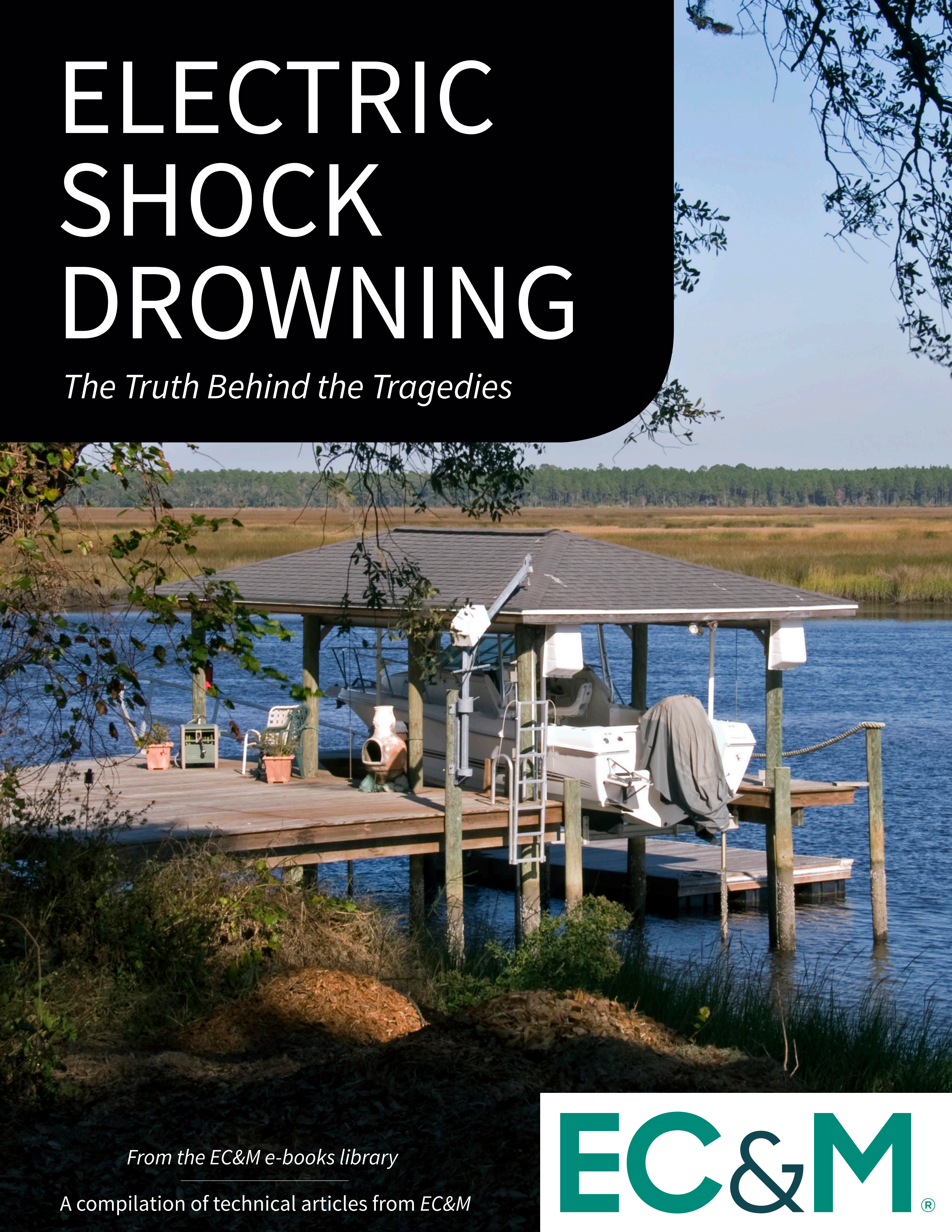

ELECTRIC SHOCK DROWNING

The Truth Behind the Tragedies

From the EC&M e-books library

A compilation of technical articles from *EC&M*

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Welcome

According to the Electric Shock Drowning Prevention Association, electric shock drowning (ESD) is "the result of the passage of a typically low level AC current through the body with sufficient force to cause skeletal muscular paralysis, rendering the victim unable to help himself/herself, while immersed in fresh water, eventually resulting in drowning of the victim."

