherwise go undetected until an accident occurs in the field.

Conduct further research to better characterize the decay in voltage/voltage gradient as distance to a fault source increases. A wide sample of marina and private dock venues must be used as the basis for this study. The data from this research would be useful in establishing basic guidelines for the placement of swimming areas (or designation of no-swimming boundaries) in proximity to boats using AC shore power. A procedure to determine the effectiveness of this placement in any particular location could be determined based upon this research.

Electric Shock Hazards of Fresh Water Swimming Pools

Source: Dalziel, Charles F. "Electric Shock Hazards of Fresh Water Swimming Pools." IEEE Transactions on Industry and General Applications IGA-2, no. 4 (1966): 263-73. doi:10.1109/tiga.1966.4180670.

Abstract:
The study of electric shock hazards of fresh water swimming pools is based on six serious swimming accidents, of which, five were fatal; electrical tests using commercial pool lighting fixtures in five of the large university swimming pools at Berkeley, Calif.; and electric shock tests on dogs in a private pool.
The 1965 edition of the National Electrical Code, Article 680, contains requirements covering swimming pool lighting circuits and fixtures, and several organizations are expending efforts to develop protective devices. However, most of the developments pertain only to protecting the lighting circuit and fixtures. It is the author's opinion that the potential hazards of the conduits supplying the circulating pump and the convenience outlets in the pool area constitute a great, if not greater, hazard than the lighting circuits. The potential hazard from ungrounded defective appliances in the vicinity of the pool area is most important since the extension cord permits bringing the convenience outlet up to the very edge of the pool where bathers, barefoot and dripping wet, operated motor driven rotisseries, record players, radio and television receivers, public address systems, and drink mixers, most of which are energized from 2-wire cords with their frames ungrounded. It is evident that the electric shock hazards of the swimming pool will not be resolved, until all of the electric circuits supplying the swimming pool area are adequately protected; fortunately, the differential circuit breaker described is adequate for the job.

Highlights: Major Cases of Electric Shock; Five Tests; Potential Hazards; Pennsylvania Code

Applicability to Project:
Because the paper goes over electrical shock hazards of fresh water swimming pools, we can expand our research scope from this paper. The author found that the major causes of electric shock in swimming pools are broken lamp or lens and ineffective grounding or bonding. In particular, the author emphasized the failure of the grounding or bonding system as a main electrical hazard. Even though all requirements such as Pennsylvania Code are met, it is difficult to explain why so many of the accidents involved conduits that were not grounded. A grounding system can lose its effectiveness due to the insidious effects of electrolytic corrosion, and the water-filled conduit sets the stage for an eventual short circuit. Therefore, it is recommended that the exposed threads at all couplings and junction boxes installed below grade be covered with a suitable protective covering to prevent the corrosion of raw metal and to maintain water-tight joints. In addition, all circuits serving the swimming pool area, such as lighting circuits, circuits supplying circulating pumps, the electric time switch, and circuits supplying receptacles and yard lights, should be protected by a differential-type circuit protectors.

Pennsylvania Code
Distribution centers, pumps, filters, and other electrical and mechanical equipment associated with a swimming pool shall be enclosed so as to be accessible only to authorized persons, and not to (barefoot) bathers; All water and other piping, including inlet and outlet pipes, shall be metallically bonded together and connected to the same grounding electrode used to ground the neutral conductors of the electrical supply system; The crossing of outdoor public bathing places by open overhead conductors is prohibited; Metal fences or railings on which a broken conductor might fall shall be effectively grounded; The electrical installation of every public bathing place shall be inspected and approved annually.

Simulation of Electric-Current-Induced Drowning Accident Scenarios for Boating Safety

Source: Koko, Tamunoiyala S., Bilal M. Ayyub, and Keith Gallant. "Simulation of Electric-Current-Induced Drowning Accident Scenarios for Boating Safety." ASCE-ASME J. Risk and Uncert. in Engrg. Sys., Part B: Mech. Engrg. 2, no. 3 (September 2016): 031003-1-31003-20. doi:10.1115/1.4032262.

Abstract:
In the companion paper (Ayyub et al., 2016, "Risk Assessment Methodology for Electric-Current Induced Drowning Accidents," ASCE-ASME J. Risk Uncertainty Eng. Syst. Part B Mech. Eng., 3(3), pp. XXX-XXX.), the authors developed a methodology to identify hazards associated with electric-current-induced drowning and electric shocks for swimmers around docks, houseboats, and other boats in both freshwater and saltwater; and to assess scenarios and risks associated with these hazards. This paper presents numerical simulations of the electric field and potential in the surrounding water for a number of these electric-current-induced drowning accident scenarios in support of boating safety studies.
A boundary-element-based computational tool was employed. A combined experimental and numerical validation study was first undertaken. The tool was then used to compute the electric field and potential in the fluid surrounding the boat with and without a person in the surrounding field for four accident scenarios, including two scenarios with boat at dock in freshwater or saltwater; and two scenarios with boat offshore in freshwater or saltwater. Parametric studies were also undertaken, giving consideration to parameters such as the location of the human with respect to the boat and dock; nature of the water body (freshwater or saltwater); and intensity of the applied current (i.e., at source); and to establish general trends of electric potential and electric field due to the presence of an electric power source in water. The observations from the parametric study are useful for developing information for communicating these risks to swimmers, first responders, boat owners and operators, marina and boatyard owners, and other persons in the vicinity of boats.

Highlights:
Corrosion Mechanism; Sacrificial Anodes; Implementation of an Impressed Current System;
Observations: Offshore Scenarios (for a boat in saltwater and freshwater, both with and without a person in the water); Boat-at-Dock Scenarios (boat is docked in saltwater and freshwater, with and without a person in the water)

Applicability to Project:
This paper considers the potential risk of electric-current-induced accidents assessed on the intensity and distribution of the electric potential and electric field in the water near a power source. The research paper considers humans to be at risk if they are swimming in water where the electric potential or field exceeds a threshold value. It does not account for the resistance of the individual in question. The author recommended that the amount of current in the human be computed and used as a risk measure. Also, it is recommended that extensive investigations of the marina and brackish water cases be undertaken in future studies to ensure complete generality of the conclusions reached for the cases.

The electric field simulations in this research paper were produced with two well-known techniques that are commonly used to prevent corrosion: sacrificial anodes and impressed current systems.

When sacrificial anodes are used, the metal to be protected is galvanically connected with another metal with a greater negative electrochemical potential with respect to the ambient electrolyte. The electrolyte will then corrode the protective metal, known as the sacrificial anode. For example, the stern and rudder of a shop structure are often protected with sacrificial zinc anodes.
When using an impressed current system, on the other hand, the metal to be protected is connected to a direct current (DC) source. The positive pole of this DC source is then coupled to an auxiliary inert anode. This anode dissolves at different rates for different metals.

With the processes above, an electric field is produced due to the difference in potentials of the two metals (electrodes). The water acts as the electrolyte, the current source on the boat acts as the anode, and the personnel within the vicinity of the boat act as the cathode. This research paper can be applied to Task 3 (hazard identification), Task 4 (risk evaluation), and Task 5 (action plan) in our report.

Assessment of Hazardous Voltage/Current in Marinas, Boatyards and Floating Buildings

Source: *Assessment of Hazardous Voltage/Current in Marinas, Boatyards and Floating Buildings*, FPRF, 2014, Quincy, MA, USA

Abstract:
The safety of electrical equipment installed and used in the vicinity of marinas, boatyards and floating buildings is a challenge. This typically requires designing, installing, operating and maintaining electrical equipment that balances inherently safe levels of equipment operation against nuisance interruptions of the applicable electrical infrastructure. This electrical equipment is typically subjected to harsh environmental conditions that can result in deterioration and other long term maintenance concerns. Reports in the mainstream media of drowning in the vicinity of marinas, boatyards and floating buildings has raised questions on possible shock hazards from nearby electrical equipment, and thus credible data is needed that clarifies the problem and provides guidance towards the most appropriate mitigation measures.
The goal of this project is to identify and summarize available information that clarifies the problem of hazardous voltage/current in marinas, boatyards and floating buildings, and to develop a mitigation strategy to address identified hazards. The Research Foundation expresses gratitude to the report authors John Adey with ABYC Foundation, Inc., and Bill Daley and Ryan Kelly both with CED Technologies, Inc. Likewise, appreciation is expressed to the Project Technical Panelists and all others who contributed to this research effort for their on-going guidance. Special thanks are expressed to the following project sponsors: Attwood Marine; Eaton Corporation; Hubbell; Intertek; Leviton Manufacturing Company; NEMA Electrical Connector Section; and Underwriters Laboratories.

Highlights: Electric Fault; Salinity; ABYC Standards; Electronic Devices

Applicability to Project: The goal of this paper is to answer the question "What is the best product to provide the most protection for a swimmer in the water?"

According to this paper, ESD begins with an electric fault on the dock or onboard a boat when a voltage source comes into contact with the body of water. The voltage radiates throughout the water in a hemispherical field. As a swimmer approaches the electric field, electric current begins to flow through the swimmer's body. The human body has a much lower resistance than fresh water so it acts as the better conductor of electricity. As little as 10 mA of current through the human body can cause loss of muscular control, which may result in drowning. ESD can be fairly insidious since the victim may not be exposed to the stray voltage field on initially entering the water. The voltage source may be intermittent as a function of when a particular AV device is automatically or manually cycled on or off, or a when a fault is intermittent in nature. Although ESD has been mostly observed in fresh water, the incidence of ESD in brackish water cannot be ignored since the conductivity of brackish water can vary based on numerous environmental conditions. Electronic devices that may mitigate ESD were researched for their application to land-based protective systems. Equipment can be installed at the power feed to the marina, at the head of a pier or group of piers, or at individual slips. ABYC standards recommend a device that interrupts the source of power feeding a fault within 100 ms from the moment stray currents exceed 30 mA. While 30 mA through the body is more than enough to kill a swimmer, it is not sufficient to assume that all of the 30 mA leaking into the water will actually go through the swimmer. Also, it is important to remember that the risk of ESD increases as water salinity decreases. This paper aids in understanding the process of ESD and the installation of electronic devices and, therefore, is applicable to the project.

An Electrical Distribution for Marinas

Source: Parise, Giuseppe, and Luigi Parise. "An electrical distribution for Marinas." 2014 AEIT Annual Conference - From Research to Industry: The Need for a More Effective Technology Transfer (AEIT), 2014. doi:10.1109/aeit.2014.7002029.

Abstract:
The design of electrical power distribution system of Marinas requires a special architecture to supply the distributed loads constituted by pleasure crafts. It must also provide for solutions to possible stray currents circulating through the earth and the water that can cause electrical hazards and corrosions.
The authors suggest the adoption of a distribution operated at 1 kV and the TN-island System to supply each pleasure craft. This distribution system is an effective way to protect persons from shock hazards in installations with contained demand load, and to greatly limit electrical interferences among systems.

Highlights:
Electrical Distribution Configuration; Basic Distribution System (BDS); Low-Voltage Local Distribution System (LDS); Local Separation Transformers (LST); Figure 1

Applicability to Project:
The authors suggest the installation of an isolating transformer with the mid-point of the secondary winding connected to a common equipotential node (called TN-island system). By connecting the transformer, it is possible to reduce stray current and touching voltage. In a boat supply system, stray current can flow and cause electric shock. This method is included as one of the mitigation plans in this project.

Figure 1. Marine-style pedestal with socket outlets

Conduction of Electrical Current to and Through the Human Body: A Review

Source: Raymond M. Fish, PhD, MD, FACEPa, and Leslie A. Geddes, MS, PhD, DScb, "Conduction of Electrical Current to and Through the Human Body: A Review." October 12 2009, Bioacoustics Research Lab & Department of Surgery, University of Illinois at Urbana-Champaign; and Weldon School of Biomedical Engineering, Purdue University, W Lafayette, Ind

Abstract:
This article explains ways in which electric current is conducted to and through the human body and how this influences the nature of injuries. This multidisciplinary topic is explained in part A by first reviewing electrical and pathophysiological principles, and later in part B by considering specific types of accidents. There are discussions of how electric current is conducted through the body via air, water, earth, and man-made conductive materials. There are discussions of skin resistance (impedance), internal body resistance, current path through the body, the let-go phenomenon, skin breakdown, electrical stimulation of skeletal muscles and nerves, cardiac dysrhythmias and arrest, and electric shock drowning. After the review of basic principles, a number of clinically relevant examples of accident mechanisms and their medical effects are discussed in part B. Topics related to high-voltage burns include ground faults, ground potential gradient, step and touch potentials, arcs, and lightning. Understanding how electric current reaches and travels through the body can help one understand how and why specific accidents occur and what medical and surgical problems may be expected.

Highlights:
Table 3, Why immersion in water can be fatal with very low voltages

Applicability to Project:
This paper explains ways in which electric current is conducted to and through the human body and how this influences the nature of injuries. The discussion of how electric current is conducted through the body via water (see Table 3) is of particular importance to this project.

Table 3 Why immersion in water can be fatal with very low voltages
1. Immersion wets the skin very effectively and greatly lowers skin resistance per unit area
2. Contact area is a large percentage of the entire body surface area
3. Electric current may also enter the body through mucous membranes, such as the mouth and throat
4. The human body is very sensitive to electricity. Very small amounts of current can cause loss of ability to swim, respiratory arrest, and cardiac arrest

Two research papers by Dalziel et al. (1956) and Smoot et al. (1964) found that 10 mA of current is enough to cause loss of muscle control in water. In the paper, there are two mechanisms of contact involving a person in the water. The first mechanism involves a person in water reaching out of the water and contacting an energized conductive object. The second involves a person in the water in an electric field created by an energized conductor in the water. The paper can be used for developing scenarios and calculating voltages and currents for this project.

Electrical Shock Hazards and Safety Standards

Source: Bernstein, T. "Electrical shock hazards and safety standards." IEEE Transactions on Education 34, no. 3 (August 1991): 216-22. doi:10.1109/13.85079.

Abstract:
The experimenter in the laboratory encounters all types of electrical equipment. Some pieces of test equipment are battery operated or operate at low voltage so that any hazard is minimal. Other types of equipment are isolated from electrical ground so that there is no problem if a grounded object makes contact with the circuit. There are, however, pieces of test equipment that are supplied by voltages that can be hazardous or that can have dangerous voltage outputs. The standard power supply used in the United States for power and lighting in laboratories is the 120/240 V, grounded, 60 Hz sinusoidalsupply. This supply provides power for much of the laboratory equipment so an understanding of its operation is essential in its safe use. Higher voltage, sometime three phase, supplies equipment or motors with large power requirements. Nonsinusoidal or high-voltage type outputs from laboratory power supplies are also encountered in the laboratory. It is important to appreciate the effect of these various voltages on the human body to understand the potential hazard.

Highlights:
Protective equipment and devices; Figure 4; Figure 5

Applicability to Project:
The paper suggests several methods for protection from electrical shock: equipment grounding, double insulation, fuses, circuit breakers, and ground fault circuit interrupters (GFCI). However, this equipment can become hazardous if it is not working properly This paper can be used to develop scenarios and a basic tree of risk management for this project.

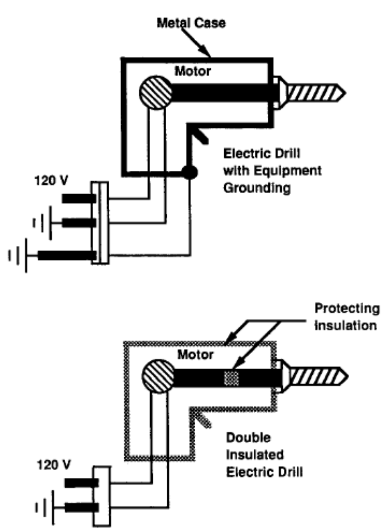


Fig. 4. Comparison of construction between electric drill with equipment grounding and one which is double insulated.

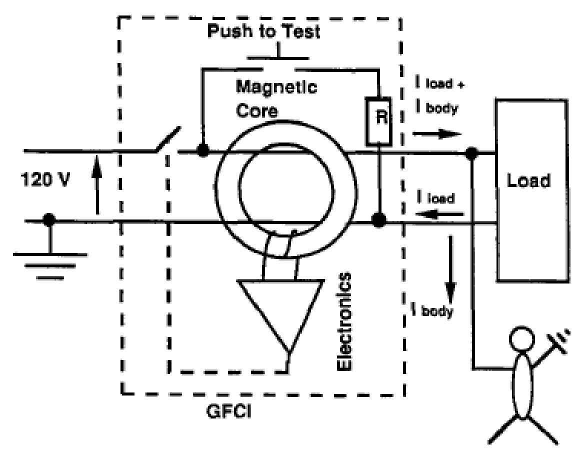


Fig. 5. Schematic diagram for the basic ground fault circuit interrupter operation.

Electrical Shock Hazard of Underwater Swimming Pool Lighting Fixtures

Source: Smoot, A. W., and C. A. Bentel. "Electric Shock Hazard of Underwater Swimming Pool Lighting Fixtures." IEEE Transactions on Power Apparatus and Systems 83, no. 9 (1964): 945-64. doi:10.1109/tpas.1964.4766095.

Abstract:
Electric equipment installed in a location where water is present may create a shock hazard for the user. This is because wet skin coming in contact with intentionally or accidentally energized parts can result in a path of low electrical resistance through the user's body for leakage or fault current. Electric equipment such as underwater swimming pool lighting fixtures fall into this category as both the fixtures and the users will be in direct contact with water.

Highlights: Figure 1; Figure 2; Figure 3; Figure 5

Applicability to Project:
This research paper found that muscular control of the legs was lost when the electric field in the water was 2.12 V/ft and 2.68 V/ft by conducting electric field measurements. This result, as well as 10 mA of current, can be used as a threshold in our project. This paper offers the threshold of electric field in the water by conducting experiments. Figures 1, 2, 3, and 5 illustrate the experiments.

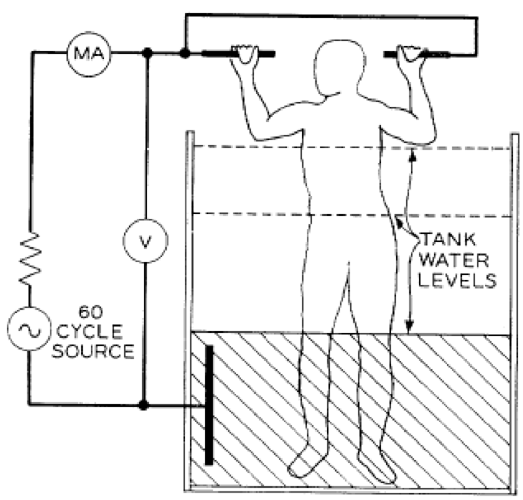


Figure 1. Potential measurements

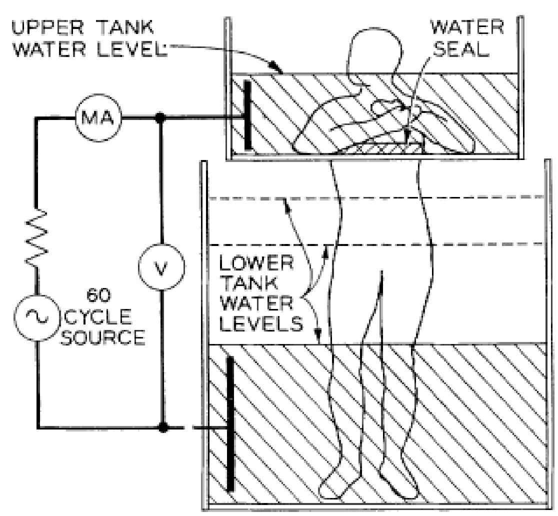


Figure 2. Electric field measurements

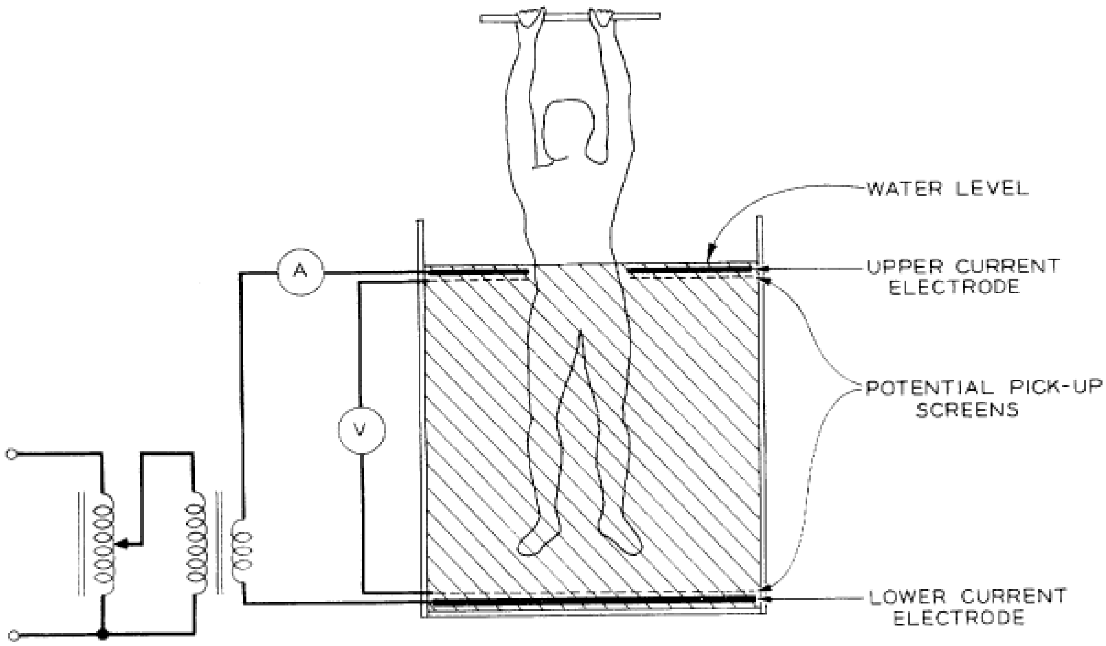


Figure 3. Electric field measurement; loss of muscular control

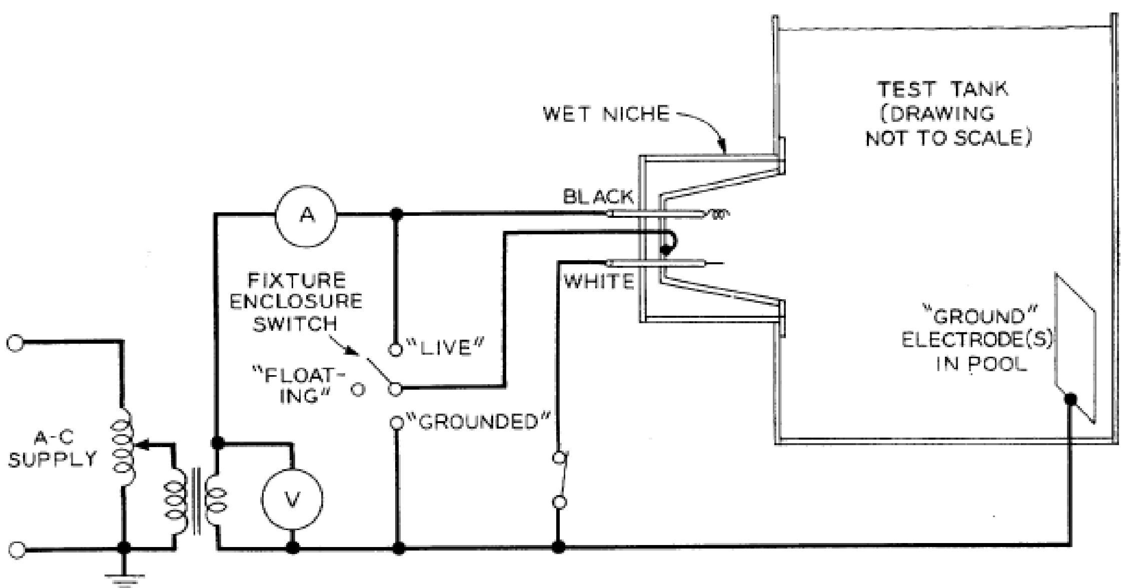


Figure 5. Schematic wiring diagram of scale model pool

Reevaluation of Lethal Electric Currents

Source: Dalziel, C. F., and F. P. Massoglia. "Let-go currents and voltages." Transactions of the American Institute of Electrical Engineers, Part II: Applications and Industry 75, no. 2 (May 1956): 49-56. doi:10.1109/tai.1956.6367148.

