# 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.

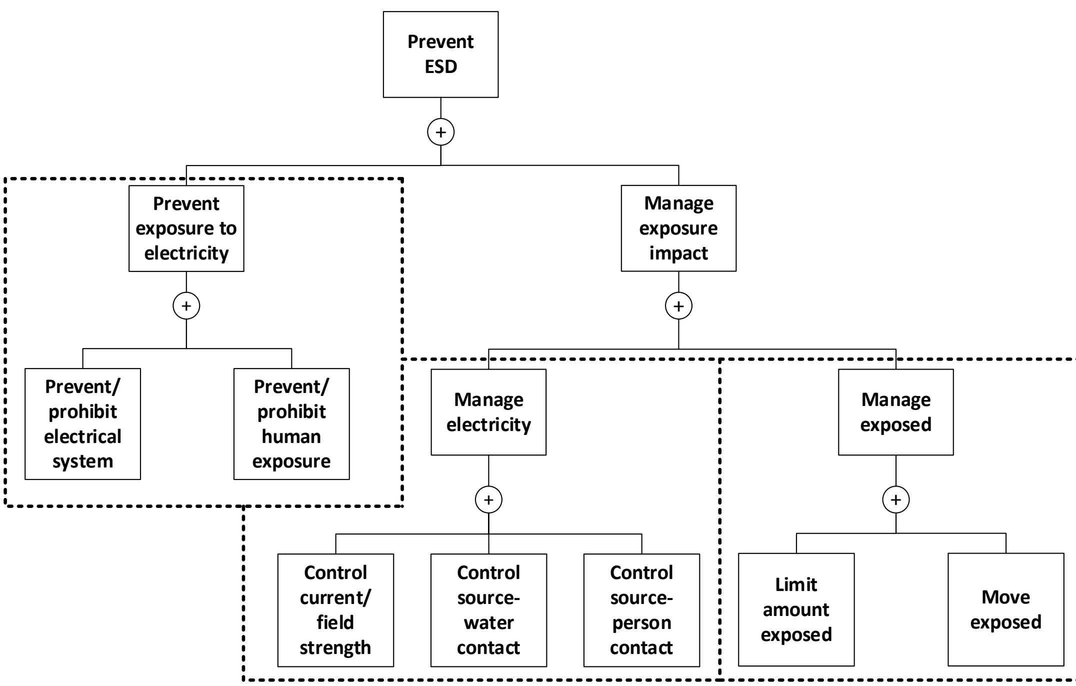


Figure 3.15 Top Level of ESD Concept Tree with Selected Lower-Tiered Gates.

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.

  - 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 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:

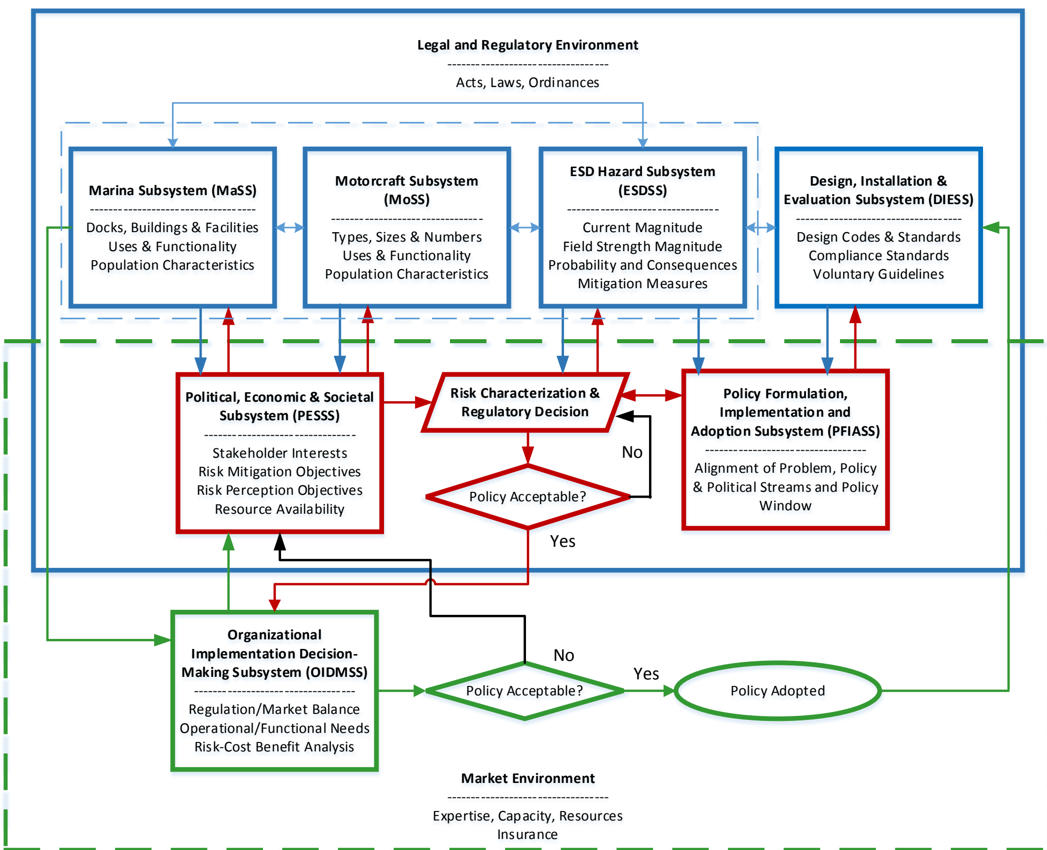


Figure 3.2 Marina-Motorcraft Regulatory System as a Socio-Technical System

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