MIKE EBY
Senior Director of Content
EC&M

Whether it's a young adult electrocuted on a leisurely float trip down a river, a family electrocuted at a water park, or teenagers swimming off of a lake dock and ultimately receiving electric shocks that lead to drowning, all of these accidents involve a deadly mix of electricity and exposure to water. The content in this eBook includes some of the most highly read articles published in *EC&M* on this topic, discussing the technical issues behind the electrocutions, legislative reform, ground fault protection requirements, and the implementation of new inspection requirements for electrical work performed on docks and at marinas.

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What Lies Beneath

Electric shock drowning is an unseen danger in marinas and boatyards, but new legislation is beginning to turn the tide.

By Matthew Halverson, Contributing Writer

"The list on my site isn't current," David Rifkin says, "but I can send you an updated version." He's referring to a Microsoft Word document titled "Electric Shock Drowning Incident List," and as its name suggests, it's a somber affair.

May 20, 2013 – Grayson County, Ky. ... A 36-year-old man ... jumped into the water when [his] dog was having problems. Witnesses report the man's eyes rolled back, and he went under the water suddenly.

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. Officials said the dock was not protected by a GFCI as required.

The document continues on like this for 14 pages, documenting more than a hundred cases of adults and children who've died — or just barely escaped death — due to stray current that leaked into the water where they were swimming. Rifkin, a retired U.S. Navy captain, owns Quality Marine Services, a Jacksonville, Fla., consulting company that specializes in corrosion analysis at marinas. He's been scanning newspapers and running Google searches for years now, amassing this collection of stories to build a case for the dangers of what he calls "electric shock drowning" or ESD. Like the name suggests, ESD is a death in the water caused by electric shock. But it doesn't have to be the result of electrocution; even small amounts of current radiating from the metal hull of a boat with faulty wiring can be enough to cause a person's body to seize and prevent them from swimming to safety.

Of all the stories on Rifkin's list, there's one that hit him especially hard. "Like all of the others, it didn't have to happen," he says. "It shouldn't have happened." But it did, and he and a handful of others are working to make sure that something good can come of it.

Even small amounts of current radiating from the metal hull of a boat with faulty wiring can be enough to cause a person's body to seize and prevent them from swimming to safety.

Silent killer. At first, when the boys started screaming, their families thought they'd been stung by bees or bitten by snakes. It was 2:20 in the afternoon on July 4, 2012 — it seems so many of these incidents occur on a July 4 holiday, as summer boating season really gets underway — and 10-year-old Noah Dean Winstead and his 11-year-old friend, Nate Lynam, were swimming between two boats at the German Creek Marina in Grainger County, Tenn.

But as the adults caught sight of Noah Dean and Nate, struggling to keep their heads above water, it was obvious that their situation was much more dire. One after another, Nate's grandparents, parents, and a family friend jumped in to help, only to have their bodies seize up as well. It wasn't until another friend tripped a breaker on the boat that the adults' muscles relaxed, and they were able to make their way out of the water. For the boys, though, it was too late. Noah Dean died there at the dock; Nate died the following day.

The culprit? Frayed wiring on one of the boats energized its hull, sending lethal levels of current into the water. But an investigation by the state's Department of Commerce and Insurance found that the entire marina was rife with problems, including nearly two dozen instances of missing ground wires or the use of power meters not rated for a marine environment.

Fourth Judicial District Attorney General Jimmy Dunn chose not to press charges, though, opting instead to encourage the

TOPIC SPARKS ONLINE OPINION AND INTERACTION

What lies beneath the surface at more marinas and docks than inspectors can cite or industry experts want to admit is the potential for stray voltage flowing through water that stems from improper electrical installations — a silent killer that only waits to add the names of more victims to its list of casualties. So what can we do as a professional community to help eliminate electric shock drowning and electrocution tragedies and better protect the public? That was a question posed to *EC&M* readers recently on our new online discussion forum, *EC&M* Talk. Here's some opinion on the subject from active posters on the thread.

"You can't help stupid," says one reader, who noted that if you look at most of the technology products introduced into the code, such as GFCIs, AFCIs, smoke detectors, and CO_2 detectors, many people never get their property inspected or reviewed by professionals. He maintains that most of these issues could be reduced, if not eliminated altogether, if people just understood how it all fits together.