Abstract:
Low-frequency electric currents of a few milliamperes flowing through the body cause muscular contractions. In the arm such an effect may make a subject unable to let go of a live conductor. The highest currents which 99.5 percent of men and 99.5 percent of women are able to let go have been shown to be 9 and 6 mA, respectively. Currents somewhat larger than this, in the range of 20 to 40 mA, passing across the chest may arrest respiration leading to asphyxia, unconsciousness, and even death. The most common cause of death in electric shock probably is ventricular fibrillation, a condition in which the circulation is arrested and death ensues very rapidly. An analysis of available experimental data indicates that body weight and shock duration are important factors in determining the maximum current not likely to cause ventricular fibrillation. Taking a weight of 50 kg as the average for a human victim it is suggested that the relationship between current and shock duration is given by I = 116/V/T, where I is the current in milliamperes and T is the time in seconds. It must be stressed that this has only been shown to be valid within the range of 8 ms to 5 seconds. Currents flowing through the nerve centers controlling respiration may cause respiratory inhibition, which sometimes persists for a long time after the current has been interrupted. Other effects produced by high currents, such as burning, etc., are not discussed in this paper.

Highlights: IEEE Standard 80-2000

Applicability to Project:
This paper explains the relationship between fibrillating current and other variables like shock duration and body weight. They can be applied to the equation in IEEE Standard 80-2000.

IEEE Std. 80-2000
$I_B = \frac{k}{\sqrt{t_s}}$ $where$: $I_B = Current\ through\ the\ body$ $k = Constant, 0.116\ for\ 50\ kg\ of\ body\ weight, 0.157\ for\ 70\ kg\ of\ body\ weight$ $t_s = Shock\ duration$

While the equation in IEEE Standard 80-2000 determines the current through the body by considering only 50 kg and 70 kg of body weight, it is possible to determine current through the body with diverse weights and shock duration times with this paper.

Research-based guidelines for warning design and evaluation

Source: Wogalter, Michael S., Vincent C. Conzola, and Tonya L. Smith-Jackson. "Research-based guidelines for warning design and evaluation." Applied Ergonomics 33, no. 3 (2002): 219-30. doi:10.1016/s0003-6870(02)00009-1.

Abstract:
During the past two decades, the body of empirical research on warning design and evaluation has grown. Consequently, there are now basic principles and guidelines addressing warning design (e.g., signal words, color, symbols, and text/content), placement (e.g., location within product instructions), and how to enhance the usability of designs by considering factors internal to the user (e.g., beliefs, perceptions of risk, stress). Similarly, evaluation methods have been developed that can be used to measure the effectiveness of warnings such as the degree to which warnings are communicated to recipients and the degree to which they encourage or influence behavioral compliance. An overview of the empirical literature on warning guidelines and evaluation approaches is provided. Researchers, practitioners, and manufacturers can use these guidelines in various contexts to reduce the likelihood that injury and product damage from exposure to a hazard will occur.

Highlights:
- Figure 1. Complex communication model demonstrating the various user group and their interdependencies
- Figure 2. Communication-human information processing (C-HIP) model
- Guidelines for warning design
- User groups

Applicability to Project:
This research paper provides a review of the guidelines for warning design and evaluation based on empirical research. To be specific, the author classified the purpose of the research as three things:
- Environmental and personal factors that influence warning effectiveness
- Factors that influence risk perception

According to the research, when designing warnings, user groups such as end-users, organizations, and product manufacturers are to be considered. Figure 1 illustrates warnings as a subsystem functioning within a larger communication system that includes the manufacturer, distributor, employer, and end-user as additional subsystems.

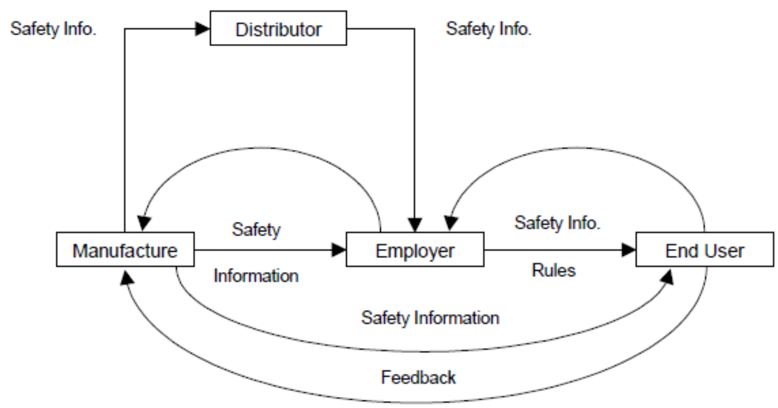


Fig. 1. Complex communication model demonstrating the various user groups and their interdependencies (Laughery and Wogalter, 1997).

In addition, the paper suggested the following guidelines for warning design:

- Salience
- Wording
- Layout and placement
- Pictorial symbols
- Auditory warnings
- Personal factors

Figure 2 describes the Communication-Human Information Processing Model (C-HIP). Two guidelines for evaluation of warnings are suggested such as formative evaluation and summative evaluation. Also, two measurements shall be considered (e.g., conducting subjective measures, and objective measures). Since lots of paper researched applying human information processing (C-HIP) model, it is necessary to research the existing warning sign for ESD if the sign is effective or not. It is possible to evaluate the effectiveness of warning sign by applying the guidelines.

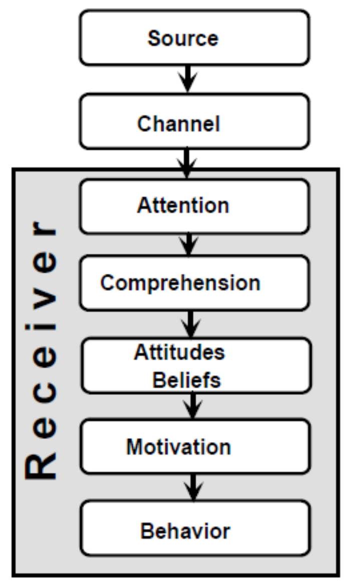


Fig. 2. Communication-human information processing (C-HIP) model. (Wogalter et al., 1999b).

WARNING! Sign and Label Effectiveness

Source: Wogalter, Michael S., and Kenneth R. Laughery. "WARNING! Sign and Label Effectiveness." Current Directions in Psychological Science 5, no. 2 (1996): 33-37. doi:10.1111/1467-8721.ep10772712.

Abstract:
The purpose of warnings is twofold. The first goal is to inform people so they appreciate potential hazards. The second goal is to change behavior, that is, to redirect people away from performing unsafe acts that they might otherwise perform. With today's technology, warnings have become increasingly necessary. Products, equipment, tools, and the environment have become more complex; how they work, their composition, and their inherent hazards are frequently not obvious. Until the past decade, relatively little empirical research on warnings had been reported — probably because warning research is difficult to do. Some of the difficulties are these: Direct behavioral observation of warning effects is time- and labor-intensive because the critical events are infrequent and sporadic; Allowing hazardous situations to occur in order to study them poses serious ethical concerns; and Laboratory studies that permit good experimental control may not be generalizable to other settings. Creating believable risk situations (that are actually safe) in the laboratory is challenging. In part as a result of these difficulties, research on warnings has proceeded on several methodological fronts employing a variety of techniques. Research has been conducted in the laboratory and in the field and has measured subjective judgements, comprehension, memory, behavioral intentions, and compliance.

Highlights:
- Purpose of warning
- Difficulties of warning research
- Successful warning
- Figure 1. A human information processing model showing a sequence of stages leading to behavior complying with a warning.

Applicability to Project:
This research paper focuses on visual warnings applying the human information processing model. According to the author, the purpose of warnings is to inform people so they appreciate potential hazards and change their behavior. Like Figure 2 in the previous report (Wogalter 2002), Figure 1 in this paper illustrates the Communication-Human Information Processing Model (C-HIP), but it includes the feedback process.
For a warning sign to be successful, three things are to be considered: It should capture attention and be understood; it should agree with existing attitudes and beliefs or be adequately persuassive to evoke a change toward agreement, and it must motivate the user to comply. Both Wogalter (1996 and 2002) reseach papers can be used in our project. Since the first author is same with previous research paper, we can apply both research papers to confirm existing warning signs

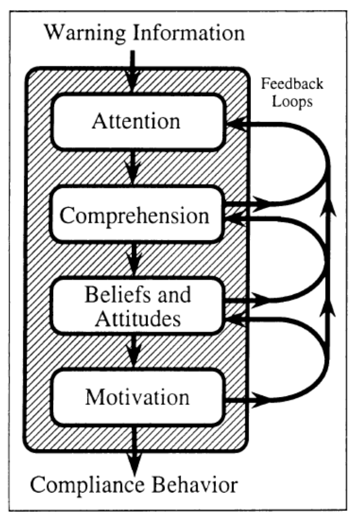


Fig. 1. A human information processing model showing a sequence of stages leading to behavior complying with a warning. The model includes feedback to earlier stages.

Effectiveness of a Warning as Measured by Behavior Change

Source: Mortimer, Rudolf G. "Effectiveness of a warning as measured by behavior change." PsycEXTRA Dataset. doi:10.1037/e577882012-005.

Abstract: Few studies of the effectiveness of warnings have evaluated the extent to which the warning actually affects the behavior that can lead to the hazard. This study provided such an opportunity. It arose because a person was injured while climbing onto a commuter rail platform instead of using the stairs that were at the other end of the platform. It was suggested that a warning may have deterred the hazardous behavior. Persons were observed by video approaching and climbing onto the platform at two stations having similar characteristics as where the accident occurred, both before and after a sign warning of the hazard was erected. Before and after the sign was in place all who approached the end without the stairs climbed onto the platform, even those who clearly looked at the sign. The sign had no effect on changing the behavior.

Highlights:
- Evaluation of the effectiveness of warnings
- Actual observation of warning sign

Applicability to Project:
The goal of this research report was to evaluate the effectiveness of warnings. The author conducted experiments with a warning signs to determine their effectiveness. To evaluate the effectiveness, two things must be considered: How well the warning label or sign is noticed, and how well the message in the warning is understood. These considerations were applied to the experiments.

Description of Experiments
- Hazard: Person who climbed onto the platform without using the stairs could be injured - Location: The end of platform in rail station - Method of observation: Video recording - Warning sign: 30 in. by 24 in. of metal plate with black legend on a white background. Signal word “WARNING” was in 4 in. high letters, with the legend of the warning itself in 3 in. The warning label stated: “DO NOT CLIMB ON THE PLATFORM. CLIMBING ON THE PLATFORM IS DANGEROUS AND CAN LEAD TO INJURY. USE PASSENGER ENTRANCE AT OPPOSITE END.” - Time period of observation: Between 6:30 AM and 8:30 AM on weekday morning

Before the warning signs were in place, 54 people were seen to approach the end of the platform, and all climbed onto it. After the warning signs were placed, 25 people were observed climbing onto the platform. Of the 25 people, 40 percent either clearly looked at or probably looked at the sign, while 60 percent did not look at the sign, or it could not be determined whether or not they looked. As a result of the experiment, the sign did not appear to change the observed behavior. Certainly, none of the people chose to walk to the designated entrance at the other end of the platform, as recommended by the sign. This research paper can be helpful to evaluate the effectiveness of warning signs for ESD. Also, by understanding the limitation of warning signs, existing warning signs for ESD can be corrected.

Safety communication: Warnings

Source: Laughery, Kenneth R. "Safety communications: Warnings." Applied Ergonomics 37, no. 4 (2006): 467-78. doi:10.1016/j.apergo.2006.04.020.

Abstract: This paper has two objectives: to identify and review factors that research has shown to be most significant in determining the effectiveness of warnings; and, to offer suggestions regarding challenges and opportunities for future research on warnings. In order for warnings to be effective, they must accomplish two objectives: they must be noticed and encoded; and they must provide understandable information needed for recipients to make informed decisions regarding compliance. A number of variables or factors have emerged as being especially significant in determining whether or not a warning achieves these objectives. These factors include both warning system design variables as well as characteristics of the target audience and the situation in which the warning is presented. While there has been significant progress in understanding the factors that influence warning effectiveness, there are also remaining challenges and opportunities. Challenges include issues associated with growing international trade such as language barriers, literacy and cultural values. Innovative approaches and opportunities are offered by developing communication technologies.

Highlights:
- Figure 1. Basic communication model
- Two objectives of warning at a general level
- Two theoretical approaches

Applicability to Project:
According to this paper, two objectives of a warning at a general level are stated: warning must attract attention, and warning must provide understandable information. These objectives are also found in other research papers reviewed previously. The basic communication model is illustrated in Figure 1. The basic communication model has four components: source (sender), medium, message, and receiver. The source can be the designer, originator, and sender of the warning message. Medium indicates how the message is presented or displayed. Message is the content of the warning, and the receiver is the target audience of the warning. As we noted in the previous literature review, the C-HIP model is useful in diagnosing warning failure. As with other research papers previously reviewed, this research paper will help to evaluate the effectiveness of existing warning signs for ESD.

Fig. 1. Basic communication model.

Alcohol-Influenced Recreational Boat Operation in the United States, 1994

Source: Pamela Logan, Jeffrey J. Sacks, Christine M. Branche, George W. Ryan, “Alcohol-Influenced Recreational Boat Operation in the United States, 1994”, Am J Prev Med 1999;16(4):278-282, PII S0749-3797(99)00022-7

Abstract:
There were 783 recreational boating fatalities in the United States in 1994. One contributor to this toll is alcohol-influenced operation of boats. Our study objective was to determine the prevalence of alcohol-influenced motor boat operation, and describe its relationship to demographic factors and other risk behaviors. In 1994, a randomly dialed national telephone survey contacted 5238 adult respondents who reported on their operation of motor boats, alcohol use, and other potential injury risk behaviors. Data were weighted to obtain national estimates and percentages. Of 597 respondents who operated a motor boat in 1994, 31% (206 respondents) reported doing so at least once while alcohol-influenced. Alcohol-influenced operation of a motor boat was significantly more likely among males, individuals between 25 and 34 years of age, and those with greater than a college education. Alcohol-influenced motor boat operation was also more common among those who drove motor vehicles while alcohol-influenced, and those who drove a motor vehicle without using a seat belt. To decrease alcohol-influenced boating, new strategies should be developed. Strategies used to decrease drinking and driving motor vehicles may prove adaptable to preventing alcohol-influenced boating. More effective means of monitoring alcohol-influenced boating is needed. Alcohol use by passengers on boats should not be overlooked as a problem.

Highlights:
- Table 1. National estimates of the prevalence of motor boat riding and operation by demographic characteristic in 1994
- Table 2. National estimates of the prevalence of alcohol-influenced motor boat operation by demographic characteristic in 1994

Applicability to Project:
This literature surveyed the number of boat operators and riders by characteristics and alcohol influence. According to the research paper, of the 783 recreational boating fatalities in the United States in 1994, 14 % were alcohol related. Indeed, the proportion of alcohol-related boating fatalities has climbed in recent years to an all-time high: 19% in 1991, 20% in 1992, 20% in 1993, 14% in 1994, 21% in 1995, and 27% in 1996. This data is from the U.S. Coast Guard. This report supports our suggested “no alcohol” mitigation method. Table 1 shows the number of boat operators and riders by characteristics, and Table 2 shows the number of alcohol-influenced boat operators.

Table 1. National estimates of the prevalence of motor boat riding and operation by demographic characteristic–1994

Characteristic	Boat Operators and Riders			Boat Operators Only		
	No.	Weighted No.	%	No.	Weighted No.	%
Overall	1136	43,387,895	22.8	597	22,254,693	11.7
Gender*†						
Male	725	25,818,292	28.3	484	17,366,119	19.0
Female	411	17,569,603	17.8	113	4,888,574	4.9
Age Group*†						
18–24	176	8,037,977	32.2	87	3,338,972	13.4
24–34	349	11,623,745	27.1	202	6,939,310	16.2
35–44	274	10,095,017	25.4	149	5,629,547	14.2
45+	327	13,324,064	16.6	153	6,127,559	7.6
Income Group*†						
$50,000+	429	16,528,039	33.5	267	9,970,271	20.2
$35,000–$49,999	219	9,016,540	27.7	112	4,448,993	13.6
$20,000–$34,999	222	8,026,908	19.6	101	3,312,347	8.1
<$20,000	148	4,978,959	12.1	62	2,224,849	5.4
Education*†						
College graduate or more	397	13,745,760	28.3	206	7,386,609	15.2
High school grad/some college	666	26,995,764	23.3	357	13,621,256	11.8
Less than high school	66	2,449,524	10.0	30	1,168,744	4.8
Marital Status*†						
Divorced/Widowed	178	4,588,094	25.1	68	1,795,548	5.5
Never Married	271	10,472,830	13.9	143	5,135,665	12.8
Married	681	28,234,670	24.5	382	15,268,450	13.3
Census Region*						
West	245	8,741,244	22.5	136	5,001,142	12.9
South	498	14,854,456	22.1	264	7,383,231	10.9
North Central	251	12,699,326	27.6	123	6,183,252	13.4
Northeast	142	7,092,869	18.8	74	3,687,067	9.8

*Riding in a motor boat vs. not riding, $p < 0.05$
†Operating a motor boat vs. riding, but not operating, $p < 0.05$

Table 2. National estimates of the prevalence of alcohol-influenced motor boat operation by demographic characteristic–1994

Characteristic	Alcohol-Influenced Motor Boat Operators (AIO)		
	No. AIO	Weighted No.	Weighted % (95% CI)
Overall	206	6,787,943	30.7 (26.4 − 34.9)
Gender*			
Male	183	6,092,538	35.3 (30.3 − 40.2)
Female	23	695,405	14.3 (7.7 − 21.0)
Age Group*			
18–24	20	770,629	23.1 (12.5 − 33.7)
25–34	88	2,756,323	40.0 (32.1 − 47.9)
35–44	49	1,472,851	26.2 (18.4 − 33.9)
45+	47	1,742,360	28.8 (20.5 − 37.0
Income Group*†			
$50,000+	105	3,584,985	36.1 (29.4 − 42.8)
$35,000–49,999	38	1,266,449	28.5 (18.9 − 38.0)
$20,000–$34,999	35	1,032,741	31.2 (21.0 − 41.3)
<$20,000	16	489,476	22.0 (10.9 − 33.1)
Education*†			
College graduate or more	91	2,997,318	40.6 (32.6 − 48.6)
High school grad/some college	107	3,559,284	26.3 (21.1 − 31.4)
Less than high school	7	217,885	19.5 (4.5 − 34.5)
Marital Status*†			
Divorced/Widowed	25	747,686	41.6 (26.9 − 56.4)
Never Married	54	1,787,239	34.9 (25.7 − 44.1)
Married	126	4,241,746	27.9 (22.9 − 32.9)
Census Region*			
West	55	1,847,495	37.3 (27.8 − 46.9)
South	89	2,194,705	30.0 (23.6 − 36.4)
North Central	40	1,848,103	29.9 (21.1 − 38.6)
Northeast	22	897,639	24.3 (14.0 − 34.6)

*Alcohol-influenced motor-boat operation vs. non alcohol-influenced boat operations, $p < .05$

"My Husband Ususally Makes Those Decisions": Gender, Behavior, and Attitudes Toward the Marine Environment

Source: Misse Wester, Britta Eklund, "My Husband Usually Makes Yhose Decisions": Gender, Behavior, and Attitudes Toward the Marine Environment", Environmental Management (2011) 48:70-80, DOI: 10.1007/s00267-011-9676-6

Abstract:
Human behavior impacts the environment we live in. In order to better understand how one group, boat owners, in three Nordic countries adjacent to the Baltic Sea; Sweden, Finland and Denmark, viewed the relationship between the marine environment, leisure boats and issues of responsibility, a survey study was conducted (n = 1701). The results show that there are differences between gender in many areas and those women in general are more environmentally friendly than men in their views and behavior. Men and women seek information about boating by different channels and this knowledge may be used in future information campaigns. Both men and women ranked boat owners as having the lowest impact on the marine environment and perceived these to be responsible for addressing environmental issues caused by leisure boat activities. The results also show that it is important to prove the effectiveness of an environmentally safe product since this factor is ranked higher than price when considering buying a product. The results suggest that once environmentally friendly behavior is established, such as recycling, this behavior continues. One implication of this study is that small changes in human behavior are seen as acceptable but larger commitments are more difficult to achieve. If individuals do not feel responsible for causing environmental damage, this aspect needs to be addressed in information aimed at this group. Novel approaches on framing the information and new ways of disseminating information are needed.

Highlights:
- Gender differences of risk perception
- Gender differences in usage of boat regarding maintenance
- Table 1. Boat owner profile by gender

Applicability to Project:
This paper introduces gender differences of risk perception and differences in usage of boats regarding maintenance. The research confirmed that there are clear differences between the risk perception of men and women. Men are thought to have more knowledge of specific risks or are perceived to have more influence over them than women do. In addition, the majority of boat owners did all the maintenance on their boats themselves, but men to a larger extent. Since the maintenance of boats can effect risk, this report is helpful to our project. Although the information is not from the United States, it is useful for comparison. Table 1 describes the percentage of boat owners by gender. This data is collected by SIFO international academy.