Another poster insists prevention is possible, but notes the problem stems from the fact that there are typically no warning signs that the danger exists. He says the only way to address these issues is to install a device that continuously monitors for dangerous voltage conditions and alerts people if and when they exist.

Part of the problem is that the local AHJ doesn't want and/or know what to do because of lack of guidance, notes another person. "NFPA 70 stops at the shore-side receptacle, while USCG invokes nothing relevant and helpful, and ABYC is focused elsewhere," he said. "That is, there is a regulatory gap." Although the Tennessee proposal to mandate GFCIs is a step, he says it won't by itself be sufficiently effective to reduce this risk closer to zero where it belongs. "Only by using isolation transformers fed from a GFCI branch circuit, together with continual leakage monitoring, AHJ initial inspection/approval and periodic inspection, etc., can the likelihood for the numbers of such events be reduced to near zero."

German Creek Marina and others in the state to be proactive in searching for and correcting their electrical system deficiencies. "It is my sincere hope," Dunn said at the time, "that this tragedy will serve as a catalyst for education, regulation, and enforcement that will save the lives of others."

But for Noah Winstead's mother, Jessica, that wasn't enough.

Ongoing dilemma. The rules that cover the installation of wiring and equipment in marinas and boatyards can be found in Art. 555 of the 2014 National Electrical Code (NEC), and the methods prescribed for preventing deaths like those that occurred on July 4, 2012 are straightforward:

555.3 Ground Fault Protection. The main overcurrent protective device that feeds the marina shall have ground fault protection not exceeding 100mA. Ground fault protection of each individual branch or feeder circuit shall be permitted as a suitable alternative."

Additional electrical wiring and equipment requirements are outlined in Chapter 5 of NFPA 303, *Fire Protection Standard for Marinas and Boatyards*. As noted in this document's official scope summary, "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 is not intended to apply to a private, non-commercial docking facility constructed or occupied for the use of the owners or residents of the associated single-family dwelling."

RESEARCH PROJECT SEEKS OUT MITIGATION STRATEGIES

In mid-December 2013, The Fire Protection Research Foundation announced a project 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 project has been broken down into five key tasks.

Task 1: Review of Literature and Data Collection

Task 2: Identification of Available Technology

Task 3: Technology Assessment

Task 4: Recommended Approach

Task 5: Final Report

And yet, despite the obvious threat presented by the combination of electricity and water, it's not uncommon to find legacy systems at older marinas with little to no ground fault protection. "Commercial docks around here are a mess because they've been there forever," says Dave Russell, of Jet City Electric, near Seattle. Russell does the bulk of his work on residential docks around Lake Washington, sticking mainly to residential installations because the larger marinas can be so gnarly. "We've walked into places to check on them, and it's pretty scary stuff."

Bruce LaLonde, of LaLonde Electric in Estacada, Ore., overhauled a 20-year-old electrical system at a marina on the Columbia River in summer 2013, and although the existing system was still in working order, it was only a matter of time before it failed. "There was no GFCI protection at all," LaLonde says. "And they'd used

The biggest variable in any marina is the human element. System modifications, improper use of existing equipment — even something as simple as failure to use marine-rated extension cords — prove that no matter how conscientious a contractor is when installing an electrical system near water, accidents may happen.

all hard conduit, whereas the new methods call for flexible, marine-rated wire." The project ended up lasting the entire summer.

If the frequency with which electric shock drowning has occurred over the last decade is any indication, older marinas willing to take corrective measures before accidents happen are few and far between. In fact, getting someone to take the initiative to address the situation at all can be a challenge. Forensic Engineer James Angelo Ruggieri, P.E., of General Machine Corp, Fairfax, Va., has investigated dozens of electric shock drownings in his career, and one issue common to all of them was the difficulty in establishing fault because there is rarely a clear authority having jurisdiction. "The NEC is the generally recognized standard for residential construction, but it stops at the receptacle feeding the dock. Whatever happens after that is somebody else's

"The NEC is the generally recognized standard for residential construction, but it stops at the receptacle feeding the dock. Whatever happens after that is somebody else's jurisdiction."

jurisdiction." As such, he says, "You've got to widen the scope of the county's authority if they're going to be the enforcement authority. However, you also have to provide relevant code requirements for them to enforce."

Taking action. It was the knowledge that so many marinas are in such poor shape — and, therefore, that so many more children could still be at risk — that made it difficult for Jessica Winstead to settle for hoping that marina owners would do the right thing. Inspired by West Virginia's Michael Cunningham Act of 2013, which more or less took the NEC's rules regarding marinas and made them law, Winstead began lobbying the Tennessee state legislature for something similar — it was about that time that she met Rifkin.

Along with running Quality Marine Services, Rifkin also partners with Kevin Ritz on the Electric Shock Drowning Prevention Association, a 501(c)(3) they launched to bring awareness to the dangers of faulty wiring at docks and marinas. Ritz has become a nationally recognized expert on the subject, having spent the last 15 years — since his 8-year-old son died in an Oregon river — preaching the need for more stringent electrical safety practices on the water.

By 2013, Rifkin had read about Noah Dean and Nate and about Jessica Winstead's work in the legislature. Her efforts to prevent future deaths on the water were right in line with the nonprofit's goals, so he reached out to her and offered help in finding just the right verbiage for the bill. "The first drafts were very, very strict," Rifkin says. "So it was a matter of crafting the language in such a way that you would make marinas safer but not bludgeon the industry into submission to the point that they couldn't afford to operate."

In the end, the bill cribbed directly from the NEC's requirements, calling for ground fault protection not to exceed 100mA. However, it goes one step further: The legislation also goes so far as to mandate that all sources of electrical supply at marinas installed after April 1, 2015, be inspected annually. It's the punishments written into the law that give it its teeth, though: A violation of the ground fault rules discovered during an inspection will set a marina back $2,500. A violation that results in a serious but non-fatal injury costs up to $5,000 and six months in jail. And a violation that leads to death? Well, that's a $50,000 fine and as much as a year in jail.

The legislation also goes so far as to mandate that all sources of electrical supply at marinas installed after April 1, 2015, be inspected annually.

Once they had the wording down, it didn't take long for the bill to move through the legislature. With sponsorship from State Representatives Tilman Goins and Steve Southerland, the Noah Dean and Nate Act passed the state senate without a single vote in opposition on March 17, 2014. A month later, it passed the state house of representatives, 95-0. Governor Bill Haslam signed it into law on May 16, and it is set to take effect April 1, 2015.

And yet, there are those who feel that additional protective measures should be put in place to protect swimmers. Ruggieri, the former electrical engineering chief of the U.S. Coast Guard, doesn't believe that GFCIs alone can provide 100% certainty in preventing in-water shocks — citing multiple cases of electric shock drowning involving GFCI-protected branch circuits. "GFCIs are better than nothing, but they're not designed to address shocks in submerged applications," he says. "The reason being is that the cross-thoracic current required to cause a problem for someone in the water is lower than the targeted Class A GFCI time-current thresholds."

It's not often you'll find a law stricter than the technical requirements that inform it, which is why he believes the NFPA is doing swimmers a disservice by calling for GFCIs and leaving it at that. John Drengenberg, an electrical engineer and UL's Consumer Safety Director, concurs — but with reservations. Although he "supports the NEC wholeheartedly," he also acknowledges that GFCIs aren't necessarily sufficient for use near water. "You can't put a simple household GFCI in a marina and say it's going to work when somebody is submerged in the water," he says. "We don't have the data to show that that is, in fact, going to protect anybody." That said, he admits we can't say for sure that GFCIs *aren't* sufficient. "We just don't know at this point," he says. "We need more data."

Having dealt with the issue of ESD for much of his career, Ruggieri offers up an additional protective measure: isolation transformers at the shore-power stations fed from a GFCI-protected branch circuit feeder. Ruggieri says such a system provides a practical means with as close to zero as possible (aside from providing no AC power means) of causing an ESD incident.

Having dealt with the issue of ESD for much of his career, Ruggieri offers up an additional protective measure: isolation transformers at the shore-power stations fed from a GFCI-protected branch circuit feeder.

Isolation transformers can set a marina owner back upward of $500, but by Ruggieri's math, that's a small price to pay to ensure the safety of anyone swimming nearby — especially compared to the price of a boat or, for that matter, a wrongful death lawsuit. "While many believe that some legislation is better than no legislation, that's not true in this case," he says. "What will happen is that folks will come to believe that GFCIs will do the trick — that they are safe — and you will have more deaths."