Table 1 Boat owner profile by gender (%)

	Men (%)	Women (%)
Type of boat		
Motorboat	69.5	72.5
Sailboat	30.5	27.5
Age		
Up to 40 years of age	30.8	40.8
Between 41 and 55	30.2	32.4
56 and over	38.9	26.7
Years of ownership		
0–5	27.3	35.1
6–10	18.4	19.2
11–15	11.9	9.8
16–20	10.4	10.5
20 or longer	32	25.5
Usage per season		
1–10 days	26.2	32.4
11–20 days	30.7	27.6
21–30 days	20.4	17.9
31 days or longer	22.7	22.1
Areas of usage		
Racing (sailboats)	2	1.5
Fishing	21.1	14.4
Mode of transportation	11.2	11.6
Shorter trips—recreational	52.5	60
Longer sailing trips	13.2	12.4
Distance traveled per day		
Up to 2.8 nautical miles	17	21.4
3–6 nautical miles	29.5	32.9
7–11 nautical miles	27	24.5
12–17 nautical miles	15.1	13.4
Over 17 nautical miles per day	11.4	7.8
Maintenance of boat		
Do all maintenance myself	64.2	60.8
Do most, but hire help	31.2	31.5
Full-service by marina	4.6	7.7

Human error in recreational boating

Source: A. James McKnight, Wayne W. Becker, Anthony J. Pettit, A. Scott McKnight, "Human error in recreational boating," Accident Analysis and Prevention 39 (2007), 398-405, doi:10.1016/j.aap.2006.09.004

Abstract:
Each year over 600 people die and more than 4000 are reported injured in recreational boating accidents (USCG). As with most other accidents, human error is the major contributor. U.S. Coast Guard reports of 3358 accidents were analyzed to identify errors in each of the boat types by which statistics are compiled: auxiliary (motor) sailboats, cabin motorboats, canoes and kayaks, house boats, personal watercraft, open motorboats, pontoon boats, row boats, sail-only boats. The individual errors were grouped into categories on the basis of similarities in the behavior involved. Those presented here are the categories accounting for at least 5% of all errors when summed across boat types. The most revealing and significant finding is the extent to which the errors vary across types. Since boating is carried out with one or two types of boats for long periods of time, effective accident prevention measures, including safety instruction, need to be geared to individual boat types.

Highlights:
- Table 1. Percent error by boat type (for errors totaling 5 % or more across types)
- Report by U.S. Coast Guard (USCG)

Applicability to Project:
This paper explores human error in recreational boating. It is reported that over 600 recreational boaters die and more than 4000 are reported injured each year in U.S. waters. The U.S. Coast Guard collects reports of boating accidents and reports boating statistics annually. The following extract from Table 1 (from the U.S. Coast Guard) shows the number of alcohol-related accidents for 9 types of boats.

Percent error by boat type (for error totaling 5 % or more across types)									
Activity in which error occurred	**Aux. sail (202)**	**Cabin motor (408)**	**Canoe kayak (291)**	**House boat (132)**	**Open motor (1176)**	**PWC (612)**	**Pont. boat (161)**	**Row boat (128)**	**Sail only (148)**
Limit consumption of alcohol	3	11	15	10	15	5	12	15	3

Among the diverse kinds of human error, consumption of alcohol must be considered in our project. Therefore, this research paper can be applied to our project.

Literature-based study of warning sign and of its effectiveness

Source: Ma, Chixiang, Shuaidong Jia, and Yanan Zhang. "Literature-based study of warning sign and of its effectiveness." Progress in Mine Safety Science and Engineering II, 2014, 543-50. doi:10.1201/b16606-102.

Abstract:
The term warning sign which is clarified as it is typically applied to organization, to product, and particularly to workplace safety, is intended to alert persons to potential dangers in the environment and/or in the product. Warnings have become an important part of our modern lives not only because they provide essential information, but also because of constantly increasing regulations that require warnings to be present almost everywhere. During the past three decades, the body of empirical research on warning design and evaluation has grown in Europe and America. However, little research in this area has been delved in China. This paper reviews the literature on warning sign (safety/warning label included) and its effectiveness to support a reasonable, effective and cost-efficient approach to the design of warnings in China, especially in coal mine. There are now basic principles and guidelines for warning sign design and placement (using system approaches). Similarly, effectiveness evaluation (behavioral intention and behavioral compliance) have been developed. And, a series of researches and literatures have investigated several factors that determine safety sign compliance, including sign characteristics (salience, wording, size, layout and placement, pictorial symbols), personal factors (age, culture/ethnicity, gender, length of service, individual experience), situational factors (familiarity and training, risk perception, rewards and punishment, cost of compliance), organizational safety climate, (organizational environment, personal communication, administrative situations).

Highlights:
- Figure 1. The common cause of accident
- Figure 2. The principle of warning sign to prevent accident
- Figure 3. The function principle of warning sign's effectivness

Applicability to Project:
Compared with the previous research paper "Research-based guidelines for warning design and evaluation" (Wogalter 2002), this paper focuses on the issue of influencing behavior. Figure 1, Figure 2, and Figure 3 from this paper can be applied to our project.
Figure 1, "The common cause of accident," describes that effective hazard control can prevent an accident from occurring since the hazard is the cause of accident. Figure 2. "The principle of warning sign to prevent accident" is a diagram of how a warning sign is aimed at accident-prevention and loss-reduction. Figure 3, "The function principle of warning sign's effectiveness," shows that if people follow directions and rules (warning signs), accidents and loss can be prevented or reduced to a large degree.

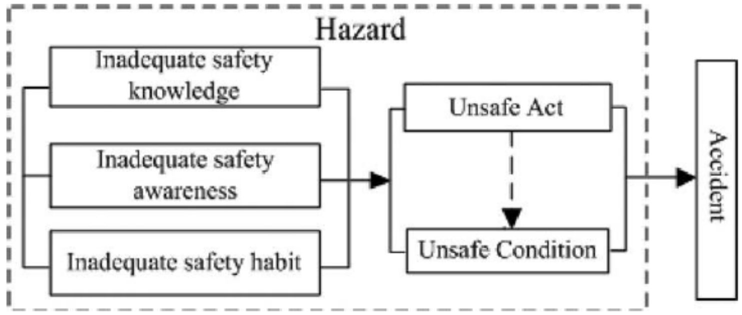


Figure 1. The common cause of accident.

Figure 2. The principle of warning sign to prevent accident.

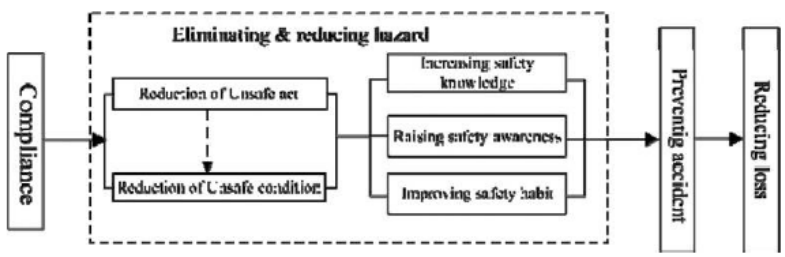


Figure 3. The function principle of warning sign's effectiveness.

The effectiveness of warning signs in hazardous work places: cognitive and social determining

Source: Adams, Austin, Stephen Bochner, and Lenka Bilik. "The effectiveness of warning signs in hazardous work places: cognitive and social determinants." Applied Ergonomics 29, no. 4 (1998): 247-54. doi:10.1016/s0003-6870(97)00047-1.

Abstract:
Recommendations have been made that good warning signs should have a number of components: an alerting word such as danger, then statements of the hazard, of its seriousness, of the probable consequences and of how to avoid the hazard. Responses from 40 blue-collar workers and 44 students were measured to five industrial warning signs to determine the extent to which these components determine estimated sign effectiveness and behavioral intentions of compliance. Each sign was presented in five versions; the original (which in each case omitted one or more of the components), a "full" in version in which missing components were generated and inserted, and versions omitting, in turn, the hazard, consequences, and instructions statements. Previous findings concerning the importance of the signal word were supported. When signs were seen singly there was no tendency for versions with components missing to be rated as poorer. Only when all versions were seen together was the "full" version ranked as being better, a result which is taken as reflecting the demand characteristics of the method. The results argue against strict adherence to a formula requiring specified components in a sign. Data also supported the third person effect, indicating that respondents considered others to be more vulnerable to the hazard and less likely to comply with the sign than they themselves. The finding that social factors are of considerable importance in sign compliance is discussed.

Highlights:
- Five components for good warning sign

Applicability to Project:
In this research paper, the author suggested five components for a good warning sign. Warning signs should attract attention, contain information about the nature of the hazard and the degree of its severity (such as whether there is a danger of injury, poisoning, or death), and be a clear statement of the adverse consequences if the warning is not obeyed. In addition, good signs should include specific instructions for action. The study's goal was to determine whether there are important differences between the worker and student populations in their reactions to the questions regarding warning signs. Like the experiment conducted in this paper, we can compare the results and the limitation of the results with our project if we conduct a similar experiment with a different target.

Effectiveness of Warning Signs: Gender and Familiarity Effects

Source: Gerald M. Goldhaber and Mark A. deTurck, "Effectiveness of Warning Signs: Gender and Familiarity Effects", Journal of Products Liability, Vol. 11, pp. 271-284 (1988).

Abstract:
Three NO DIVING signs were placed in conspicuous locations by a pool in a Buffalo suburban high school for a period of one month. A comparable suburban high school served as a control – no sign was placed by the swimming pool. Over 300 students at both schools completed a questionnaire after the one month testing period. Results indicated that males were more likely than females to dive into the shallow end of their school's pool, especially in the school where the NO DIVING sign was present. Moreover, it was argued that students with a history of: 1) diving into the shallow end of the pool, or 2) diving into above-ground pools, or 3) participating on the swimming team would be more likely than students without this history to dive into the shallow end of the pool. Results confirmed that all students with a history of diving into shallow water were more likely to dive into the shallow end of their school's pool than students without this history. It was concluded that pool owners should be more responsible for communicating warnings face-to-face with people who use their pools. By including oral communication as a mode for communicating warnings, awareness of hazards and perceived risk can be determined through immediate feedback. Warning consumers about the hazards of a product is a communication process. At a minimum, to be effective, a warning must provide a consumer with the information he/she needs to know so as to be able to use a product safely. Because consumers may be unfamiliar with a product, they may be uncertain about how to use it properly. It is this uncertainty that must be reduced as efficiently as possible by a warning message. Unfortunately, consumers differ with respect to their degree of familiarity or experience with products. As a result, it is almost impossible to design a warning that is tailored to the large number of individual differences identified by social science researchers. The purpose of the current study is to determine the effectiveness of a warning message when male and female consumers have different levels of experience with a product.

Highlights:
- Fundamental differences between men and women
- Effects of familiarity
- Table 1. Percentage of males and females that noticed warning sign without being prompted
- Table 2. Percentage of males and females that noticed warning sign after being prompted
- Table 3. Percentage of males and females that noticed a picture in the warning sign
- Table 4. Percentage of males and females comprehending consequences of hazard

Applicability to Project:
The goal of this research paper is to find out the differences effect by gender and familiarity in terms of effectiveness of warning signs. Fundamentally, males seem to decide whether to agree with the recommendations of a persuasive message after only learning a fraction of the information in the message. By contrast, females tend to withhold their affective response to a message until they have processed most, if not all, of a persuasive message. In addition, males may process less information from a warning sign than females. In addition, it is confirmed that as people become more familiar with a product by using it, they are less likely to notice the product has a warning message and perceive less risk associated with using

the product (Godfrey et al. 1983). The experiment was conducted with a sample of 328 students (180 males and 148 females) from two Buffalo suburban high schools.

Tables 1, 2, 3, and 4 are results of the experiment, and we can apply it to our project as a different mitigation plan by gender.

Table 1. Percentage of Males and Females That Noticed NO DIVING Sign Without Being Prompted

Did you see any signs by pool?	Sign			
	Present		Absent	
	Male	Female	Male	Female
Yes	26 %	9 %	8 %	6 %
No	15 %	10 %	1 %	4 %
Not Sure	59 %	80 %	91 %	90 %

Table 2. Percentage of Males and Females That Noticed NO DIVING Sign After Being Prompted

Did you see any signs by pool?	Sign			
	Present		Absent	
	Male	Female	Male	Female
Yes	37 %	8 %	14 %	9 %
No	41 %	14 %	20 %	8 %
Not Sure	22 %	80 %	66 %	83 %

Table 3. Percentage of Males and Females That Noticed a Picture in the NO DIVING Sign

Was there a picture in the sign?	Sign			
	Present		Absent	
	Male	Female	Male	Female
Yes	67 %	33 %	7 %	8 %
No	16 %	7 %	16 %	3 %
Not Sure	17 %	60 %	77 %	89 %

Table 4. Percentage of Males and Females Comprehending Consequences of Hazard

Can you be paralyzed by diving into the shallow end of the pool?	Sign			
	Present		Absent	
	Male	Female	Male	Female
Yes	91 %	84 %	80 %	79 %
No	6 %	3 %	8 %	3 %
Not Sure	3 %	14 %	12 %	18 %

It won't happen to me: Unrealistic optimism or illusion of control?

Source: Mckenna, Frank P. "It won't happen to me: Unrealistic optimism or illusion of control?" British Journal of Psychology 84, no. 1 (1993): 39-50. doi:10.1111/j.2044-8295.1993.tb02461.x.

Abstract:
Distinguishes between the two notions of unrealistic optimism and illusion of control. Past research on people's assessment of the probability of encountering negative events; Working definitions of the two concepts; Examination of conditions in which personal control is either present or absent; Evidence in favor of the illusion of control.

Highlights:
Unrealistic optimism
Illusion of control

Applicability to Project:
This research paper conducted two experiments to distinguish between the two notions of unrealistic optimism and illusion of control. Optimism is usually defined as a generalized expectancy for positive outcomes. It is difficult to determine whether the optimism is realistic or unrealistic. Research reveals that unrealistic optimism occurs not only in terms of a decreased subjective probability of negative events but also in an increased subjective probability for positive events; unrealistic optimism has had implications not only for different research areas but also for different level of analysis. Illusion of control is another theoretical construct as well as unrealistic optimism. The illusion of control is played an important explanatory role. It is readily exhibited and exaggerated when factors from skill situations are imported. The research paper conducted two experiments with those two hypotheses like unrealistic optimism and illusion of control by giving people two questions: "Compared to other drivers, how likely do you think you are of being involved in a road accident when you are driving?" and "Compared to other drivers, how likely do you think you are of being involved in a road accident when you are a passenger?". For the second experiment extended from the first experiment, it is conducted with driving scenario. The result of experiments is proved that it is important to distinguish the two hypotheses unrealistic optimism and illusion of control. To our project, in the aspect of perceiving the risk, those two hypotheses are necessary to be considered.

The role of enforcement programs in increasing seat belt use

Source: Williams, Allan F., and Joann K. Wells. "The role of enforcement programs in increasing seat belt use." Journal of Safety Research 35, no. 2 (2004): 175-80. doi:10.1016/j.jsr.2004.03.001.

Abstract:
Seat belt laws by themselves led to increased belt use in the United States and Canada, but initial effects were limited. Canadian provincial officials launched highly publicized enforcement campaigns in the early 1980s that resulted in substantially increased belt use. Canadian-style enforcement programs subsequently were adopted in the United States, and the use of such programs has grown in recent years. Lessons from these efforts include the importance of police leadership, focused publicity about enforcement, and sustained rather than single-shot effort. What is needed in the United States to achieve a national belt use rate of 90% or greater is widespread, methodical, and sustained application of enforcement programs augmented by creative publicity. Enhanced penalties —in particular drivers license points —likely will be needed to reach hard-core nonusers.

Highlights:
Means to increase complying with the law (e.g., education, campaigns, leadership by police, communication)

Applicability to Project:
This research paper shows the effectiveness of enforcement programs by investigating actual statistics information regarding seat belt use in the United States and Canada. According to this paper, a certain number of people use seat belts voluntarily. Persuading people to use seat belt is difficult because most of them already believe that seat belts should be used; they know they should use them but do not believe, or do not want to believe, they will need them. This fact shows the limitation of increasing the rate of complying laws only by education. In addition, initial effects of laws are limited to keep high rate of complying the law and it is proved by statistical data in Canada. To make high rate of following the laws and keep the rate for a long time, diverse kinds of means to be combined. This combination is called as "Highly publicized enforcement programs." It includes education, campaign, leadership by police, communication, and sign. Although this research paper reflects using seat belt, however it can be applied to our project as a part of table that we developed. Based on the findings in this paper, it can be shown that providing warnings, education, licensing or registering, regulations or penalties regarding noncompliance, permits, and public safety communications can be effective strategies to increase effectiveness of enforcement in terms of ESD.

Consumer behavior and the safety effects of product safety regulation

Source: W. Kip Viscusi, "Consumer Behavior and the Safety Effects of Product Safety Regulation," 18 J. Law & Econ. 527, (1985)

Abstract:
A recurring issue in the economic analysis of risk regulation agencies is whether these efforts have had any significant favorable effect on safety. Although the existence of such an effect would not necessarily imply that these efforts were worthwhile, without an enhancement in safety there is no potential rationale for these regulations. The Consumer Product Safety Commission (CPSC) represents an intermediate case in terms of the level of the risks possibly affected by agency actions. This paper is intended to provide a detailed empirical assessment of the effect of CPSC regulations on product safety.

Highlights:
Pattern of poisoning rate

Applicability to Project:
The research paper shows the effect of Consumer Product Safety Commission (CPSC) regulations on product safety. Among the rate patterns, the pattern of the poisoning rate after the advent of the safety cap is significant. For products covered by safety caps, there was no downward shift in poisoning rates. From the paper, this ineffectiveness appears to be attributable in part to increased parental irresponsibility, such as leaving the caps off bottles. This lulling effect in turn led to a higher level of poisonings for related products not protected by the caps. It implies that technological solutions to safety problems may induce a lulling effect on consumer behavior. The safety benefits will be muted and perhaps more than offset by the effect of the decreased efficacy of safety precautions, misperceptions regarding the risk-reducing impact of the regulation, and spillover effects of reduced precautions with other products. For our project, individual actions are an important component of the accident-generating process, and this research will be applied to provide education for swimmers, boat owners, and marina/dock owners.

A review of methods for analysis of regulatory effectiveness

Source: Denne, T and L Wright, "A review of methods for analysis of regulatory effectiveness" NZ Transport Agency research report 605. 132 pp. (2017)

Abstract:
This project aimed to identify the best approach for determining and monitoring the contribution that government regulatory interventions in New Zealand make to mitigate the major risks associated with the land transport system. It analyzed the safety and environmental risks in the New Zealand road transport sector, and reviewed the local and international literature to provide a framework for assessing the effectiveness of regulatory interventions aimed to mitigate these risks. The literature shows a preference for regulation that is less interventionist and provides greater freedom of choice to those regulated. Findings also suggest that many New Zealand transport regulations have been introduced and not revisited. This calls for a more periodic and systematic approach to ex-post (after-the-event) analysis to ensure that land transport regulation is fit for purpose. A suggested approach to evaluation of existing regulations includes the following components: 1) definition of the problem justifying the regulation, based on the identification of market failures and the underlying causes; 2) review of the effectiveness of the regulation in achieving targeted outcomes; 3) identification of options including no regulation; 4) cost-benefit analysis of regulations and alternatives; 5) identification and analysis of opportunities for regulatory improvement.

Highlights:
- Regulatory analysis in the United States
- The U.S .Environmental Protection Agency (EPA) criteria and questions used for regulatory reviews

Applicability to Project:
From the report, the author introduces the regulatory analysis in the United States can be applicable to our project. The EPA suggests the criteria for regulatory review in the following table:

US EPA criteria for regulatory reviews
Benefits justify costs • Now that the regulation has been in effect for some time, do the benefits of the regulation still justify its costs? **Least burden** • Does the regulation impose requirements on entities that are also subject to requirements under another EPA regulation? If so, what is the cumulative burden and cost of the requirements imposed on the regulated entities? • Does the regulation impose paperwork activities (reporting, recordkeeping, or third party notifications) that could benefit from online reporting or electronic recordkeeping? • If this regulation has a large impact on small business, could it feasibly be changed to reduce the impact while maintaining environmental protection? • Do feasible alternatives to this regulation exist that could reduce this regulation's burden on state, local, and /or tribal governments without compromising environmental protection? **Net benefits** • Is it feasible to alter the regulation in such a way as to achieve greater cost effectiveness while still achieving the intended environmental results? **Performance objectives** • Does the regulation have complicated or time-consuming requirements, and are there feasible alternative compliance tools that could relieve burden while maintaining environmental protection?

- Could this regulation be feasibly modified to better partner with other federal agencies, state, local, and/or tribal governments?

Alternatives to direct regulation
- Could this regulation feasibly be modified so as to invite public/private partnerships while ensuring that environmental objectives are still met?
- Does a feasible non-regulatory alternative exist to replace some or all of this regulation’s requirements while ensuring that environmental objectives are still met?

Quantified benefits and costs/qualitative values
- Since being finalized, has this regulation lessened or exacerbated existing impacts or created new impacts on vulnerable populations such as low-income or minority populations, children, or the elderly?
- Are there feasible changes that could be made to this regulation to better protect vulnerable populations?

Open exchange of information
- Could this regulation feasibly be modified to make data that is collected more accessible?
- Did the regulatory review consider the perspectives of all stakeholders?

Coordination, simplification, and harmonization across agencies
- If this regulation requires coordination with other EPA regulations, could it be better harmonized than it is now?
- If this regulation requires coordination with the regulations of other federal or state agencies, could it be better harmonized with those regulations than it is now?

Innovation
- Are there feasible changes that could be made to the regulation to promote economic or job growth without compromising environmental protection?
- Could a feasible alteration be made to the regulation to spur new markets, technologies, or jobs?
- Have new or less costly methods, technologies, and/or innovative techniques emerged since this regulation was finalized that would allow regulated entities to achieve the intended environmental results more effectively and/or efficiently?

Flexibility
- Could this regulation include greater flexibilities for the regulated community to encourage innovative thinking and identify the least costly methods for compliance?
- Scientific and technological objectivity
- Has the science of risk assessment advanced such that updated assessments of the regulation’s impacts on affected populations such as environmental justice communities, children or the elderly could be improved?
- Has the underlying scientific data changed since this regulation was finalized such that the change supports revision to the regulation?
- Has the regulation or a portion(s) of the regulation achieved its original objective and become obsolete?
- Does the regulation require the use of or otherwise impose a scientific or technical standard? If so, is that standard obsolete or does it otherwise limit the use of updated or improved standards?

Regulatory Effectiveness: The impact of regulation and regulatory governance arrangements on electricity industry outcomes

Source: Stern, Jon, and John Cubbin. "Regulatory Effectiveness : The Impact of Regulation and Regulatory Governance Arrangements on Electricity Industry Outcomes." Policy Research Working Papers, 2005. doi:10.1596/1813-9450-3536.

Abstract:
The paper reviews a number of studies of the effectiveness of utility regulatory agency and governance arrangements for the electricity industry, particularly for developing countries. It discusses governance criteria and their measurement, both legal frameworks and surveys of regulatory practice. It also discusses the results from economic studies of effectiveness for regulatory agencies in the electricity and telecommunications industries and compares these with the results from econometric studies of independent central banks and their governance. The paper concludes with a discussion of policy implications and also of priorities for information collection to improve understanding of these issues.

Highlights:
Key points arising from the literature review

Applicability to Project:
This research paper conducted several literature reviews and the following key issues were found:

- A well-designed industry structure is crucial — good regulation cannot overcome bad design of industry and market structures.
- The industry and the regulatory arrangements must be based within an effective governance framework — effective regulation cannot take root in corrupt systems or ones where the law courts are unreliable.
- Commercialization has to be accepted as the basis of utility service provision, including pricing which avoids large-scale implicit subsidy of prices to final users — the political economy of pricing reform has destroyed many utility reforms and new regulatory systems and threatens many more. This has been and remains a serious problem in electricity but seems to be worse in water and perhaps (passenger) railways.

The research also provide some clear research priorities such as the following:

- The use of regulatory indices combining governance factors in future econometric and related statistical work.
- The need for better data, particularly on regulatory practice, showing the evolution of regulatory systems.
- Data on regulatory systems, their performance over time, and their impact can be collected by informed researchers carrying out systematic and well-coded case studies.

Building an institutional framework for regulatory impact analysis (RIA)

Source: "Building an Institutional Framework for Regulatory Impact Analysis (RIA)." 2008. doi:10.1787/9789264050013-en.

Abstract:
The text draws on the work of the OECD, which has published extensively on the RIA practices of OECD members. This includes the 24 country reviews published under the OECD Horizontal Programme of Regulatory Reform including reviews on Russia and Brazil, the first two non-member countries to undergo such a review process. In addition, the paper draws upon and references relevant literature covering different aspects of RIA design and implementation including case studies and research papers, as well as international technical analyses prepared by international organisations, government and academic institutions, and consulting firms working on regulatory reform (examples are the World Bank Group, the Centre on Regulation and Competition of the University of Manchester, the UK Department for International Development). Examples of how countries have succeeded in designing RIA are referenced through the guide.

Highlights:

- Regulatory Impact Analysis (RIA)
- Expected benefits from implementing RIA
- Important factors for ensuring the quality of RIA

Applicability to Project:
This research paper introduces Regulatory Impact Analysis (RIA), and it is based on the Organisation for Economic Co-operation and Development (OECD) principles for effective RIA implementation.
From this report, RIA is an institutional model for analysis that draws from the same analytical basis as the following checklist:

The OECD Reference Checklist for Regulatory Decision-making
1. Is the problem correctly defined? The problem to be solved should be precisely stated, giving evidence of its nature and magnitude, and explaining why it has arisen (identifying the incentives of affected entities). **2. Is government action justified?** Government intervention should be based on explicit evidence that government action is justified, given the nature of the problem, the likely benefits and costs of action (based on a realistic assessment of government effectiveness), and alternative mechanisms for addressing the problem. **3. Is regulation the best form of government action?** Regulators should carry out, early in the regulatory process, an informed comparison of a variety of regulatory and non-regulatory policy instruments, considering relevant issues such as costs, benefits, distributional effects and administrative requirements. **4. Is there a legal basis for regulation?** Regulatory processes should be structured so that all regulatory decisions rigorously respect the “rule of law”; that is, responsibility should be explicit for ensuring that all regulations are authorized by higher-level regulations and consistent with treaty obligations, and comply with relevant legal principles such as certainty, proportionality and applicable procedural requirements.

5. **What is the appropriate level (or levels) of government for this action?**
Regulators should estimate the total expected costs and benefits of each regulatory proposal and of feasible alternatives, and should make the estimates available in accessible format to decision-makers. The costs of government action should be justified by its benefits before action is taken.

6. **Do the benefits of regulation justify the costs?**
Regulators should estimate the total expected costs and benefits of each regulatory proposal and of feasible alternatives, and should make the estimates available in accessible format to decision-makers. The costs of government action should be justified by its benefits before action is taken.

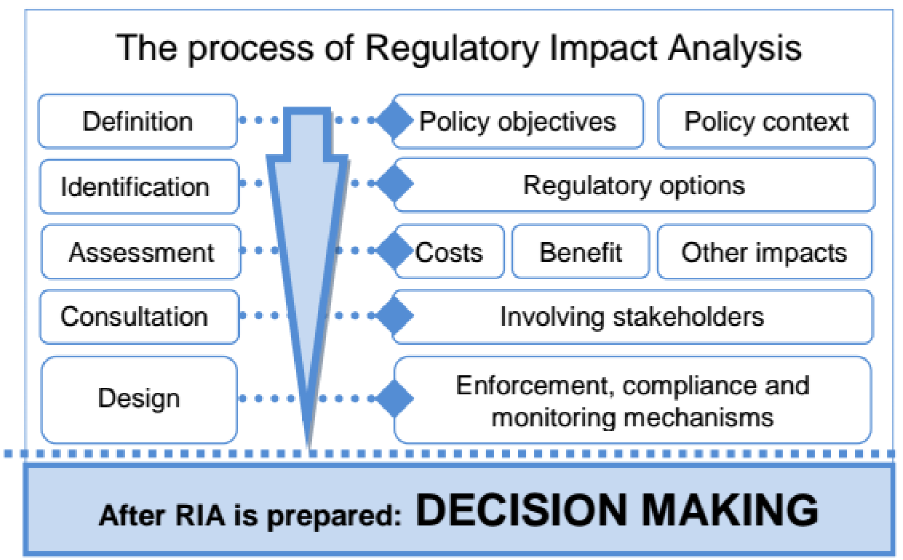
7. **Is the distribution of effects across society transparent?**
To the extent that distributive and equity values are affected by government intervention, regulators should make transparent the distribution of regulatory costs and benefits across social groups.

8. **Is the regulation clear, consistent, comprehensible and accessible to users?**
Regulators should assess whether rules will be understood by likely users, and to that end should take steps to ensure that the text and structure of rules are as clear as possible.

9. **Have all interested parties had the opportunity to present their views?**
Regulations should be developed in an open and transparent fashion, with appropriate procedures for effective and timely input from interested parties such as affected business and trade unions, other interest groups, or other levels of government.

10. **How will compliance be achieved?**
Regulators should assess the incentives and institutions through which the regulation will take effect, and should design responsive implementation strategies that make the best use of them.

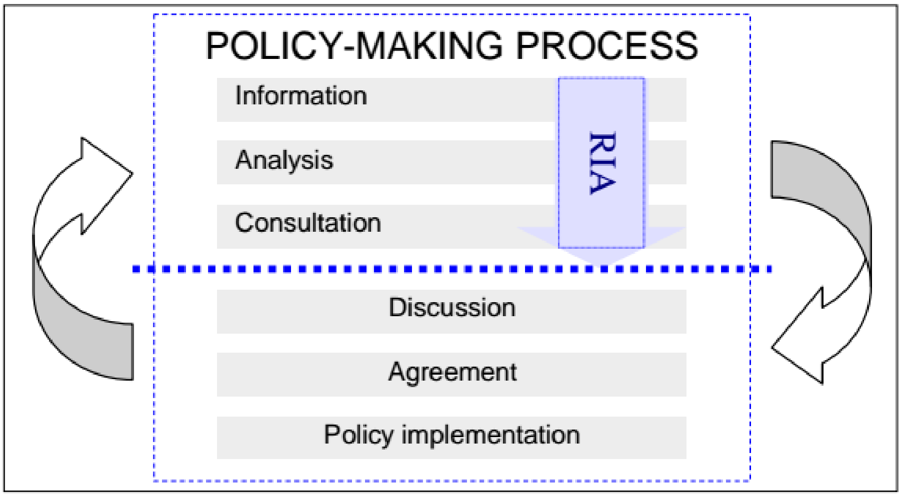
This paper defines RIA as a systematic policy tool used to examine and measure the likely benefits, costs, and effects of new or existing regulation. The process of RIA is illustrated in the following figure:



In OECD, the benefits of RIA are as follows:

1. RIA improves understanding of the real-world impacts of government action, including both the benefits and the costs of action.
2. RIA integrates multiple policy objectives.
3. RIA improves transparency and consultation.
4. RIA improves government accountability

RIA can also be defined as a policy tool that helps government officials make decisions. The RIA policy-making process is illustrated in the following figure:



Introductory handbook for undertaking regulatory impact analysis (RIA)

Source: “Introductory Handbook for Undertaking Regulatory Impact Analysis (RIA).” Version 1.0, October 2008, Organisation for Economic Co-operation and Development (OECD)

Abstract:
Governments need to work systematically to ensure that the regulation they develop and implement is of high quality, since the costs to society of poor quality regulation are substantial. Poor quality regulation increases compliance costs for business and other groups, leads to unnecessary complexity and associated uncertainty as to regulatory obligations and reduces the ability of government to achieve its objectives.
This handbook provides practical guidance on using Regulatory Impact Analysis (RIA) as a way of improving regulatory quality and, as a result, government effectiveness and efficiency. RIA systems are fundamental to initiatives pursuing a comprehensive improvement in regulatory practices and performance for both OECD countries and countries in transition.
RIA is a process of systematically identifying and assessing the expected effects of regulatory proposals, using a consistent analytical method, such as benefit/cost analysis. RIA is a comparative process: it is based on determining the underlying regulatory objectives sought and identifying all the policy interventions that are capable of achieving them. These “feasible alternatives” must all be assessed, using the same method, to inform decision-makers about the effectiveness and efficiency of different options and enable the most effective and efficient options to be systematically chosen. According to the OECD:
“…RIA’s most important contribution to the quality of decisions is not the precision of the calculations used, but the action of analyzing — questioning, understanding real-world impacts and exploring assumptions”. RIA should be integrated with a public consultation process, as this provides better information to underpin the analysis and gives affected parties the opportunity to identify and correct faulty assumptions and reasoning. RIA is now used in virtually all OECD countries and in many developing countries.

Highlights:
- Cost/benefit analysis (CBA)
- Best practice for RIA (BCA)
- Cost effectiveness analysis (CEA)

Applicability to Project:
As in the previous research paper, “Building an Institutional Framework for Regulatory Impact Analysis (RIA)" (2008), this report introduces cost/benefit analysis (CBA). CBA can be defined as an approach to guiding decision-making and as a specific methodology for conducting RIA. All RIA can be considered to be based on the use of benefit / cost analysis.

From the report, it is very common in RIA to find that important benefits and costs cannot be quantified. However, if the BCA approach is used in such cases, a “partial” BCA can be generated. This can still be very useful to decision-makers as it narrows the range of issues that must be dealt with through more subjective, qualitative analysis. Thus, developing even an incomplete BCA can greatly improve decision-making. The following table illustrates a method for ensuring that all relevant costs are considered.

Affected group	Examples of costs
Business	• Cost of familiarizing with the regulations and planning how to comply (may include purchase of external advice) • Higher input costs due to regulatory impacts on the costs of materials • Higher production costs due to changes to production, transport or marketing processes required by the regulations • Costs of lost sales due to restricted access to markets • License fees or other charges imposed by the regulations • Cost of internal inspections, audit fees etc. to ensure compliance is being achieved
Consumers	• Increased prices for products or services • Reduced range of products available • Delays in the introduction of new products (e.g., due to the need for producers to meet regulated product testing requirements)
Government	• Cost of administering the regulations: includes providing information to business, recruiting and training government staff, processing license or product approval applications • Cost of verifying compliance: includes conducting inspections and audits, monitoring outputs (e.g., air quality) • Cost of enforcement: includes investigating possible non-compliance, conducting prosecutions
Other	• Cost of reduced competition – e.g., by favoring existing producers and making entry to a market more difficult (leads to both efficiency losses and transfers from producers to consumers due to higher prices) • Distributional costs – e.g., if some of the above costs are disproportionately borne by the poor, or some vulnerable group • Restrictions on innovation & the ability to develop and market new products and services

The research paper also suggests using cost effectiveness analysis (CEA) when it is not feasible to use BCA. Since CEA is a more limited methodology than BCA, it is less demanding of resources and expertise to complete.

ANNEX C – STATISTICS

Source: James D. Shafer, Capt. David E. Rifkin, Quality Marine Services, LLC 2418 Fallen Tree Drive West, Jacksonville, FL 32246, 904-382-7868, qualitymarinesvcs@comcast.net

Retrieved from http://www.electricshockdrowning.org/esd-resources.html

Abstract:
Low level ground fault leakage in the marina AC shore power system can cause lethal potentials to appear on any underwater metal surface – either on a boat or on the dock. In fresh water the electric field surrounding this surface can paralyze a swimmer. There is no warning that this condition exists, and it has resulted in a number of drownings. Further, there is no post-mortem evidence that electric shock was the cause. Therefore, many of the fatalities listed below are only the known electric shock caused drownings, which were investigated because of circumstantial evidence, i.e., multiple deaths, eye witnesses, considerable distress, cries for help, shock sensation reported by rescuers, etc.

Our studies have shown that, in salt water, the high voltage gradients required for electric shock drowning could not be established with the available fault current levels. In no cases can we attribute cause of death to electric shock drowning in salt water. We do not know the exact wiring errors or ground faults that created some of the incidents listed below, but it can be assumed that an energized AC conductor (L1 or L2) came in contact with a bonded (grounded) metal object, and coincidently, this object was not connected to the shore bonding (grounding) system. This caused a voltage to appear on these under-water metal objects (both on boats and docks). This created a lethal electric field around the object (a person in this electric field can be paralyzed leading to drowning, or direct electrocution). This was true in every case that was investigated. No database has been found that catalogs "Electric Shock Drowning" – our term for this phenomenon. The incidents listed below came from various sources, i.e., investigation, press, third party, and eye witness reports. Dates and details are missing for some. There is no way to know what fraction of the total fatalities this listing represents, but it may be reasonable to assume that it could be small. We have no reports of fatalities in salt water due to electric shock drowning. Some of the fatalities listed here were actually caused by ventricular fibrillation (electrocution), because the victim's head was reported not to have been submerged. They are technically not drownings but are listed here since the causes are similar to drowning by electric shock.

Applicability to Project:
This resource provides records of electric shock drowning incidents. Although the resource includes incidents caused by ventricular fibrillation (electrocution), it is useful to see the trend of incidents because the incidents are similar to drowning by electric shock.

ELECTRIC SHOCK DROWNINGS

1.	Sep 10, 2016	South Bend, IA. A women was found dead in 6” of water in a flooded basement after heavy rains. A box fan was found submerged nearby. Authorities concluded she was electrocuted in the water. There was nothing mentioned about ground fault protection (GFCIs) being used.
2.	Sep 3, 2016	Raleigh, NC. A 17 year old girl was found unresponsive in a community swimming pool. She was the lifeguard on duty and was shocked when reaching into the water to check pool chemistry. Another pool worker received a shock trying to pull her from the water. A faulty pool pump and broken grounding wire are cause. The required GFCI was not installed. The pool was in correct configuration for the 1978 NEC. Some rewiring in 2011 should have required a permit which would have triggered an inspection requiring a GFCI. Community pools in some areas must be inspected annually.
3.	Jul 3, 2016	A Tennessee Lake, TN. A 13year old boy was swimming from a boat. He was noticeably in trouble when 2 adults jumped in to rescue. They were both overcome by electric shock. They were able to save the boy. Exact time and location are unknown. Story reported by WSOCTV.com in Charlotte, NC.
4.	May 29, 2016	Silver Spring Township, PA. An 8 year old girl was among 8 kids swimming in a backyard pool. When the pool light was turned on 7 other kids were able to get out of the water. The cause was a faulty pool light circuit. Last known in critical condition.
5.	Jun 27, 2016	Phoenix, AZ. 27 year old man in a private pool was trying to repair a broken light fixture. He was shocked and killed while working on the light. The exact cause of the accident is unknown.
6.	May 28, 2016	Wildwood Crest, NJ. 34 year man was found at the bottom of a motel pool unconscious. The exact cause of the accident is unknown but a pool drain is suspected. Owner said pool was recently inspected and bonded. Last known in critical condition.
7	Apr 16, 2016	Smith Lake, Princeville, AL. Two teenage girls entered the water from a private dock. Both girls were getting shocked in the water. One girl drowned, the other treated and released from hospital. The victim’s father and his son jumped into the water to assist. The father blacked out after both were feeling the shocks. The power was turned off at the house, after which the father came to and survived along with son. A missing ground and faulty lighting fixture are suspected to be the cause.
8.	Mar 27, 2016	Palm Springs, FL. Six people were shocked in a private swimming pool, one of them a man who jumped in to rescue his daughter. He was overcome by electric shock and pronounced dead at the hospital. The 5 others were treated, and one young girl remained hospitalized in critical condition. Faulty pool wiring is suspected as the cause. Homes were built in 1963, but not sure of the age of the swimming pool.

9. June 21, 2015 — Lake of the Ozarks, Woods Hollow Cove, 22.2 mile marker, MO. A 21 year old man and fellow swimmer felt electricity in the water near a dock. The 21 year old grabbed a dock ladder to get out when he was electrocuted and fell back into the water. Someone ran ashore and turned off the power likely saving the other man in the water. A faulty junction box between dock and residence is suspected. The occupants tried to reset the circuit breaker but it would trip after 10-15 seconds of being turned on. The last attempt to turn the breaker on coincided with the 2 swimmers being near the dock as it got dark (breaker controlled dock lights).

10. Aug 24, 2014 — Lake Bruin, Tensas Parish, LA. Two teenage girls were shocked when trying to exit the water using a ladder on a pontoon boat. The 13yo died, the 17yo was hospitalized. A faulty boat lift is blamed for energizing the ladder of the boat.

11. June 10, 2014 — Lake Powell, UT. A 22 year old man jumped off the stern of a boat docked at the Bullfrog Lake Marina. He surfaced briefly then went back under. His death was caused by electric current leaking into the water from a boat docked at the next slip over. The cause of the leakage is being investigated.

12. Apr 23, 2014 — North Miami Beach, FL. A 7 year old boy was electrocuted at his home in the family swimming pool. An older brother felt a shock and urged the victim and a younger brother to get out. The victim did not hear his brother, and immediately thereafter was killed. A rescuer performing CPR put his hand in the water and felt a shock. A faulty swimming pool light is the likely cause of the accident. The presence of a GFCI was not mentioned in the newspaper reports.

13. Sep, 2013 — Houston, TX. An older man was killed in a swimming pool attempting to rescue a child. Faulty pool lights were suspected as the cause. Date approximate (Labor Day weekend, 2013).

14. July 25, 2013 — Ellijay, GA. A 19 year old girl was electrocuted after a power outage at a home where she was watching a 5 year old girl. A power line came down about 25 ft from the house. She went outside to investigate the power outage and either stepped in puddle of water or soggy ground. The voltage gradient from the downed power line was enough to electrocute her.

15. July 19, 2013 — Syracuse, NY. A 12 year old girl was electrocuted while filling an inflatable pool in her backyard. Witness say she picked up an extension cord or electric pump plugged into a receptacle, and began shaking. She then fell into the pool. Rescuers received shocks trying to get her out of the pool. Although not mentioned, it was likely that the receptacle was not protected by an operable GFCI as required by the National Electric Code for all outdoor receptacles.

16. July 17, 2013 — Davidson County, NC. An 11-year-old girl was electrocuted in a swimming pool. It was reported that a power line wire came down in the parking lot near the pool. The girl touched the ladder of the pool and was shocked. Rescuers trying to help the girl were also shocked. Electricity was likely flowing from the downed wire into the earth, and passed through the pool enroute to its source.

17. July 4, 2013 — Eagle Lake in Orrick Township, Sherburne County, MN. A man was holding a plugged-in battery charger while standing in 20" of water. He was preparing to connect the charger to his houseboat. He slipped and immersed the charger which resulted in a severe electrical shock. He died on 7 July. A woman who went to his aid was also shocked and unconscious but was revived at the scene. It is unknown whether the charger was properly grounded.

18. June 30, 2013 — Pulaski County, KY, near South Fork of Lake Cumberland near Garland Bend. A man swimming at a private dock reaches up to pull a ladder down to exit the lake. The ladder contacted a frayed electrical wire energizing the ladder. The man was electrocuted, but was able to move his 2-year-old son out of danger. Others felt shocks trying to help the man.

19. May 20, 2013 — Grayson County, KY, Rough River Lake. A 36 year old man and one of his dogs were lost near a marina boat slip. He jumped into the water when the dog was having problems. Witnesses report the man's eyes rolled back and he went under the water suddenly. Inspectors found a shore cord (with a submerged coupling between two cords) was energized and reported this was the cause of the electrocution. The man was reportedly 10-15 feet from the houseboat. They found multiple NEC violations at the marina.

20. Sep, 2012 — Americus, GA, South Georgia Technical College. A 19 year old woman was electrocuted in a fountain pond while retrieving her young son's ball. Efforts to assist her were thwarted by others receiving electrical shocks. Investigators found 17 violations in the electrical supply to the pond. One month earlier another student reported shocks (the pond was only drained and cleaned as a result).

21. Aug 30, 2012 — Bingham County, Idaho. Two men and a woman were electrocuted in an irrigation ditch. The woman went in to rescue a dog, and the 2 men tried to rescue the woman. A faulty irrigation pump was responsible for this tragedy.

22. Aug 22, 2012 — Los Angeles, CA. A man speeding in a car hit a fire hydrant and electrical pole. The energized from the pole ended up in the large puddle created by the broken fire hydrant. 2 women were electrocuted when they entered the puddle to try and assist the driver.

23. July 25, 2012 — Tampico, IL. A 14 year old boy and girl were electrocuted while detasseling corn in an IL cornfield. A lightning strike is suggested to have destroyed the grounding system for an irrigation pump. A fault in the pump then leaked electricity into the ground creating electrical gradients across puddles and other wet areas.

24. July 25, 2012 — Cohasset, MN, Pokegama Lake. Two men and a woman were shocked by an extension cord in the water, presumably from a boat lift. One of the men could not be revived and died. The other two were hospitalized in serious condition.

25. July 7, 2012 — Lake of the Ozarks, MO. A 26 year old woman was swimming with her 2 stepbrothers when the brothers felt a tingling. The boys swam to one dock and were unharmed. The woman swam to a different dock, apparently where there was faulty wiring. She may have been electrocuted when she touched something metallic on this dock. She could not be revived at the scene.

26.	July 4, 2012	Lake of the Ozarks, MO. A 13 year old girl and her 8 year old brother were killed by electricity while swimming near a private dock. The hot wire to an electrical outlet had chafed and shorted to the dock framing steel. This steel structure was not bonded, nor was there GFCI protection as required by the National Electric Code.
27.	July 4, 2012	German Creek Marina on Cherokee Lake, Bean Station, TN. A 10 year old boy and an 11 year old boy were killed by electricity in the water at a TN marina while swimming between 2 docked houseboats. An 8 year old girl also swimming with the boys was shocked but pulled to safety. Several adults and another 12 year old boy were shocked trying to rescue the 2 boys. Faulty houseboat wiring on one of the boats is believed to be one of the causes.
28.	June 27, 2012	Celebration, FL. An 11 year old girl was electrocuted when she reached into a mini golf pond at an Orlando, FL resort to retrieve a golf ball. A man trying to help her was also shocked. The cause was faulty pond pump that was not protected by the required GFCI. Water came in contact with the pumps windings and electrified the small cement pond on the mini golf course.
29.	May 5, 2012	Lake Sinclair, Putnam County, GA. A 25-year-old woman was apparently electrocuted when she reached from the water and touched either a box or bare wire on the dock (it was being worked on at the time). Another woman in the water was shocked when she pulled the 25 year old away from the dock and held her head above water. She could not be revived at the scene.
30.	Aug 15, 2011	Traverse City, MI, Clinch Marina. An 18 year old boy died in West Arm Great Traverse Bay when an electrical fault (reportedly from dock wiring) caused current to enter the water where the boy and a friend were swimming. The friend reported feeling electricity in the water. “No Swimming” signs were posted in some locations in the marina.
31.	May 28, 2011	Lake City, MN. A 50 year old man was electrocuted in Lake Pepin near a boat lift which had exposed wiring. His dog was in the water and was shocked and began to sink. Another man jumped in to rescue the dog but was shocked (he escaped the water). The 50 year old man then jumped in for his dog and appeared to have been electrocuted.
32.	July 26, 2010	Lake Freeman, Carroll County, IN. A 13 year old boy was swimming with 3 other children when they started to feel a tingle. The 13 year old attempted to exit the water at the dock but fell back into the water. The other children managed to exit the water. A water-soaked electrical junction box was located on the dock nearby and is the likely source for the electrical current in the water.
33.		Removed.
34.	July 10, 2010	York, SC. A 54 year old man died after jumping into a swimming pool to help his granddaughter. The granddaughter was receiving a shock from the pool’s railing when the man jumped in to help her. He grabbed the pool’s railing and reportedly “stuck” to it. His grandson reported that he had felt electricity in his chest when near the edge of the pool (until a light was turned off). Electric shock is the probable cause of death.