Rifkin isn't swayed. "Some believe that if you can't solve the problem completely then do nothing," he says. "Put it this way: Reducing the speed limit to 1 mph will prevent 99.9% of traffic accident deaths. But is that to say that lowering it from 70 mph to 60 mph will have zero effect?"

Poised for change. Although this law's scope is obviously limited to just one state, the tide appears to be turning. There is, of course, West Virginia's Michael Cunningham Act, which passed in 2013, and efforts are underway in the Kentucky legislature to pass a similar bill, known as the Samantha Chipley Act. That means countless marinas will soon fall under the new regulations.

"Electric Shock Hazard Risk: No Swimming Within 100 Yards of the Boat Dock."

"If I was a contractor, I'd be sending all of the marinas a copy of this legislation," Rifkin says. "Then just spell it out: These are the specific electrical requirements, and they must be provided by somebody qualified. We can provide the services, and here's what our estimate would be to do your marina."

Even the annual inspection requirement opens up a host of opportunities. There's checking connections for tightness, corrosion, wear, and tear. There's checking the integrity of the grounding system and verifying that the ground fault protection — if there is any — is working properly. "It's tedious work," Rifkin says. "But you're going to find issues, and those issues will need to be repaired. It's like going to the doctor for a physical: He finds problems, and then he treats those problems."

Even in states without laws like the Noah Dean and Nate Act, there will always be plenty of chances to do things the right way. Dave Russell, of Jet City Electric, gets requests all the time to install outlets at the end of private docks that owners can plug their motorized jet ski lifts into. "Well, once you do that, then they can use it for something else," he says. Instead, he wires the lifts directly and makes sure they're GFCI-protected. "That way, it prevents them from going out there with extension cords and doing all kinds of crazy stuff."

In other words, there are things you can control and things you can't control. The biggest variable in any marina is the human element. System modifications, improper use of the existing equipment, even something as simple as the failure to use marine-rated extension cords — all of them prove that no matter how conscientious a contractor is when installing an electrical system near water, accidents happen.

That's why there's one other requirement in Tennessee's new law: the installation of signs in every marina stating "ELECTRIC SHOCK HAZARD RISK: NO SWIMMING WITHIN 100 YARDS OF THE BOAT DOCK." The signs were included in the bill as a concession to marina owners — warn boaters of the potential for danger in the water, the thinking goes, and you've reduced your own liability considerably — but it's also an acknowledgement of the simple fact that the only way to completely prevent electric shock drowning is to stay out of any water near electrical systems.

Rifkin's not naïve. Even with the Noah Dean and Nate Act in place, he'll continue to read newspapers and run his Google searches for stories to add to his electric shock drowning list, because this is just the first step. But it is a step, nonetheless. "Change is incremental," he says. "We can't get it all in one shot, but if we can change things a little, then we'll be better off than we were the previous year. And we will save lives. Maybe it's one, maybe it's a hundred. But we're better off than we were."

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The Case of the Floating Dock

Boy is electrocuted after severed ground wire and water buildup in junction box make for fatal electrical combination.

By John Cavallaro, P.E., Forensic Engineering, Inc.

What started out as a beautiful day at the lake quickly turned to tragedy for a grandfather and his grandson. The pair headed out to enjoy the warm waters of Lake Waccamaw, N.C., with the intention of playing under the dock in 3 ft of water. However, by raising the boat lift to allow more room, the grandfather inadvertently exposed a live 120V line to the hands of a child.

The scene. Lake Waccamaw is a beautiful lake with depths that average 6 ft to 10 ft in most places and 2 ft to 3 ft along the shoreline. Many lakefront owners have a long walkway leading out to a wooden dock. This particular covered dock, located about 200 ft out on the lake, contained a picnic table, barbecue grill, motorized boat lift, ceiling fans, and two staircases that descended down to the water's edge — overall, a very nice place to swim and enjoy the lake (**Photo 1**).

On this day, the grandfather/grandson duo decided to go swimming in the open area where a boat would have been located. Because he did not own a boat, the grandfather lifted the metal rails of the boat lift about 2 ft out of the

Photo 1. The boat dock on the far right is where the accident occurred. The wiring to the dock is routed on the opposite side of the walkway.

water, operating a 1-hp motor connected to a pulley system with metal cables. Normally, the grandfather let the rails sit in the water.