35.	June 21, 2010	Smith Lake, Birmingham, AL. A 16 year old boy was climbing a dock ladder when he suddenly fell back into the water. He was immediately unresponsive when recovered by friends. Electrocution (from an energized dock ladder) is suspected as a possible cause of death.
36.	June 2010	Lake Waccamaw, NC. A boy was killed swimming near a boat lift. The owner was told by another child that he was feeling tingles in the water. The owner reached up, touched the boat lift and was shocked. He told the other kids to get out of the water. After exiting he noticed one boy face down in the water. He could not be revived at the scene. There was an open ground in the lines from the house to the dock, and one of the small junction boxes under the dock was filled with water. The cause may have also been a fault to the lift motor.
37.	May 29, 2010	Stonewall Jackson Lake, WV. A 15 year old boy was climbing onto the swim platform of a boat. When he touched the ladder he received an electrical shock and he fell back into the water and reportedly drowned. A girl still in the water felt the shock and was treated and released from a local hospital. Cause was improper repair of the pedestal end of shore cord (hot and ground were reversed). It is likely this was an electrocution rather than a drowning.
38.	Aug 23, 2008	Lake Hamilton, Hot Springs, AR. 14 year old girl swimming near a metal swim ladder with a 7 year old boy and his mother nearby. Without warning the boy began to scream and his mother became incapacitated on the swim ladder. As the girl attempted to help the boy she sank out of sight. The boy's father pulled him to safety and helped his wife onto the dock. Preliminary investigation revealed an unbonded metal pole, welded to the dock, on which was mounted a halogen light, which had just been turned on by its photo cell, and had an AC fault due to chafed wires which energized the dock frame and ladder. Boy and mother required hospitalization. Voltage to ground on the ladder measured at 103 VAC. The girl was recovered later that night.
39.	July 28,2007	Lake of The Ozarks, MO Twenty four year old female attempted to exit the water using a metal ladder at the end of a private dock. She apparently experienced a paralyzing electric shock which caused her to fall back into the water and drown. Several people had reported being shocked by the ladder and the dock owner had gone to shut the power off. The dock power wiring termination was found submerged under the dock near the exit point.
40.	July 24, 2006	Lake Lanier, Cumming, GA. Seventeen year old boy in water near a private dock, working on a jet ski with two friends, was overcome by electric shock. Extension cord with damaged insulation caused the metal dock to become energized. Friends also shocked, and partially disabled, could not help their friend. Father of victim fought paralyzing shock and pulled unconscious son away from dock – he could not be resuscitated. Investigation planned.

41. July 14, 2006 River Street Marina, Port Huron, MI. A 20 year old man jumped, or fell, into the water from the pier behind a 29' boat, moored stern too. He became disabled as he attempted to climb onto the swim platform. Two friends attempting to pull him onboard reported being shocked. He could not be resuscitated. Shock induced ventricular fibrillation likely cause of death. The next day an inspector reported 107vac in the water behind the boat. Subsequent investigation confirmed the voltage behind the boat. The cause was an AC to DC fault in the battery charger energizing the underwater gear and no AC to DC bonding connection.

42. June 24, 2006 Brady Mountain Resort, Lake Quachita, Hot Springs, AR. A 14 year old boy died from electric shock while swimming near a houseboat. A friend was also shocked and taken to a hospital and released. A man jumped in to help and was rendered unconscious but was unharmed after regaining consciousness. The cause appeared to be inserting a shore cord with a 30A/125V (L5-30) plug (with the grounding pin bent back) into a 50A-125/250V receptacle in such a way so as to energize the neutral, which was connected to the bonding system, thereby energizing the hull.

43. June 10, 2006 Lake Michigan, Racine Harbor, WI. A 56 year old man was killed when he went swimming from the stern platform of a boat. Inquest listed death as "Accidental Electrocution" and did not establish a root cause. Victim's wife stated that the Reverse Polarity light flickered on and went out when power applied to vessel. Comment: A reverse polarity situation along with a grounded neutral can energize underwater metals on a boat.

44. May 22, 2006 Weiss Lake, Cherokee County, AL. A 24 year old young man was killed while in the water near a pier. He was attempting to rescue his friend who had become paralyzed by an electric shock while trying to exit the water via a metal ladder. Another friend was also disabled by shock as he entered the water to assist. The two young men, who were shocked, were not seriously injured. There was an electric windmill on a metal tower attached to the ladder, and was apparently powered by an incorrectly modified extension cord, and which may have been connected to a non-functioning GFCI outlet. A bystander on the dock pulled the power cord just in time, or there may have been two more victims. Investigation underway.

45.	Mar 18, 2006	Summerset Lake near Desoto, St. Louis, MO. In the early evening a teenage boy became paralyzed by electric shock, and drowned, while attempting to swim toward a metal ladder attached to a private dock. Two friends were rendered unconscious but were resuscitated and required hospitalization. During several investigations, initially and over the next months, it was determined that the dock wiring was properly installed, the metal dock frame and ladder were bonded, and no loads were operating at the time of the accident. However, clamping the dock supply cable with an AC ammeter disclosed 10 amps flowing (likely in the ground wire) and 4-6 VAC was measured approximately 2 ft. away from the ladder on several separate occasions. The subsequent legal action resulted in a jury finding the local utility at fault. It seems that a near-by underground power distribution cable had a defective (or missing) neutral which caused the neutral current to seek a path back to the substation through the earth and into the lake. This earth leakage current concentrated at the bonded swim ladder resulting in a lethal gradient of more than 2 V/Ft near the ladder. These earth leakage currents are fairly common but this is the first serious incident we have recorded due to this phenomenon.
46.	June 27, 2005	Scott's Creek Marina at Cave Run Lake, Moorhead, KY. A 19 year old girl drowned, while in the water near a houseboat, due to electric shock caused by a battery charger in the engine compartment which had become partially submerged and energized the hull. Owner had rewired the boat with no bonding system. Another girl sustained burns on her legs while reaching into the water to help the victim. A nearby rescuer swam toward the scene and was shocked and paralyzed by the electrical field. Only two feet from the victim he had to turn around and swim out of the field to survive.
47.	Sept 2004	Lake Of The Ozarks, MO 22 year old male stepped on an electrical cable upon exiting the water after swimming behind a private residence – fell face down into water unconscious – could not be revived. No information on cable.
48.	Sept 13, 2004	Ross Barnett Reservoir, Ridgeland, MS. A 16 yr old boy was swimming in the marina when he approached a houseboat. He screamed as if in pain and disappeared under the water. He could not be revived after divers recovered his body. A friend in the water also felt a shocking sensation. The cause was a homemade shore cord, hard wired to the panel which was passed through a hole in sheet metal siding with no chafe protection. The insulation was cut by boat motion and shorted the hot conductor to the siding. The siding was not adequately grounded to the shore grounding system but was connected to the boat's bonding system, which caused the hull to go up in potential killing the boy.
49.	Aug 8, 2004	Lake Travis, Austin, TX. Young man, in good health, swimming, in evening, unobserved, between two sections of marina dock – disappeared. Came to surface two days later. No toxic substance found on post mortem, but Joule marks (electrical contact points) found on right wrist and left leg and shin. Suspected electric shock drowning. Accident under investigation. (See follow-up, last page)

50.	June 19, 2004	Lake Waccamaw, NC Ten year old boy drowned while swimming with friends near a private dock boat lift that had just been raised from the water. An adult reported a heavy shock when touching the lift and several children in the water reported being shocked. Victim was noticed motionless face down nearby – could not be revived. Lift frame had become energized and the bonding conductor from the supply panel was not connected.
51.	June 5, 2004	Lake Wylie, Charlotte, NC. Two young boys swimming at bow of houseboat called for help. Father of victim and friend rushed forward – boy on ladder said he was being shocked, other boy in water not moving. Friend rushed aft to pull shore cord as father went onto water – his son could not be resuscitated. May not be exact sequence. Causes of energized hull were substantial errors in wiring on the dock as well as on the boat, apparently done by nonqualified individuals.
52.	Aug 3, 2003	Bull Shoals Lake, Bull Shoals, AR. Diver found Aug. 5 in shallow water 8 ft. from his dock, drowned. Incorrectly wired dock junction box caused 117 VAC to appear on metal dock components. Rescue diver reported feeling shock sensation 20 ft. from dock!
53.	June, 2003	Allatoona Lake, GA. Six wildlife fatalities (ducks!!) Houseboat pulled away from the dock and still connected shore power cord separated in middle and fell into water. Six dead ducks found floating nearby.
54.	May, 2003	Cape Coral, Florida. Double drowning, section of re-bar driven through power cable to back yard boat lift caused line potential to appear on lift frame, salt water. Ventricular fibrillation likely cause of death – not confirmed.
55.	May 31, 2002	Lake Cumberland, Monticello, KY. Double drowning (mother and daughter), fault on houseboat, fresh water. 125V plug at boat end of shore cord rewired by owner for 220V – L2 connected to "GR" pin - ground lead in 4 wire cord cut and taped off! Hull rose to line potential.
56.	March, 2002	Bay Marina Boat Works, Biloxi, MS. Some electrical work had recently been done at this yard, which resulted in reverse polarity connections at the shore cord receptacles for the stored boats. Over a short time period several boat owners reported being shocked as they worked on their boats, and one owner was electrocuted. The possibly of a missing ground combined with a ground-neutral connection on the lethal boat was not investigated.
57.	Sept 15, 2001	Farr Shores, Lake Hamilton, Hot Springs, AR. Girl receiving electric shock after water-sliding into water at stern. Man attempting rescue drowns. Reverse polarity, neutral to ground fault in a light fixture on the boat, and poor bonding to the service caused the accident, fresh water. Boat unplugged in time to save girl.
58.	June 6, 2001	Residence, Timber Ridge Dr., Dumfries, VA, Lake Montclair. Two young boys entered water near pontoon boat. Battery chargers (2) connected to modified extension cord from house. Electric shock drowning – cause of energized hull not reported.
59.	May, 2001	New Orleans, Electrocution – Boy using conveyor to transfer shrimp – no ground, salt water.

60.	Apr 10, 2001	Norris Lake, Lafollette, TN. Two teenage boys swimming behind house boat. One boy climbed onto swim platform complaining of feeling severe shock – other boy fell back from ladder– his head *not* below water (ventricular fibrillation?). Could not be resuscitated. Damaged power cable to boat, black lead energized hull, ground wire burned in two – breaker did not trip due to incorrect connection (may not be exact sequence).
61.	2000 or 2001	Put-in-Bay, Ohio, Grand Banks 42. Owner's prescription sunglasses went overboard. Young bystander disappeared while trying to retrieve glasses, electric shock drowning.
62.	Sept 30, 2000	Tims Ford Lake, Winchester, TN. Two boys (21&22). Electric shock drowning. Rescue diver felt electric shock. Live wire in water near dock.
63.	Aug 1, 1999	Multnomah Channel, Portland, OR. 8yr old boy tubing with friends in freshwater marina along slow moving river. Boy decides to swim to dock (was wearing type 3 life vest). Suddenly he rolled over on back near the stern of a boat. Mother enters water and helps get boy on dock (she felt tingle in water). Diagnosed as electrocution (head was above water almost all the time). Cause was AC to DC short on boat and no connection between AC ground and DC ground. 84vac measured behind stern upon subsequent investigation.
64.	July, 1999	Lake Mohave, AZ. Young man swimming toward stern of a house boat became disabled and drowned, fresh water. Boat had a neutral-ground bond. Homemade shore cord "Y" became partly disconnected causing hull to become energized. 17vac measured behind stern-drive.
65.	July18, 1999	Cedar hill Lake, Smithville, TN. Two young boys, with flotation devices, were discovered in water, face down, a few feet behind a houseboat. 7 year old could not be revived. 8 year old recovered. Electric shock drowning suspected.
66.	July, 1999	S. Carolina, single drowning – 3 feet of water, woman in great distress, husband attempts rescue and drowns, fresh water.
67.	Approx. 1999	Rio Vista, CA. Several boys reported a tingle while swimming in this fresh water marina and got out of the water. A short time later two other boys, 8 – 10 years old, drowned at the same spot. Forty-year-old power wiring running under moored boats found to have substantial fault to ground because of insulation failure.
68.	Sept 1998	Lake Sonoma, CA. Single drowning, young girl in great distress, fault on dock, fresh water.
69.	Approx. 1998	AF Base, Washington, DC, boy walking on ice slipped and grabbed exposed wires on dock that were supposed to have been de-energized, electrocuted.
70.	July 1997	Lake Mead, NV. Single drowning, fault on houseboat, freshwater.
71.	Feb 1995	Bolling AFB, Washington, DC. Young boy reaches from water and grabs support structure for electrical junction boxes receiving lethal shock. Bare energized wires found touching metal case inside junction box. Grounding wire had been cut and never reattached to the junction boxes.
72.	Approx. 1994	Texas, single drowning, fault on boatlift, salt water. Cause of death not available.
73.	Sept 1993	Oklahoma, single drowning, fault in submersible pump, fresh water.

74.	August 1993	Alexandria Bay, NY. Double drowning. Two teenage girls snorkeling near dock were paralyzed by electric shock and drowned. Fault was in dock wiring gnawed by rodents. Two bystanders entered the water to lend assistance, but were shocked by the voltage in the water (they were treated at hospital and released).
75.	July 1993	Oklahoma, single drowning, fault in dock lights – energized dock frame, fresh water.
76.	May 11,1991	Lake Hamilton, Hot Springs, AR. A canoe carrying four young boys tipped over a few dozen yards from a dock. As they swam toward the dock they felt a light tingle. Three of the boys diverted away from the dock while the fourth boy continued into the electric field and drowned. Cause was broken insulation on a dock wire hanging in the water.
77.	July 1991	Oklahoma, single drowning, fault in dock wiring, fresh water.
78.	Dec 1989	Oklahoma, single drowning, fault in submersible pump, fresh water.
79.	Apr 23, 1988	New York State University at Albany. Sophomore waded into a pond on campus and was electrocuted. Several others injured in rescue attempt. Cause was broken electrical cable under the ground.
80.	July 1988	Park Township, MI, Lake Macatawa, Bay Haven Marina. 18-year-old boy falls off dock, in great distress, two attempts to assist thwarted because of severe electric shock as rescuers entered water.
81.	1987 or 1988	(A) Gross Pointe Yacht Club, single drowning, diver, freshwater (B) Petosky, MI, single drowning, diver, fresh water. NOTE: Both incidents relayed 3rd hand.
82.	July 29, 1986	Harrods Creek, Lexington, KY – Ohio River. About 2030 two dogs jump into water from owners 20 ft. runabout, and were observed to be in great distress. Owner's wife jumps in to help and was immediately in trouble. Husband goes in to save his wife – both drown. Rescuers felt strong electric shock and could not approach victims, but were able to rescue dogs later. Faulty light switch and missing ground on nearby houseboat determined to be the cause.
83.	June 8, 1986	St Croix River, Prescott, Wisconsin. 44 year old swimmer dove off of the dock near his 28' power boat. As he approached the swim platform he said he felt like he was being shocked, and was becoming numb, and then disappeared below the surface. Recovery and attempted resuscitation in a matter of minutes were unsuccessful. Battery charger had faulted to its metal chassis, and the boat's mfgr. had deliberately not installed the AC grounding wire to the boats bonding system – as required – causing AC potential to appear on the underwater metal gear.

84.	Date Unknown	Community swimming pool in Oklahoma, 10 year old electrocuted while inserting coins in a soda vending machine. Power cord damaged by one of the 4 legs, grounding pin on plug missing, machine chassis later measured at nearly line voltage, NO GFCI.
85.	June, 2017	PUT-IN-BAY, Ohio. 19 year old boy from suburban Columbus died Friday evening after he was shocked by an electrical current in the water around his family's boat as it was moored at a local marina. The ODNR spokesman said, he is believed to have died from a combination of the electrical shock and drowning. The boy's family had docked its boat at Miller Marina about 6:30 p.m. and plugged shore power into the boat, according to the report. When the family dog fell into the water, it began to struggle for an unknown reason, and when family patriarch jumped in to assist the dog, he too began to struggle. The family's two sons then jumped in and began to struggle as well, at which point bystanders told their mother, in the report, to unplug the shore power to the boat, ODNR said. When she did so, the electric current stopped. Electrician summoned by ODNR checked the shore-power wiring on the dock and found everything to be in proper working order. Investigators were checking the boat to determine if it was the problem's source.
86.	June. 2017	45 Tobago Ave. Toms River, NJ. An 11 year old girl was electrocuted in a lagoon behind a home in New Jersey. The incident happened Saturday night at a home on Tobago Avenue in waterfront section of Toms River known as Shelter Cove. According to Toms River police, initial reports indicate that the girl and her two friends were using an inflatable raft and swimming in the lagoon behind the home. Two of the girls touched the rail to a metal boat lift and an electric current appears to have energized the equipment, causing the injury. Within minutes police and Tom River EMS units arrived and took over CPR that was begun by adults who were at the home. The first responders utilized an Automated External Defibrillator and transported the girl to Community Medical Center, where she died later in the evening. The girl were wearing life jackets and in the presence of adults police said. The two other girls that accompanied her were evaluated at the scene and were not hurt.

ELECTRIC SHOCK – NEAR MISSES

1.	Oct 7, 2016	Shiloh, MO. A worker was pulled from an electrified puddle of water at a business. He was using saw to cut concrete. A second worker tried to pull him out of the water but was shocked. Rescuers were able to get the man out, perform CPR, and revive him. The electrical source for the tool was likely not protected with a GFCI (as would have been required at the construction site.
2.	Jul 3, 2016	A Tennessee Lake, TN. A 13year old boy was swimming from a boat. He was noticeably in trouble when 2 adults jumped in to rescue. They were both overcome by electric shock. They were able to save the boy. Exact time and location are unknown. Story reported by WSOCTV.com in Charlotte, NC.
3.	May 29, 2016	Silver Spring Township, PA. An 8 year old girl was among 8 kids swimming in a backyard pool. When the pool light was turned on 7 other kids were able to get out of the water. The cause was a faulty pool light circuit.
4.	Apr. 16, 2016	Smith Lake, Priceville, AL. Two teenage girls entered the water from a private dock. Both girls were getting shocked in the water. One girl drowned, the other treated and released from hospital. The victim’s father and son jumped into the water to assist. The father blacked out after both were feeling the shocks. The power was turned off at the house, after which the father came to and survived along with son. A missing ground and faulty lighting fixture are suspected to be the cause.
5.	Mar 27, 2016	Palm Springs, FL. Six people were shocked in a private swimming pool, one of them a man who jumped in to rescue his daughter. He was overcome by electric shock and pronounced dead at the hospital. The 5 others were treated, and one young girl remained hospitalized in critical condition. Faulty pool wiring is suspected as the cause. Homes were built in 1963, but not sure of the age of the swimming pool.
6.	Aug 25, 2015	Portsmouth, NH. A diver in mid 20s was shocked while cleaning a boat at Portsmouth Naval Shipyard in NH. Faulty wiring is suspected as cause.
7.	June 21, 2015	Lake of the Ozarks, Woods Hollow Cove, 22.2 mile marker, MO. A 21 year old man and fellow swimmer felt electricity in the water near a dock. The 21 year old grabbed a dock ladder to get out when he was electrocuted and fell back into the water. Someone ran ashore and turned off the power likely saving the other man in the water. A faulty junction box between dock and residence is suspected. The occupants tried to reset the circuit breaker but it would trip after 10-15 seconds of being turned on. The last attempt to turn the breaker on coincided with the 2 swimmers being near the dock as it got dark (breaker controlled dock lights).
8.	Apr 27, 2014	Hialeah, FL, condominium community pool. At least 3 children and 2 adults were shocked from an electrical fault in an improperly grounded pool pump. The children recovered after 4 days in a hospital.

9.	July 4, 2014	Lake of the Ozarks, MO, 7 mile marker. Several people were swimming at a private dock when they started feeling tingles. Turning off power at the dock did not solve problem. Contractor found an electrical short to an abandoned boat ramp about 100yds away. Power was disconnected and the electricity in the water ceased.
10.	July 2013	Lake Norman, NC. Time frame approximate. Man swimming off docked boat feels shock and paralysis from electric current. He is able to move far enough away to regain control. Cause unknown.
11.	July 11, 2013	Lake of the Ozarks, MO, 35 mile marker. 8 college age girls were swimming around some docks with electrical service. One of the girls felt her arm go numb. She swam the other direction and the numbness went away. Several other girls felt tingling and were shocked trying to exit at a nearby dock.
12.	June 18, 2013	Scott City, MO. After the neighborhood became flooded, a woman went down her flooded basement attempted to rescue a cat. She began unplugging electrical cords when she began getting shocked. She rescued the cat and got on top of some floating furniture until rescued. Likely the circuits involved were not protected with GFCIs.
13.	May 27, 2013	Lake Lanier, Gainesville, GA. A man and his 6yo daughter were swimming 10ft from a dock when the man received an electric shock in the arm. He grabbed his daughter, swam to the dock and lifted her to safety. Then he was shocked at least 2 more times, but survived. Appears to have been an intermittent problem possibly correlated to a power outage in the vicinity. Cause is unknown.
14.	Aug 14, 2012	Garden Grove, CA. Two girls (15yo and 23yo sister) were swimming in a swimming pool when the teenager called out and went face down in the pool. The older sister's legs and arms went numb. The father was able to get the girls out of the pool (and was also shocked when pulling the girl out). Paramedics were able to restore the teenager's breathing and pulse. She is expected to make full recovery. Cause unknown but work had just been done on the pool which had underwater lights.
15.	Aug 4, 2012	Gravois Arm of Lake of the Ozarks, MO. A woman received a shock as she reached for a dock ladder while swimming. She swam away from the dock. Her husband did the same and confirmed the shock. They both swam away and exited the water at a neighbor's dock because of awareness following 3 deaths from electric shock a month earlier.
16.	July 23, 2012	Lake of the Ozarks, MO. Two children and one adult were swimming near a dock undergoing electrical repairs. They all felt an electrical shock in the water. Power to the dock was turned off. The swimmers exited the water without serious injury. Exact cause is under investigation.
17.	July 4, 2012	German Creek Marina on Cherokee Lake, Bean Station, TN. A 10 year old and 11 year old boys were killed by electricity in the water at a TN marina while swimming between 2 docked houseboats. An 8 year old girl also swimming with the boys was shocked but pulled to safety. Several adults and another 12 year old boy were shocked trying to rescue the 2 boys. Faulty houseboat wiring on one of the boats is believed to be one of the causes.