The accident. As they were enjoying themselves in the water, several neighbor children (ranging in age from eight to 13) decided to join them. Everyone gathered under the shade of the covered dock, in and around the raised metal boat lift and 3 ft of water (**Photo 2**).

Out of the corner of his eye, the grandfather noticed a child hanging and swinging from the metal rails. He immediately told the child to get off, which he did. A short time later, another child said he felt a tingle on his legs. Immediately dismissing this claim, the grandfather maintained this was not possible. The child, standing in the water and not touching anything, continued to insist he had felt a tingle. Perplexed, the grandfather cautiously walked up to the metal rails and touched them. Feeling an electric shock go up his arm, he advised the children to "Get out of the water, now!"

Everyone scrambled out of the water, climbing the nearest stairs onto the wooden deck surface. As the grandfather assessed the situation, standing near the lift controls, he looked down into the water and saw a child floating face down in the water. He called out to him, but did not get a response. Not knowing who the child was, he asked another child if he was playing a game. That child jumped into the water, raised the boy's head, and found him to be unconscious. The grandfather immediately brought the child to the deck's surface and administered CPR, while his wife dialed 911. When the emergency medical staff arrived, they couldn't revive the child, pronouncing him dead at the scene (cause of death was electrocution).

Photo 2. This image is of the boat lift assembly that was energized, with the metal rails visible, attached to the metal wires.

The investigation. After the tragic accident, the family of the deceased boy, as well as the grandfather (homeowner), wanted answers. How did this happen? Where did the voltage come from? How long had this situation existed? These and other questions were going through everyone's minds when my firm was called in to investigate this accident on behalf of the grandfather, who was being sued by the victim's family (who also sued the electrician).

Once at the scene, I started my investigation, logging data and interviewing the grandfather and grandmother. Based on this initial visit, I was able to ascertain several clues.