18.	June 27, 2012	Celebration, FL. An 11 year old girl was electrocuted when she reached into a mini golf pond at an Orlando, FL resort to retrieve a golf ball. A man trying to help her was also shocked. The cause was faulty pond pump that was not protected by the required GFCI. Water came in contact with the pumps windings and electrified the small cement pond on the mini golf course.
19.	May 28, 2012	Lake of the Ozarks, MO. 3 women were shocked while swimming near a dock. Someone turned off the power fast enough to save them. One needed CPR at scene. All survived. The older dock had no GFCI protection and an "inadequate ground wire from dock to shore".
20.	Aug 28, 2011	Near Shady Beach, Norwalk, CT. A dog was electrocuted in floodwater from recent storm (Hurricane Irene). The two women walking their dogs felt electrical shocks (other dog, leashed, survived). Witnesses report "water boiling" where a grounding cable was entering standing water. This is indicative of electrical current in the water.
21.	June 21, 2011	Charleston, Kanawha River, Lou Wendell Marine, WV. A woman entered the water via a boat ladder for a swim. She was overcome by electrical current and reportedly could not escape, then sunk below the water for approx 90 seconds before being rescued. An electrician reportedly found a grounded neutral in the pedestal, but the exact fault is unknown.
22.	March 18, 2011	Houston, TX. A dog jumped into a neighborhood retention pond with fountain and was killed by an electric current in the pond. A man went in after the dog but when he was ankle deep he could feel the strong electric current in his feet so he retreated. Power was secured to the fountain. Comment: Had the man dove into the pond, he could have become a casualty as well.
23.	Sept 5, 2010	Lake at Perrine Wayside Dog Park, Miami, FL. Man playing fetch with dog threw object into a lake. The dog jumped in and swam toward a fountain in the center of the lake. The dog began yelping and struggling. The man went in the water to help his dog, but was stopped by electric shocks and could not reach the dog. The dog died, the man survived. The fountain was turned off but it was still putting electrical current into the water. It was removed for inspection.
24.	Sept 5, 2010	Hartwell Lake, Anderson, SC. A 12 year old girl was playing in the water near a dock with a friend. She grabbed an electrical wire and went into cardiac arrest. She was resuscitated by her father and airlifted to a hospital. The police report stated that there was a grounding problem on the dock.
25.	Aug 8, 2010	Green River Lake, Campbellsville, KY. A woman swimming behind a houseboat was seen arching back and sinking in the water. She surfaced long enough to scream for help. A man on the boat attempted to pull her out but was badly shocked as he was trying to help. Another man on the boat was able to pull both of them out of the water using a rope after turning off the boat's power. Another houseboat owner attempted to swim to them but was turned back due to the electrical current in the water. The woman and man pulled from the water were treated and released from the hospital.
26.	July 31, 2010	Lake Champlain, VT. A father and his two 13-year-old sons were shocked, but survived. No further information.

27. July 3, 2010 International Harbor, Friendsville, TN. Three females, 12, 20, and 30 years old were shocked while swimming near a docked boat. When the boat's power was turned off, the electrical current went away. Two of the three swimmers were injured and required hospitalization. One was not breathing when EMS arrived. They were able to revive her. A 63 year old woman was shocked trying to assist the other three in the water. She also required hospitalization. The cause was never determined.

28. June 24, 2010 Lake Travis, TX. A 15 year old girl and her 8 year old sister were swimming by a private boat dock when they were shocked in the water. The older sister was unresponsive at the scene and was in critical condition in the hospital. Shoddy wiring of boat lift resulted in direct hot to frame short with no grounding connection. Girls survived.

29. May 24, 2010 Clear Lake, IA. A man was throwing balls to his dogs from the dock behind his house. One dog approached the boat lift and went under. The man jumped in and received an electrical shock in the water. Family members quickly turned off the dock power. The man survived, the dog did not. Exact cause of fault not known.

30. Sept 2007 Franklin Lock Campground on the Caloosahatchee River, FL. Boat docked in freshwater marina receiving AC shore power. Owner was cleaning prop shaft under the boat using a metal scraper. As his foot touched the bottom and the scraper connected the shaft and the strut he felt an electric shock which caused his "teeth to clench and muscles to contract". He also saw blue sparks at the scraper. After the shock he was able to exit the water and observed that one of two 30amp shore power breakers had tripped. He was not wearing a wetsuit.

31. Aug 28, 2007 Private pond, Eden, NY 22 year old male entered the pond in an attempt to rescue his dog, which was in great distress, and was thrown back and lay unresponsive. His father dragged him from the water and started CPR which was continued by the rescue squad on the way to the hospital, where he is still recovering as of 9/1. Submersible irrigation pump was considered likely cause.

32. July 20, 2007 Lake Arcadia, Edmond, OK Adult male entered water at the end of a private dock and was immediately paralyzed by electric shock, and began to sink. His wife, reaching from the dock, kept his head above water. A bystander, entering the water from his boat was also shocked so he got back into the boat and assisted the wife in pulling the man onto the dock. High water had submerged the electrical outlets at the end of the dock.

33. July 1, 2007 Collins Bay, Lake Ontario, Kingston, ON. As a SCUBA diver, with no wet suit, approached a moored sail boat he felt a tingling sensation. Approaching closer he experienced a moderate electric shock so he backed away. Later examination disclosed damage to a steel dock section at the boat's stern and the battery charger was found to have a "short circuit". The condition of the bonding system was not reported.

34.	August 2006	Lake Michigan, Racine, WI. Owner decided to check underwater as he was having vibration on one engine. He donned scuba gear and jumped in water. When he touched the bronze prop he was hit with current that almost paralyzed him causing great difficulty in breathing. He was able to get away from the zone of danger. Cause is thought to be the boat in the next slip. A yellow barrel connector on the water heater Neutral #16 wire was loose, due to the terminal being the wrong size and not correctly crimped. It heated up which burnt terminal insulation and shorted the hot to the grounded case. As the phase did not see excessive current, the breaker did not trip. The neutral dock pedestal socket pins had corroded due to poor connection and the ensuing heating so that eventually only intermittent connection was made. The diver's wetsuit may have saved his life. He was only inches from the neighboring boat when touching the prop on his boat (which provided the path back to the source).
35.	July 2, 2006	Lake L'Homme Dieu, Douglas County, MN. Three men were nearing an aluminum dock in an outboard boat (aluminum hull?) when the prop caught on an extension cord laid under water (powered a boat lift), and were severely shocked as they entered the water. Possibly two of the three men entered the water to rescue the third man who had fallen face down into the water, half out of boat, and was not moving – exact sequence not known. A bystander unplugged the cord. The third man spent several days in the hospital. No investigation planned.
36.	July 2005	Brooklyn, NY. A diver went into the water behind a boat in this small, private marina. He surfaced seconds later complaining about tingling and pain in his arm. A probe in the water measured 40vac to ground behind the boat. Cause was determined to be a neutral-ground short on a recently installed water heater (although there was most likely a bad ground too at that pedestal to cause this). He was wearing a short, spring wet suit.
37.	July 2004	Sahauro Lake, AZ, a man-made, freshwater lake near Phoenix. A man was diving to perform maintenance on a dock structure. He left the water after feeling a tingling sensation in the water near a pontoon houseboat. The shore cable was disconnected from the boat and the diver resumed his work without further incident. The cause may have been an improperly wired battery charger on the boat.
38.	July 2004	Sacramento River, CA. Man entering water around several boats (being supplied by genset power from one of the boats) receives shock in water. Two other men jump in to rescue man. One of the 2 rescuers became imperiled. Generator secured immediately. Incorrect wiring on one boat caused a ground fault which introduced current into the water between boats.
39.	May 31, 2004	Lake Barkley, Grand Rivers, KY. After receiving permission from marina two adult women went swimming near their rented houseboat. As they started back to the boat from the swim slide entry point both felt a strong electric shock sensation, and had the presence of mind to *swim away* from the boat! A relative entered the water and felt the same thing – which disappeared when the boat was disconnected from shore power. Close call was brushed off by staff so no action was taken to locate source of fault current. A fatality waiting to happen!

40.	August 2003	Green River, Campbellsville, KY. Marina manager using Hioki clamp-on ammeter checking shore cords for leakage and discovered one houseboat with 4 amps on one of two shore cords. Hull potential to dock ground 8 VAC and owner commented that one of his children reported a tingle in the water!! Boat had just been reassembled after being trucked from Texas and problems were being experienced with 120 VAC deck light. Deck lights were rewired and neutral / ground fault in inverter was cleared – leakage current no longer exists.
41.	July 2002	Allatoona Lake, GA. Three swimmers in great distress near houseboat, by stander pulls shore cord, all saved, one spent several days in hospital, fresh water, and fault on boat.
42.	Fall 2002	Lake Murray, SC. Swimmer reports strong tingle, hi-level fault currents in dock frame, fresh water.
43.	Date Unknown	Man jumps into water to rescue dog, feels high level tingle, cause unknown, fresh water.
44.	2002-2003	Florida, interviews with divers – many reports of high level tingle while cleaning bottoms, all salt water, and no fatalities.
45.	Sept 2000	Niagara River, Grand island, NY – On the dock behind his home the owner watched his dog sink near a steel piling while retrieving a ball. He jumped into the water to rescue the dog and found himself sitting on the bottom in 5’ of water completely paralyzed. In a few seconds he began getting tunnel vision and assumed he was going to die. Within the next few seconds a slight current moved him about 4’ away from the steel pile. He was able to get his head above water and move another 8’ to a ladder. A romex cable, which powered a light on top of the piling, had chaffed and caused the energized conductor to contact the pile. The dog was lost.
46.	Date&Location Unknown	Swimmer feels a tingle as his hand enters the A/C discharge stream. Cause not determined, salt water.
47.	July 3, 1998	Lake Chelan, Chelan, WA. 21 year old exiting water – shocked on swim ladder – 48 hours in the hospital – rescuers shocked.
48.	August 1995	Lake Cumberland, KY, Jamestown Resort and Marina. Seven children swimming behind houseboat received electrical shocks (no fatalities). Lights went out on boat and children immediately started screaming. Cause was loss of neutral, a neutral-ground connection on the air conditioning system and a poor grounding connection on the shore cord. The grounding connection deteriorated when cooking loads were energized causing a loss of return path to the source (reason lights went out).
49.	July 1981	Brackish water on the Connecticut River in Essex, CT. Diver checking zincs felt strong “electric pulses” as he approached the boat so he backed away. After securing power to the boat, the electric pulses were gone (exact fault unknown)

CODE VIOLATIONS

1.	January 1994	Oklahoma State Department of Health (OSDH) inspected eleven commercial docks and five private docks, and an earlier (1989) inspection of 116 commercial docks, found 96% not in NEC compliance; most common fault was open ground.
2.	Aug 8, 2004	Follow-up to #9 in the Electric Shock Drowning Section above:
	Follow-up	Lake Travis, Austin, TX. Because of this accident the manager of a neighboring marina now shuts down power to the docks whenever an employee enters the water to do any kind of service. In Nov., 2005, an employee who was in the water, to move the feeder cables that run near the pier access ramp, discovered badly damaged insulation. A fatality was likely prevented because the power had been turned off.

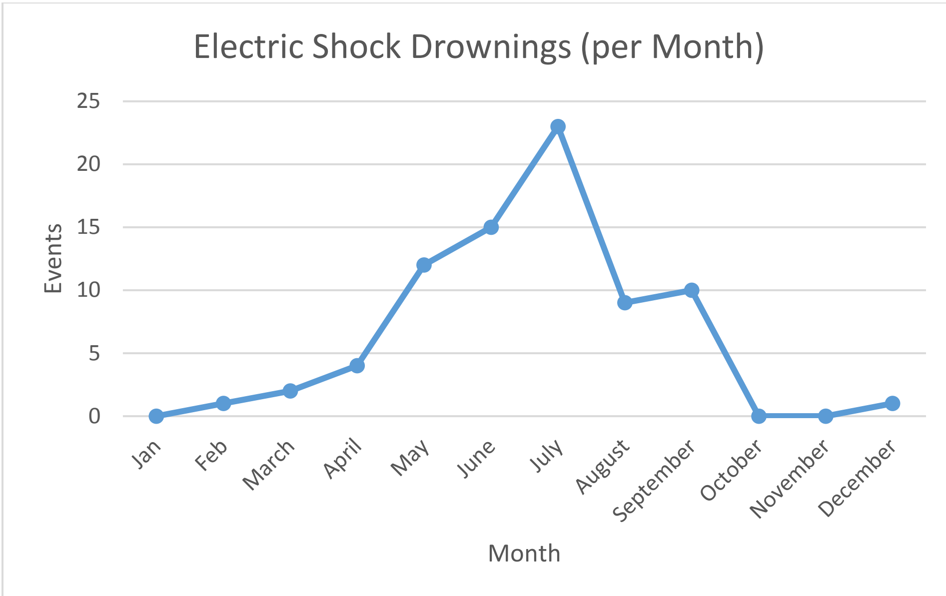


Fig. C.1 Number of ESD Incident per Month (1986-2016), (Reflects Shafer and Rifkin 2017)

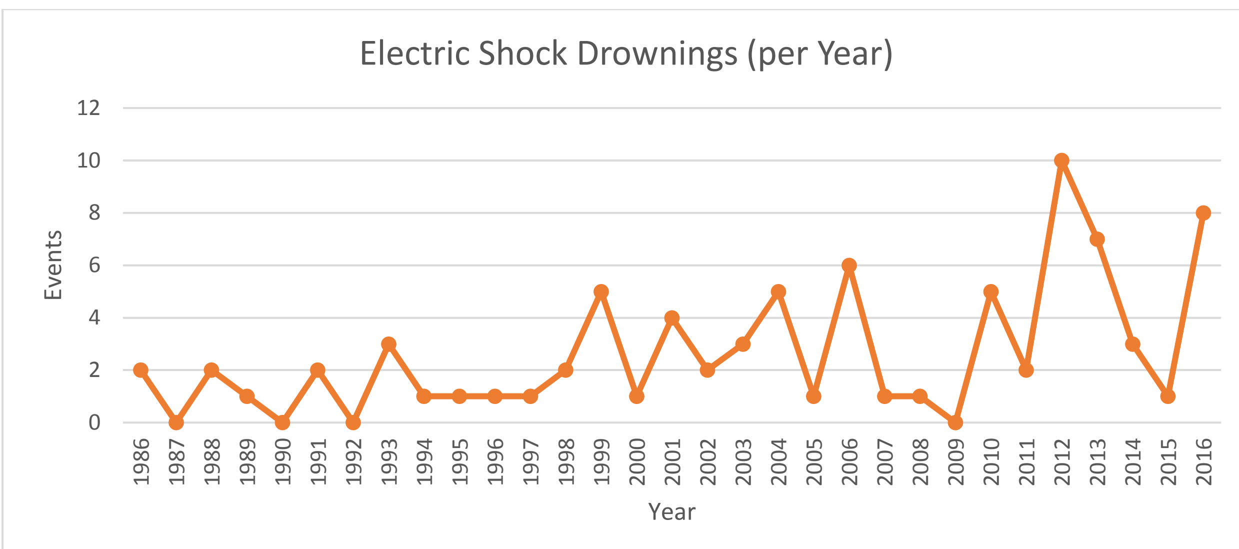


Fig. C.2 Number of ESD Incident per Year (1986-2016), (Reflects Shafer and Rifkin 2017)

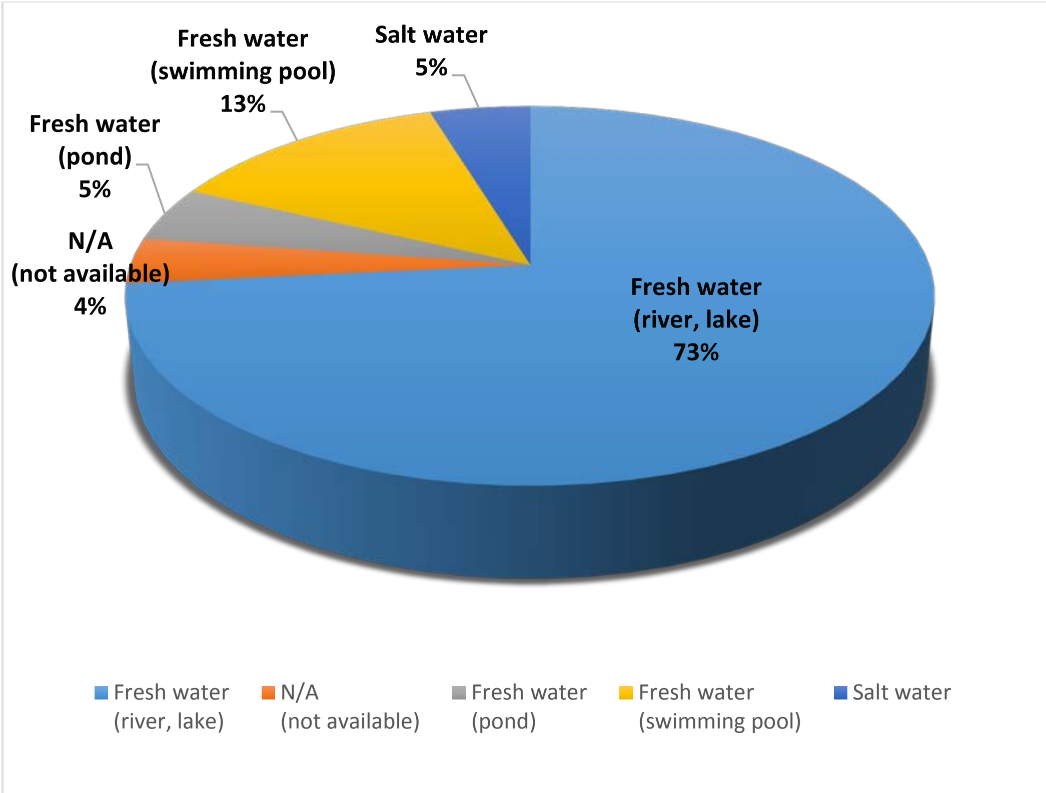


Fig. C.3 Percentage of ESD Incident by Location (1986-2016), (Reflects Shafer and Rifkin 2017)

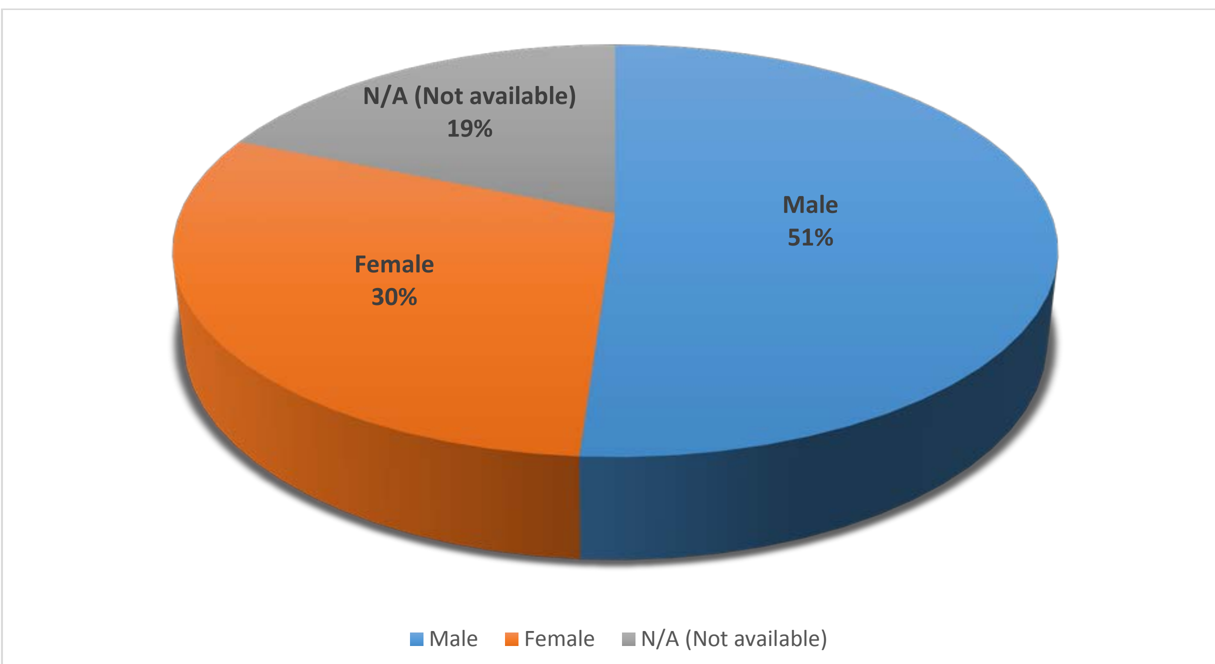


Fig. C.4 Percentage of ESD Incident by Victim (1986-2016), (Reflects Shafer and Rifkin 2017)

ANNEX D – ESD CONCEPTS TREE

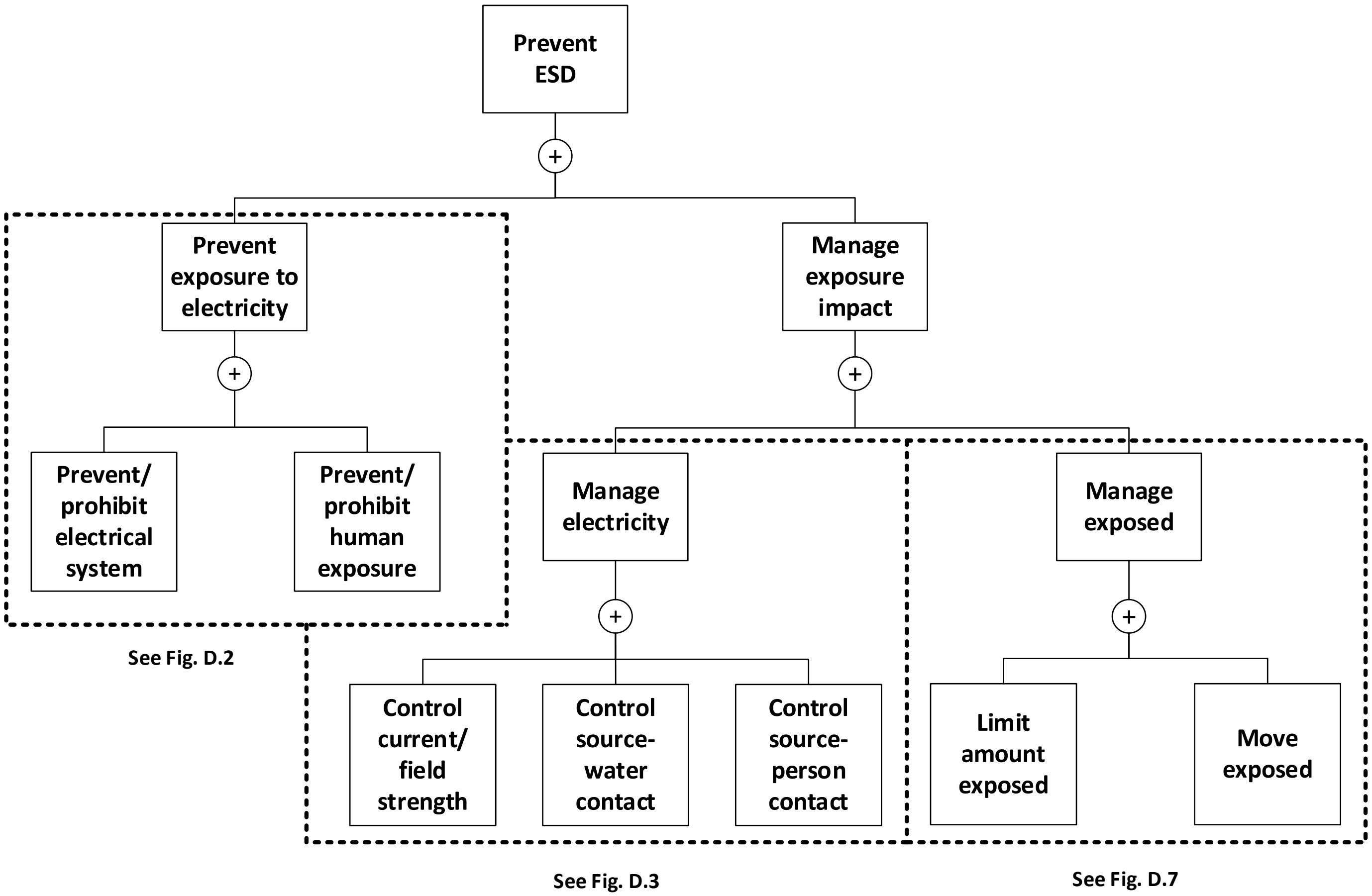


Figure D.1 Top Level of ESD Concept Tree with Selected Lower-Tiered Gates.

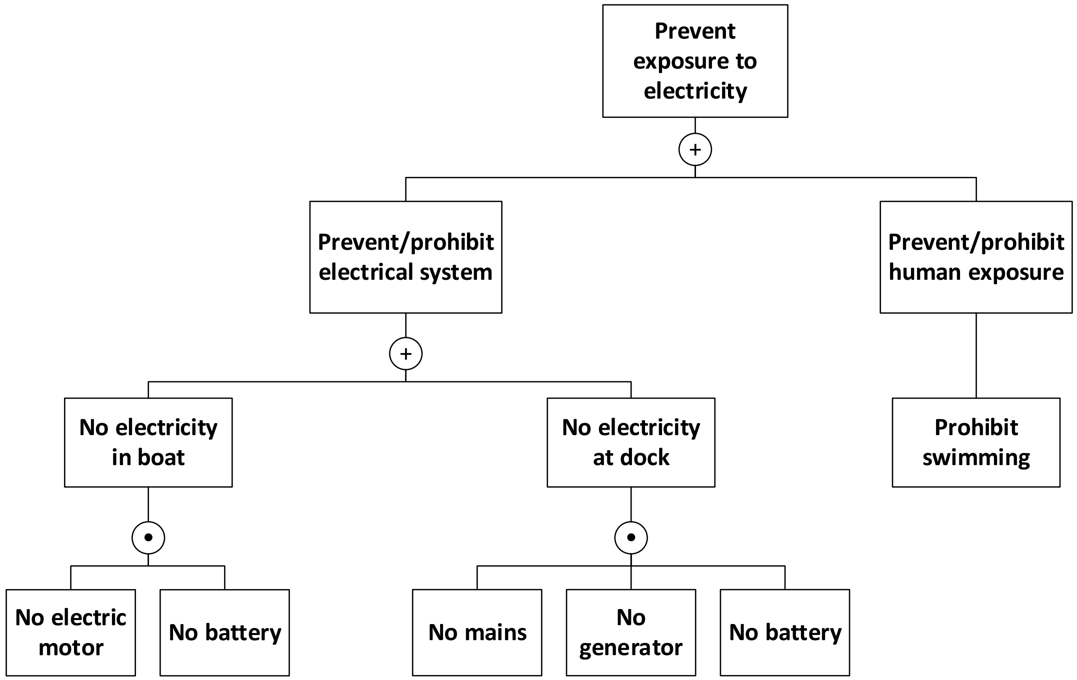


Figure D.2 Prevent Exposure Branch of ESDCT.

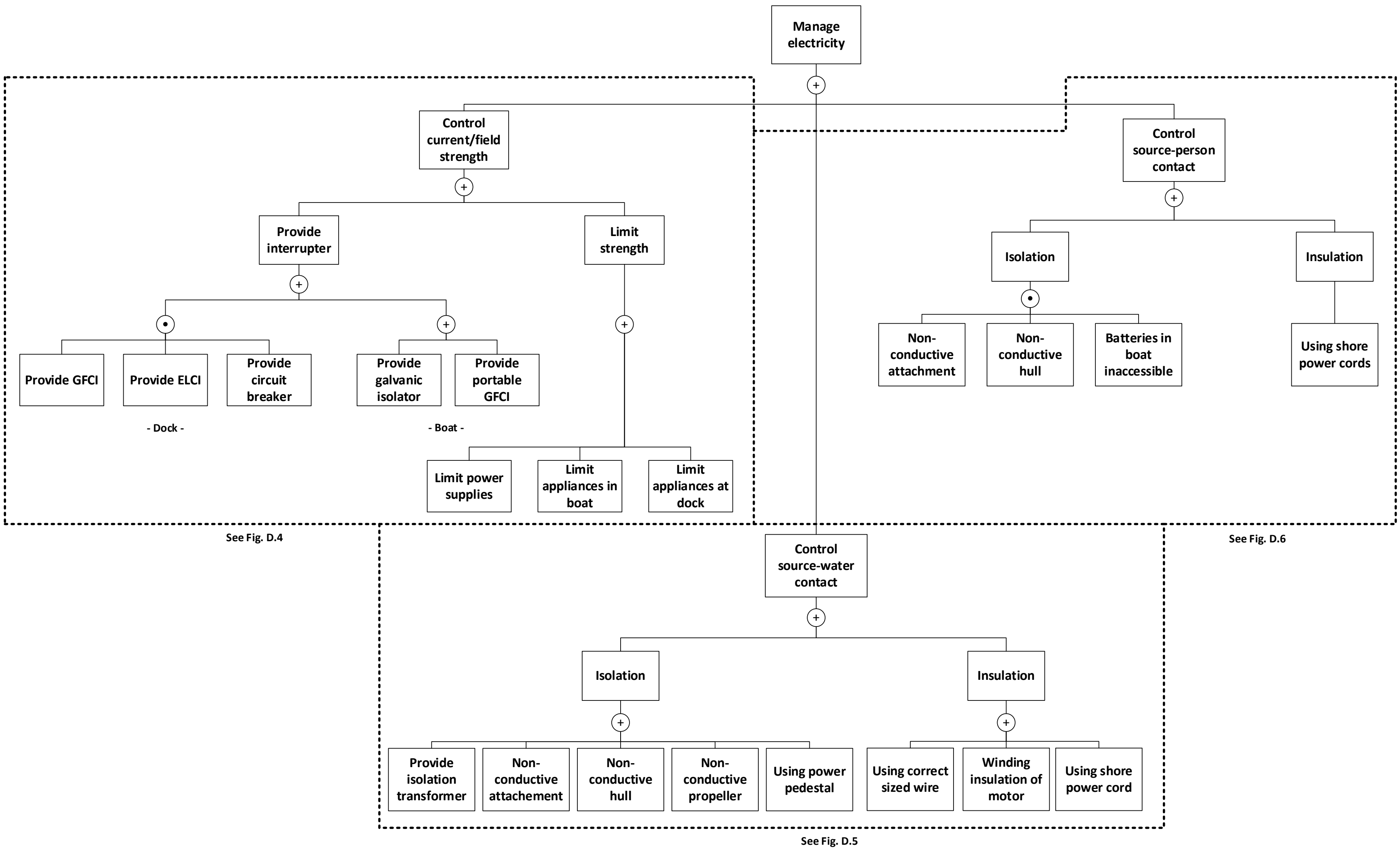


Figure D.3 Manage Electricity Branch of ESDCT with Selected Lower-Tiered Gates

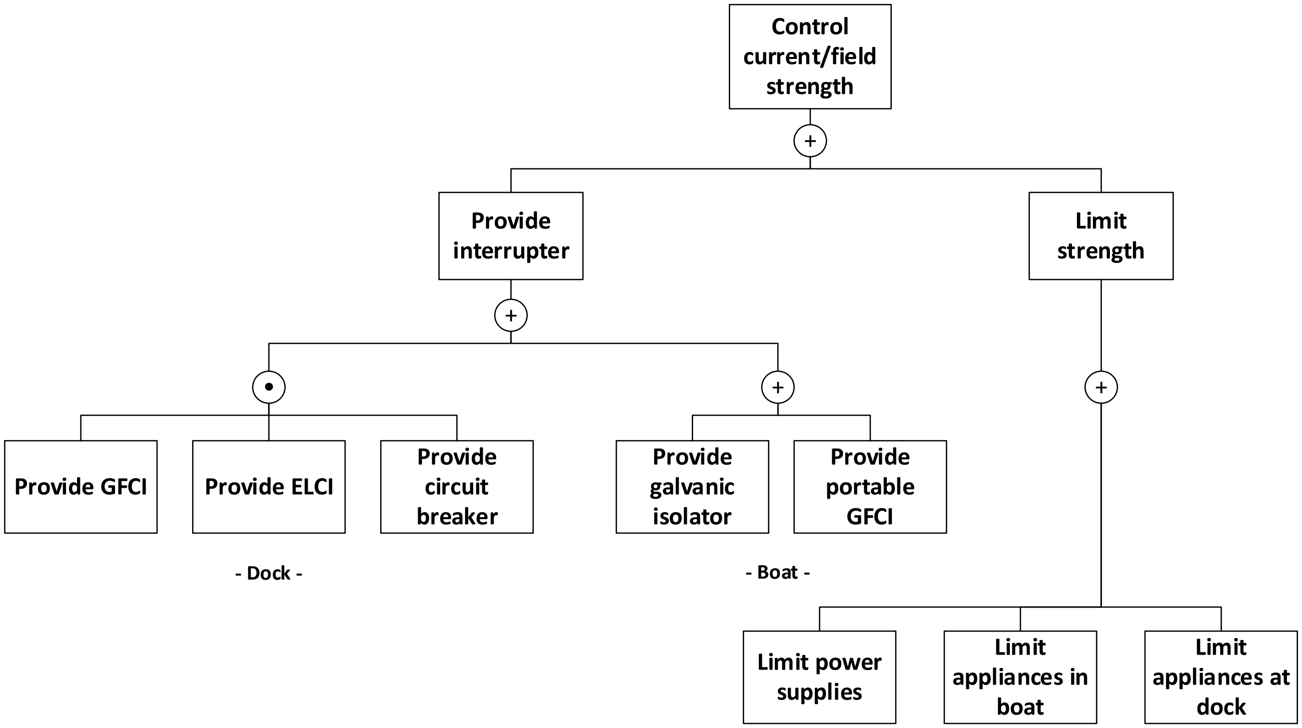


Figure D.4 Control Current/Field Strength Branch of ESDCT.

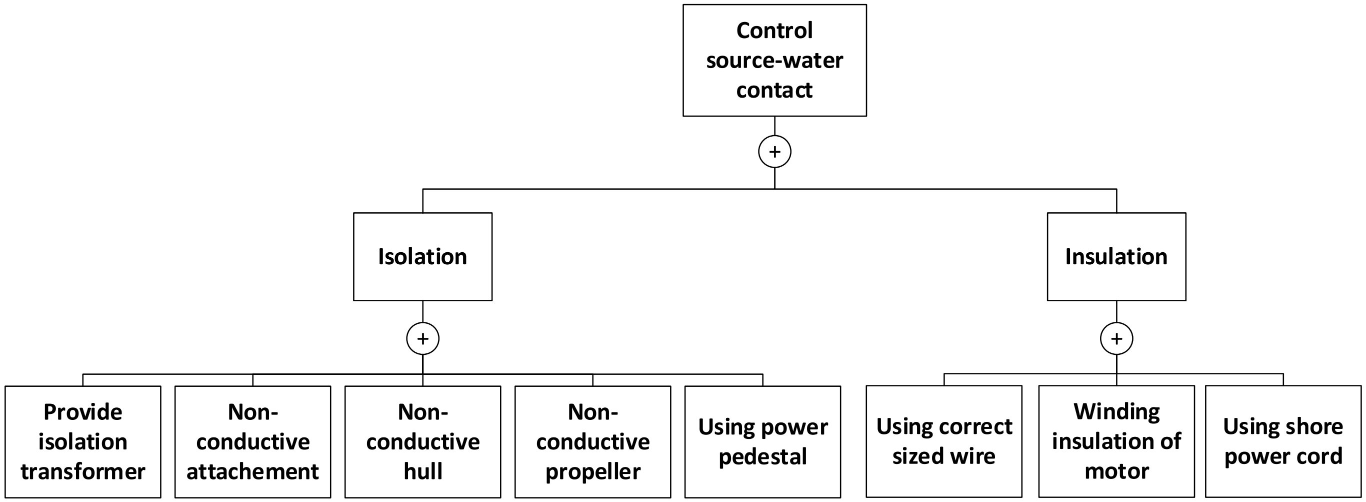


Figure D.5 Control Source–Water Contact Branch of ESDCT.

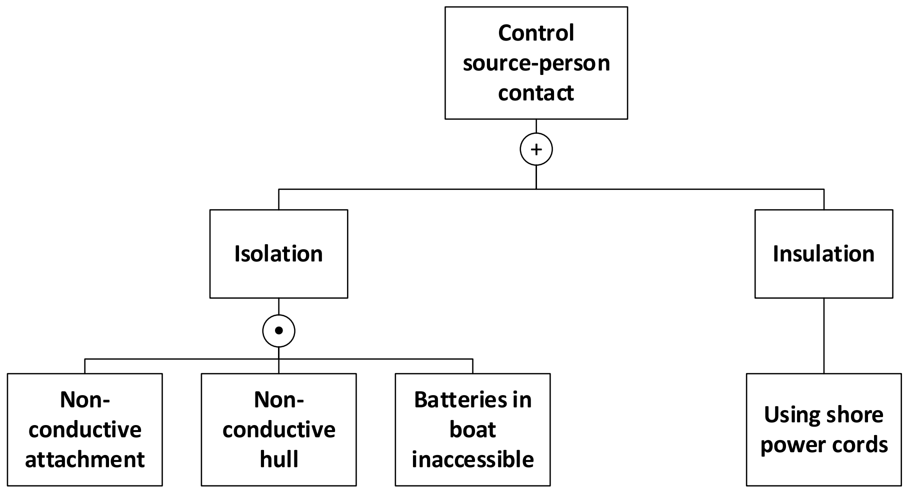


Figure D.6 Control Source–Person Contact Branch of ESDCT.

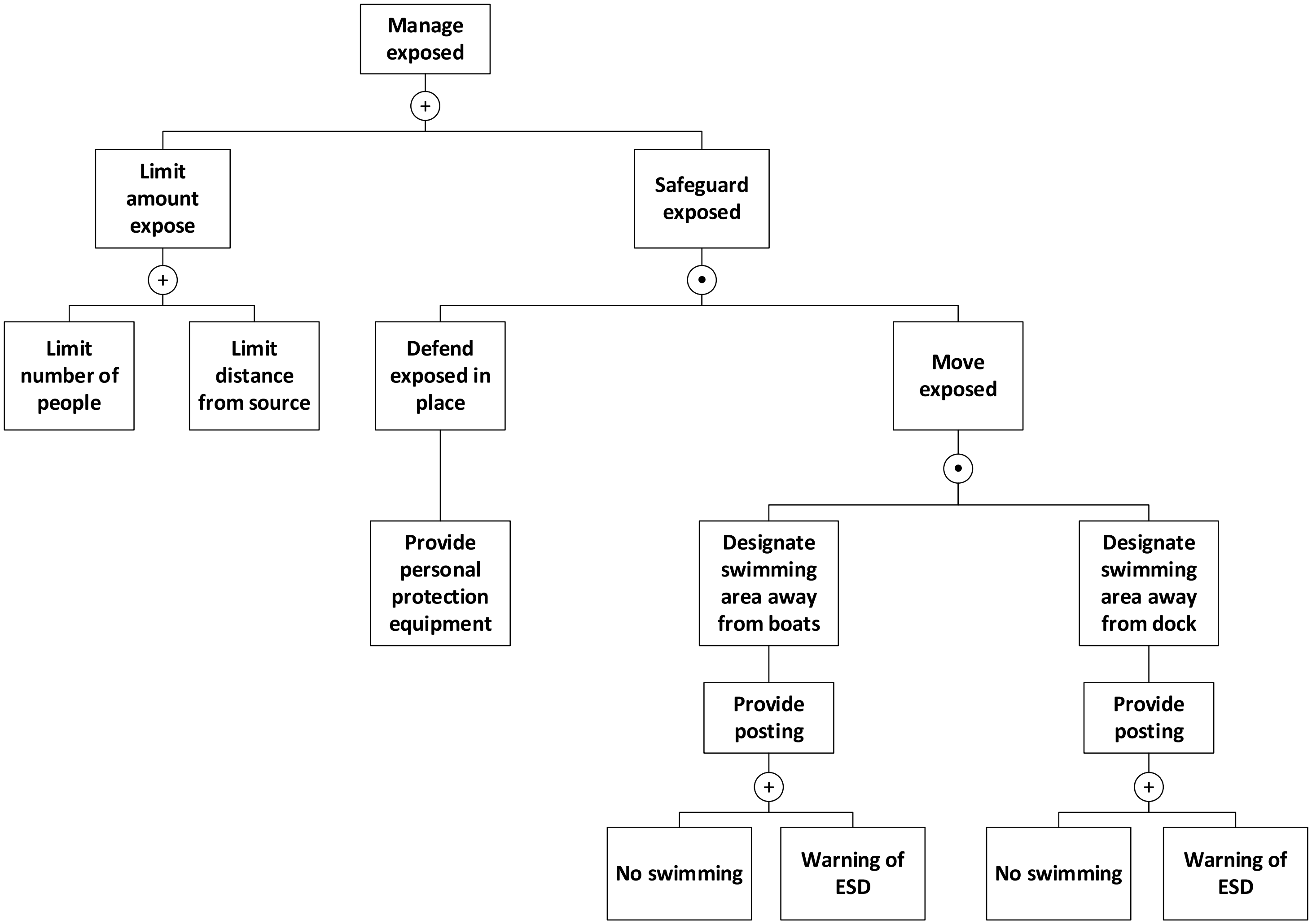


Figure D.7 Manage Exposed Branch of ESDCT.

ANNEX E – RELEVANT STANDARDS/CODES

National Fire Protection Association (NFPA)

Source: National Fire Protection Association, 1 Batterymarch Park, Quincy, MA, 02169-7471, Phone: (617) 770-3000, Fax: (617) 770-0700. Website: www.nfpa.org

List of Standards:

- NFPA 70®, *National Electrical Code®,* 2017 edition
- NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft,* 2015 edition
- NFPA 303, *Fire Protection Standard for Marinas and Boatyards,* 2016 edition

Applicability to Project:

- NFPA 70®, *National Electrical Code*, 2017 edition, Article 555, Marinas, Boatyards, and Commercial and Noncommercial Docking Facilities.
  This article covers the installation of wiring and equipment in the areas comprising fixed or floating piers, wharves, docks and other areas in marinas, boatyards, boat basins, boathouses, yacht clubs, boat condominiums, docking facilities associated with one-family dwellings, two-family dwellings, multifamily dwellings, and residential condominiums; any multiple docking facility or similar occupancies; and facilities that are used, or intended for use, for the purpose of repair, berthing, launching, storage, or fueling of small craft and the moorage of floating buildings.

- NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft,* 2015 edition
  This standard shall apply to the following boats of less than 300 gross tons that are used for pleasure or commercial purposes:
  (1) Boats that use engines for propulsion
  (2) Boats that use engines for generating power
  (3) Boats that use cooking, heating, or auxiliary appliances
  (4) Boats that have permanently installed ignition source(s)
  (5) Boats that have permanently installed electrical systems
  The standard shall not apply to personal watercraft, and no requirement of this standard shall be constructed as reducing applicable federal regulations.

- NFPA 303, *Fire Protection Standard for Marinas and Boatyards,* 2016 edition
  This standard applies to the construction and operation of marinas, boatyards, yacht clubs, boat condominiums, docking facilities associated with residential condominiums, multiple-docking facilities at multiple-family residences, and all associated piers, docks, and floats. This standard also applies to marinas and facilities servicing small recreational and commercial craft, yachts, and other craft of not more than 300 gross tons. The standard is not intended to apply to a private, noncommercial docking facility constructed or occupied for the use of the owners or residents of the associated single-family dwelling.

American Boat & Yacht Council (ABYC)

Source: ABYC – American Boat & Yacht Council, Inc., 613 Third Street, Suite 10, Annapolis, MD 21403, Phone: (410) 900-4460, Fax: (410) 990-4466. Website: www.abycinc.org

List of Standards:

- ABYC A-28, *Galvanic Isolators*
- ABYC A-31, *Battery Chargers and Inverters* (2015 Edition)
- ABYC E-11, *AC and DC Electrical Systems on Boats* (2015 Edition)
- ABYC T-5, *Safety Signs and Labels* (2016 Edition)
- ABYC T-24, *Owner/Operator's Manuals* (2014 Edition)

Applicability to Project:

- ABYC A-28, *Galvanic Isolators*
  This is a performance-based standard and guide for the qualification and installation of galvanic isolators, and if applicable, their status monitors, in alternating current (AC) electrical systems on boats. Boats with metal in contact with water are subject to galvanic corrosion when connected to shore power as a result of connection to the common AC grounding conductor. This standard applies to galvanic isolators and their status monitors used on boats equipped with alternating current (AC) shore power systems operating at frequencies of 50 or 60 Hz, and less than 300 volts, wired in accordance with ABYC E-11.

- ABYC A-31, *Battery Chargers and Inverters*
  This standard is a guide for the design, construction, and installation of permanently installed marine alternating current (AC) battery chargers, power inverters, and inverter/chargers. This standard applies to the following:
    - Permanently installed marine battery chargers powered by less than 300 volts AC providing current at a potential of 50 volts DC or less
    - Permanently installed DC to AC marine inverters supplying less than 300 volts AC at a frequency of 50 or 60 Hz
    - Permanently installed inverters/chargers supplying less than 300 volts AC at a frequency of 50 or 60 Hz
- This standard does not apply to devices intended to supply DC loads without a battery.

- ABYC E-11, *AC and DC Electrical Systems on Boats*
  This standard is a guide for the design, construction, and installation of alternating current (AC) electrical systems on boats and of direct current (DC) electrical systems on boats.
  This standard applies to:
    - Alternating current (AC) electrical systems on boats operating at frequencies of 50 or 60 Hz and less than 300 volts, including shore-powered systems up to the point of connection to the shore outlet and including the shore power cable.
    - It can be applied to direct current (DC) electrical systems on boats operating at nominal 50 volts or less.

- Exceptions: Any conductor that is part of an outboard engine assembly and does not extend beyond the outboard engine manufacturer's supplied cowling; Engine manufacturer–supplied engine management systems and their associated conductors up to and including 20 AWG.

- ABYC T-5, *Safety Signs and Labels*
  This technical information report applies to all safety information labels used on boats, associated equipment, instructions, and manuals. The words "sign" and "label" are used interchangeably within this report.
  Exceptions: Labels required by law or government regulation.

- ABYC T-24, *Owner/Operator's Manuals*
  This technical information report includes elements to consider in the development of owner/operator's manuals for boats. The owner/operator's manual should give sufficient information regarding the owner/operator's responsibility and proper operation and maintenance of the boat. Further, the development of owner/operator's manuals should be done with careful consideration of all elements relating to the specific boat models to which the manual applies. This report does not require that each and every item listed in this document be in the manual. The writer of an owner/operator's manual should consider each of the points raised in this document and include in the manual those items which are pertinent to the given boat models.

Code of Federal Regulations (CFR)

Source: Obtained from the Superintendent of Documents, United States Government Information, PO Box 371954, Pittsburgh, PA 15250-7954. Phone: (202) 512-1800, Fax: (202) 512-2104. Website: https://www.gpo.gov/ . An excerpted edition of the CFR is also available from ABYC, Inc.

List of Standards:

- Title 33 - Navigation and Navigable Waters (Parts 1–499) (July 1, 2006)
  Chapter 1 – Coast Guard, Department of Homeland Security
  Subchapter S – Boating Safety (Parts 173–199)

Applicability to Project:

- 33 CFR 173 –Vessel Numbering and Casualty and Accident Reporting
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part173.pdf

- 33 CFR 174 – State Numbering and Casualty Reporting Systems
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part174.pdf

- 33 CFR 175 – Equipment Requirements
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part175.pdf

- 33 CFR 177 – Correction of Especially Hazardous Conditions
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part177.pdf

- 33 CFR 179 – Defect Notification
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part179.pdf

- 33 CFR 181 – Manufacturer Requirements
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part181.pdf

- 33 CFR 183 – Boats and Associated Equipment
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part183.pdf
  –Subpart D - Safety Powering
  –Subpart I - Electrical Systems
  - Section 183.405 General
  - Section 183.415 Grounding
  - Section 183.430 Conductors in circuits of less than 50 volts
  - Section 183.435 Conductors in circuits of 50 volts or more
  - Section 183.445 Conductors: Protection
  - Section 183.455 Overcurrent protection: General
  - Section 183.460 Overcurrent protection: Special applications

- 33 CFR 187 – Vessel Identification System
  https://www.gpo.gov/fdsys/pkg/CFR-2006-title33-vol2/pdf/CFR-2006-title33-vol2-part187.pdf

Underwriters Laboratories (UL)

Source: UL Marine Department, P.O. Box 13995, 12 Laboratory Drive, Research Triangle Park, NC 27709. Phone: (919) 549-1400. Website: www.ul.com

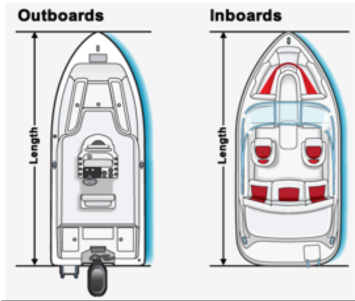
List of Standards:

- UL 1168, *Standard for Recreational Boats*, 2nd edition, July 12, 1999
- UL 1199, *Standard for Recreational Boats Less Than 20 Feet in Length*, 2nd edition, July 22, 1999
- UL 1426, *Standard for Electrical Cables for Boats,* 5th edition, December 6, 2010

Applicability to Project:

- UL 1168, *Standard for Recreational Boats*
  These requirements cover recreational boats, and the installation and resultant performance of various materials, equipment, and structures thereon including hull performance as it relates to static stability and maneuvering speed.
  These requirements cover boats that are subject to United States Coast Guard (USCG) regulations as specified in 33 CFR 181, Manufacturer Requirements, and 33 CFR 183, Boats and Associated Equipment, as well as boats not specifically subject to USCG regulations. Boats that comply with these requirements are in accordance with the applicable USCG regulations.
  These supplement, and are used in conjunction with, NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft,* 2015 edition; and UL 1199, *Standard for Recreational Boats Less Than 20 Feet in Length*.

- UL 1199, *Recreational Boats Less Than 20 Feet in Length*
  These requirements cover maximum weight and persons capacity, maximum power capacity, flotation, level flotation, and flotation materials of monohull-inboard, inboard-outdrive, and outboard boats, and boats intended for manual propulsion. These requirements cover boats that have a length of less than 20 feet. These requirements do not cover sailboats canoes, or kayaks; nor do they cover pontoon or inflatable boats with inboard engine or inboard-outdrives or that are intended for use with one or more outboard engines. The length of the boat can be measured using the figure at right.



Source: Boat Ed, a division of Kalkomey Enterprises, Inc., 2014, "The official boating handbook of the Massachusetts department

- UL 1426, *Standard for Electrical Cables for Boats*
  These requirements cover electrical cables for boats. The cables are intended for use in marine pleasure craft and consist of a single insulated conductor without a jacket or of two or more insulated conductors with or without an overall nonmetallic jacket.

Institute of Electrical and Electronics Engineers (IEEE)

Source: IEEE, 3 Park Avenue, New York, NY 10016-5997, USA

List of Standards:

- IEEE 45, *IEEE Recommended Practice for Electrical Installations on Shipboard*, 2002 edition
- IEEE 80, *IEEE Guide for Safety in AC Substation Grounding*, 2000 edition

Applicability to Project:

- IEEE 45, *IEEE Recommended Practice for Electrical Installations on Shipboard*, 2002 edition
  These recommendations establish the minimally acceptable guidelines for the design, selection, and installation of systems and equipment aboard marine vessels applying electrical apparatus for power, propulsion, steering, automation, navigation, lighting, and communications. These recommendations describe present-day acceptable electrical engineering methods and practices.
  The main purpose of this recommended practice is to provide a consensus of recommended practices in the unique field of marine electrical engineering as applied specifically to ships, shipboard systems, and equipment.

- IEEE 80, *IEEE Guide for Safety in AC Substation Grounding*, 2000 edition
  The intent of this guide is to provide guidance and information pertinent to safety grounding practices in AC substation design. The specific purposes of this guide are to:
    - Establish, as a basis for design, the safe limits of potential differences that can exist in a substation under fault conditions between points that can be contacted by the human body.
    - Review substation grounding practices with special reference to safety, and develop criteria for a safe design.
    - Provide a procedure for the design of practical grounding systems, based on these criteria.
    - Develop analytical methods as an aid in the understanding and solution of typical gradient problems.

ANNEX F – EXISTING DATA BY STATE

Table F.1 Florida Boating Laws and Regulations

Do you need Florida Boating education?

- You need education if you were born on or after Jan. 1, 1988, and will be operating a motorized boat of 10 hp or more in Florida.
- There is no minimum age requirement to take this online course.
- You do not have to be resident of Florida to take this online course.

Exemptions

- Operators are exempt from needing to get the license if they are:
  - Licensed by the U.S. Coast Guard as a master of a vessel
  - Operating on a private lake or pond
  - Accompanied on board by a person who is exempt from the education requirement or by a person who is at least 18 years old, possesses the required identification cards, and is attendant to the operation of the vessel and responsible for any violation that occurs
  - Operating a vessel within 90 days after purchases and have a bill of sale on board and available for inspection

Age and Operator Restrictions

- No one under the age of 14 years may operate a personal watercraft (PWC) on Florida waters at any time, even if such person possesses a Florida Boating Safety Education I.D. Card.
- No one under the age of 18 years may rent/lease a PWC
- It is also illegal for the owner of a PWC to knowingly allow a person under 14 years of age to operate a PWC.

Enforcement

- Florida law enforcement officers patrol the waterways to make your boating experience safe and pleasant. Cooperate with them by following the laws and guidelines.
- Carry the Card: Vessel operators who are required to have a Boater Education Card must carry the card on board the vessel and have it available for inspection by an enforcement officer.
- Penalty: Not carrying your Boater Education Card when one is required can result in a fine.

Is the Boating Card the same as the Boating License?

- The Florida Boating Safety Education I.D. Card is proof that you have successfully completed all of the components of an approved Boating safety course and allows you to go boating. Because the Boating education card or certificate does not expire and does not need to be renewed, it is not called the Florida Boating License.
- Even if not required by law to get the Florida boating education card, many boaters take the boat safety course in order to save on their PWC or boat insurance.
- Do your part to make boating in Florida an enjoyable pastime! Become an educated, responsible boater by completing the Boat Florida course, and practice what you learn.

Reciprocity

- All states, territories, and provinces will recognize boating education cards that meet NASBLA requirements and Canadian Pleasure Craft Operator Cards that meet Transport Canada's requirements. (This is known as "reciprocity.")

Florida-Approved Boating Course

- The Florida Boat Ed Course is approved and accepted by the Florida Fish and Wildlife Conservation Commission.

United States Coast Guard Recognized

- The Florida Boat Ed Course is recognized by the United States Coast Guard as meeting the standards of the National Recreational Boating Safety Program.

- USCG Auxiliary Course Provider
    - Boat Ed is the only boater safety course provider that develops print materials on behalf of the U.S. Coast Guard Auxiliary, the uniformed, civilian volunteer arm of the United States Coast Guard.

NASBLA Approved

- The Florida Boat Ed Course is approved by the U.S. Association of State Boating Law Administrators (NASBLA) and meets U.S. Boating Education Standards.
- NASBLA is a U.S. nonprofit organization that works to develop public policy for recreational boating safety. NASBLA represents the recreational boating authorities of all 50 states and the U.S. territories.
- The NASBLA standards are intended to prescribe the minimum body of knowledge necessary to effect safe, legal, and enjoyable boating. In addition, the proposed standard of care is predicated on reducing risks in recreational boating based on empirical accident and boating violation statistics.

Source:
Florida Fish and Wildlife Conservation Commission
http://myfwc.com/

Table F.2 Texas Boating Laws and Regulations

Do you need Texas Boating education?

Texas:

- You need education if you were born on or after Sept. 1, 1993, and will be operating a boat over 15 hp, a PWC, or a sailboat over 14 feet long in Texas.
- You must be at least 13 years old to take this online course.
- You do not have to be a resident of Texas to take this online course.

Elsewhere:

- Boating education is currently required in several U.S. states and Canadian provinces.

Age and Operator Restrictions

- Operators must meet the age and boater education requirements shown below in order to operate any of the following vessels legally in Texas:
  - A powerboat powered by a motor of more than 15 hp or…
  - A PWC or…
  - A windblown vessel over 14 feet in length.
- A person less than 13 years old age may operate only if he or she is supervised by a person who:
  - Is 18 years of age or older and…
  - Can lawfully operate the watercraft and…
  - Is on board when the vessel is underway.
- A person at least 13 years of age and born on or after Sep. 1, 1993, may operate without supervision only if he or she has passed a boater education course that is accepted by Texas Parks and Wildlife.

Enforcement

- Texas law enforcement officers patrol the waterways to make your boating experience safe and pleasant. Cooperate with them by following the laws and guidelines.
- Carry the Card: Vessel operators who are required to have a Boater Education Card must carry the card on board the vessel and have it available for inspection by an enforcement officer.
- Penalty: Not carrying your Boater Education Card when one is required can result in a fine.

Is the Boating Card the same as the Boating License?

- The Texas Boater Education Certificate is proof that you have successfully completed all of the components of an approved Boating safety course and allows you to go boating. Because the Boating education card or certificate does not expire and does not need to be renewed, it is not called the Texas Boating License.
- Even if not required by law to get the Texas boating education card, many boaters take the boat safety course in order to save on their PWC or boat insurance.
- Do your part to make boating in Texas an enjoyable pastime! Become an educated, responsible boater by completing the Boat Texas course, and practice what you learn.

Reciprocity

- All states, territories, and provinces will recognize boating education cards that meet NASBLA requirements and Canadian Pleasure Craft Operator Cards that meet Transport Canada's requirements. (This is known as "reciprocity.")

Texas-Approved Boating Course

- The Texas Boat Ed Course is approved and accepted by the Texas Parks and Wildlife.

United States Coast Guard Recognized

- The Texas Boat Ed Course is recognized by the United States Coast Guard as meeting the standards of the National Recreational Boating Safety Program.
- USCG Auxiliary Course Provider
  - Boat Ed is the only boater safety course provider that develops print materials on behalf of the U.S. Coast Guard Auxiliary, the uniformed, civilian volunteer arm of the United States Coast Guard.

NASBLA Approved

- The Texas Boat Ed Course is approved by the U.S. Association of State Boating Law Administrators (NASBLA) and meets U.S. Boating Education Standards.
- NASBLA is a U.S. nonprofit organization that works to develop public policy for recreational boating safety. NASBLA represents the recreational boating authorities of all 50 states and the U.S. territories.
- The NASBLA standards are intended to prescribe the minimum body of knowledge necessary to effect safe, legal, and enjoyable boating. In addition, the proposed standard of care is predicated on reducing risks in recreational boating based on empirical accident and boating violation statistics.

Source:
Texas Parks and Wildlife
https://tpwd.texas.gov/

Table F.3 California Boating Laws and Regulations

Do you need California Boating education?

California:

- Starting January 1, 2018, California law will require boaters to carry the California Boater Card. The law will be phased in over eight years.
- There is no minimum age requirement to take this online course.
- You do not have to be a resident of California to take this online course.

Elsewhere:

- Boating education is currently required in several U.S. states and Canadian provinces.

Age and Operator Restrictions

- California law requires a person to be 16 years of age or older to legally operate a vessel powered by a motor of 15 hp or more, including personal watercraft (PWCs).
- Exceptions to this law are:
  - Persons 12 to 15 years of age may operate a vessel powered by a motor of 15 hp or more, including PWCs, if they are supervised on board by a person at least 18 years of age.
  - There is no age restriction for operating a sailboat under 30 ft. long (with wind as the main source of propulsion) or a dinghy used between a moored vessel and shore or between two moored vessels.
- It is illegal to permit a person under the age of 16 to operate a vessel powered by a motor of 15 hp or more, including PWCs, without onboard supervision by a person 18 years of age or older.

Additional Information

- Any person convicted of any moving violation in the Harbors and Navigation Code, the Federal Rules of the Road and regulations adopted by the California Division of Boating and Waterways while operating a vessel must be ordered by the court to complete and pass a boating safety course approved by the California Division of Boating and Waterways. Proof of completion and passage of the course must be submitted to the court within seven months of the time of the conviction. This boating safety course will satisfy court-ordered mandatory boater education required by California law when a boater is convicted of a moving violation.

Enforcement

- California law enforcement officers patrol the waterways to make your boating experience safe and pleasant. Cooperate with them by following the laws and guidelines.
- Carry the Card: Vessel operators who are required to have a Boater Education Card must carry the card on board the vessel and have it available for inspection by an enforcement officer.
- Penalty: Not carrying your Boater Education Card when one is required can result in a fine.

Is the Boating Card the same as the Boating License?

- The California Boater Education Certificate is proof that you have successfully completed all of the components of an approved Boating safety course and allows you to go boating. Because the Boating education card or certificate does not expire and does not need to be renewed, it is not called the California Boating License.
- Even if not required by law to get the California boating education card, many boaters take the boat safety course in order to save on their PWC or boat insurance.
- Do your part to make boating in California an enjoyable pastime! Become an educated, responsible boater by completing the Boat California course, and practice what you learn.

Reciprocity

All states, territories, and provinces will recognize boating education cards that meet NASBLA requirements and Canadian Pleasure Craft Operator Cards that meet Transport Canada's requirements. (This is known as "reciprocity.")

California-Approved Boating Course

- The California Boat Ed Course is approved and accepted by the California Division of Boating and Waterways.

United States Coast Guard Recognized

- The California Boat Ed Course is recognized by the United States Coast Guard as meeting the standards of the National Recreational Boating Safety Program.
- USCG Auxiliary Course Provider
    - Boat Ed is the only boater safety course provider that develops print materials on behalf of the U.S. Coast Guard Auxiliary, the uniformed, civilian volunteer arm of the United States Coast Guard.

NASBLA Approved

- The California Boat Ed Course is approved by the U.S. Association of State Boating Law Administrators (NASBLA) and meets U.S. Boating Education Standards.
- NASBLA is a U.S. nonprofit organization that works to develop public policy for recreational boating safety. NASBLA represents the recreational boating authorities of all 50 states and the U.S. territories.
- The NASBLA standards are intended to prescribe the minimum body of knowledge necessary to effect safe, legal, and enjoyable boating. In addition, the proposed standard of care is predicated on reducing risks in recreational boating based on empirical accident and boating violation statistics.

Source:
Division of Boating and Waterways
http://www.dbw.ca.gov/

Table F.4 North Carolina Boating Laws and Regulations

Do you need North Carolina Boating education?

North Carolina:

- You need education if you were born on or after Jan. 1, 1988, and will be operating a boat or PWC of 10 hp or more in North Carolina.
- There is no minimum age requirement to take this online course.
- You do not have to be a resident of North Carolina to take this online course.

Elsewhere:

- Boating education is currently required in several U.S. states and Canadian provinces.

Age and Operator Restrictions

- A person younger than 14 years old may not operate a PWC legally.
- A person 14 or 15 years old may operate a PWC only if:
    - He or she is accompanied on board the PWC by a person who is at least 18 years old and who is in compliance with the requirements for operating a vessel or…
    - He or she has on his or her person identification showing proof of age and a boating certification card showing proof of passing a boating safety course approved by NASBLA and accepted by the North Carolina Wildlife Resources Commission or…
    - He or she has on his or her person identification showing proof of age and proof of other boating safety education in compliance with state laws.
- Anyone 16 years old or older and born on or after January 1, 1988, may operate a PWC with a motor of 10 hp or greater only if he or she is in compliance with the requirements for operating a vessel.

Enforcement

- North Carolina law enforcement officers patrol the waterways to make your boating experience safe and pleasant. Cooperate with them by following the laws and guidelines.
- Carry the Card: Vessel operators who are required to have a Boater Education Card must carry the card on board the vessel and have it available for inspection by an enforcement officer.
- Penalty: Not carrying your Boater Education Card when one is required can result in a fine.

Is the Boating Card the same as the Boating License?

- The North Carolina Boater Education Certificate is proof that you have successfully completed all of the components of an approved Boating safety course and allows you to go boating. Because the Boating education card or certificate does not expire and does not need to be renewed, it is not called the North Carolina Boating License.
- Even if not required by law to get the North Carolina boating education card, many boaters take the boat safety course in order to save on their PWC or boat insurance.
- Do your part to make boating in North Carolina an enjoyable pastime! Become an educated, responsible boater by completing the Boat North Carolina course, and practice what you learn.

Reciprocity

- All states, territories, and provinces will recognize boating education cards that meet NASBLA requirements and Canadian Pleasure Craft Operator Cards that meet Transport Canada's requirements. (This is known as "reciprocity.")

North Carolina-Approved Boating Course

- The North Carolina Boat Ed Course is approved and accepted by the North Carolina Wildlife Resources Commission.

United States Coast Guard Recognized

- The North Carolina Boat Ed Course is recognized by the United States Coast Guard as meeting the standards of the National Recreational Boating Safety Program.
- USCG Auxiliary Course Provider

- Boat Ed is the only boater safety course provider that develops print materials on behalf of the U.S. Coast Guard Auxiliary, the uniformed, civilian volunteer arm of the United States Coast Guard.

NASBLA Approved

- The North Carolina Boat Ed Course is approved by the U.S. Association of State Boating Law Administrators (NASBLA) and meets U.S. Boating Education Standards.
- NASBLA is a U.S. nonprofit organization that works to develop public policy for recreational boating safety. NASBLA represents the recreational boating authorities of all 50 states and the U.S. territories.
- The NASBLA standards are intended to prescribe the minimum body of knowledge necessary to effect safe, legal, and enjoyable boating. In addition, the proposed standard of care is predicated on reducing risks in recreational boating based on empirical accident and boating violation statistics.

Source:
North Carolina Wildlife Resources Commission
http://www.ncwildlife.org/

Table F.5 New York Boating Laws and Regulations

Do you need New York Boating education?

New York:

- You need education in New York if you are at least 14 years old and will be operating a PWC or if you are at least 10 years old and born on or after May 1, 1996, will be unaccompanied, and will be operating another type of vessel.
- You must be at least 10 years old to take this online course.
- You do not have to be a resident of New York to take this online course.

Elsewhere:

- Boating education is currently required in several U.S. states and Canadian provinces.

Age and Operator Restrictions

- A person at least 10 years old and born on or after May 1, 1996, may operate a recreational boat (other than a PWC) only if he or she:
  - Has passed a boating safety course approved by the New York State Office of Parks, Recreation and Historic Preservation and carries the New York State Boating Safety Certificate on board or…
  - Is accompanied on board by a person 18 years of age or older who either has a New York State Boating Safety Certificate on board or is not required to have a certificate.
- No person under the age of 14 may operate a PWC.
- New York State Parks Adventure License Program
  - After successfully completing this course, you can choose to have your certification noted, as an anchor icon, on your NY driver's license or other identification document issued by the Department of Motor Vehicles (DMV). The advantage is that you will no longer need to carry your boating safety certificate with you when boating, as long as you have your driver's license with you. For more information, go to New York's Adventure License webpage.

Enforcement

- New York law enforcement officers patrol the waterways to make your boating experience safe and pleasant. Cooperate with them by following the laws and guidelines.
- Carry the Card: Vessel operators who are required to have a Boater Education Card must carry the card on board the vessel and have it available for inspection by an enforcement officer.
- Penalty: Not carrying your Boater Education Card when one is required can result in a fine.

Is the Boating Card the same as the Boating License?

- The New York State Boating Safety Certificate is proof that you have successfully completed all of the components of an approved Boating safety course and allows you to operate on New York waters. The New York Adventure License program lets you choose to have your certification noted, as an anchor icon, on your NY driver's license or other identification document issued by the Department of Motor Vehicles (DMV).
- Even if not required by law to get the New York boating education card, many boaters take the boat safety course in order to save on their PWC or boat insurance.
- Do your part to make boating in New York an enjoyable pastime! Become an educated, responsible boater by completing the Boat New York course, and practice what you learn.

Reciprocity

- All states, territories, and provinces will recognize boating education cards that meet NASBLA requirements and Canadian Pleasure Craft Operator Cards that meet Transport Canada's requirements. (This is known as "reciprocity.")

New York-Approved Boating Course

- The New York Boat Ed Course is approved and accepted by the New York State Parks.

United States Coast Guard Recognized

- The New York Boat Ed Course is recognized by the United States Coast Guard as meeting the standards of the National Recreational Boating Safety Program.

- USCG Auxiliary Course Provider
    - Boat Ed is the only boater safety course provider that develops print materials on behalf of the U.S. Coast Guard Auxiliary, the uniformed, civilian volunteer arm of the United States Coast Guard.

NASBLA Approved

- The New York Boat Ed Course is approved by the U.S. Association of State Boating Law Administrators (NASBLA) and meets U.S. Boating Education Standards.
- NASBLA is a U.S. nonprofit organization that works to develop public policy for recreational boating safety. NASBLA represents the recreational boating authorities of all 50 states and the U.S. territories.
- The NASBLA standards are intended to prescribe the minimum body of knowledge necessary to effect safe, legal, and enjoyable boating. In addition, the proposed standard of care is predicated on reducing risks in recreational boating based on empirical accident and boating violation statistics.

Source:
New York State Parks
https://parks.ny.gov/recreation/boating/education.aspx