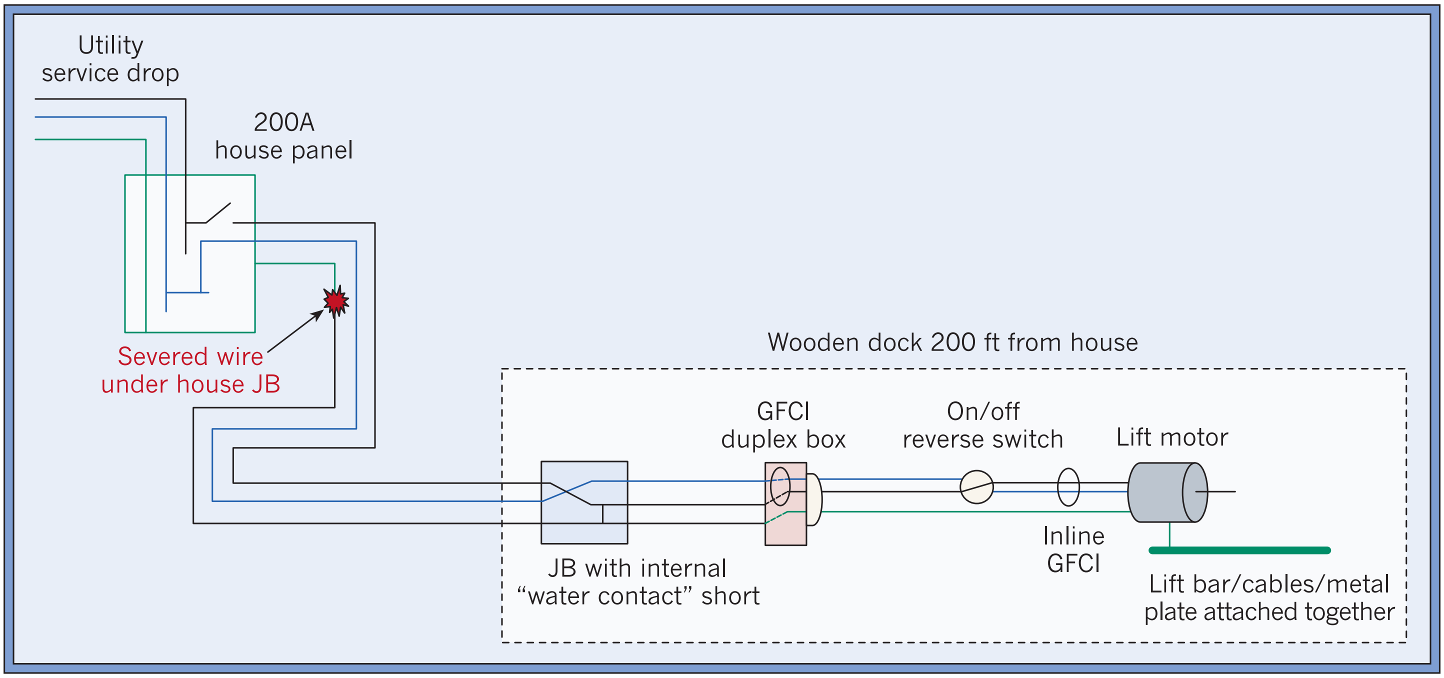

Fig. 1. This electrical schematic indicates the relative location of the severed wire under the house to the dock.

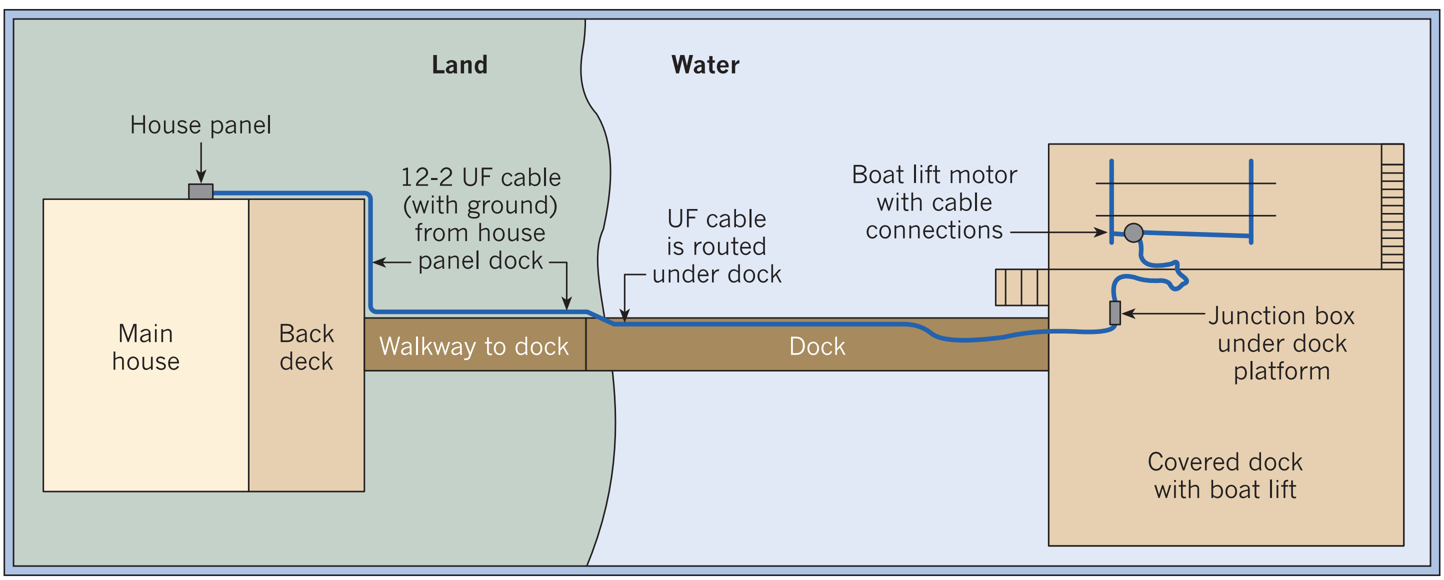

Fig. 2. Overhead view of the area allows you to see the full path of the electrical circuit.

The dock was fed by a UF (underground feeder cable) 12-2 rated cable with ground, which was routed from a junction box located in the house's crawl space (**Fig. 1** and **Fig. 2**). A UF cable is suitable for direct burial in the earth. A portion of the UF cable ran along the edge of a deck, exposed to the environment and foot traffic. Fed from a 20A circuit breaker at the main panel, a bare ground wire in the junction box appeared awkwardly twisted onto

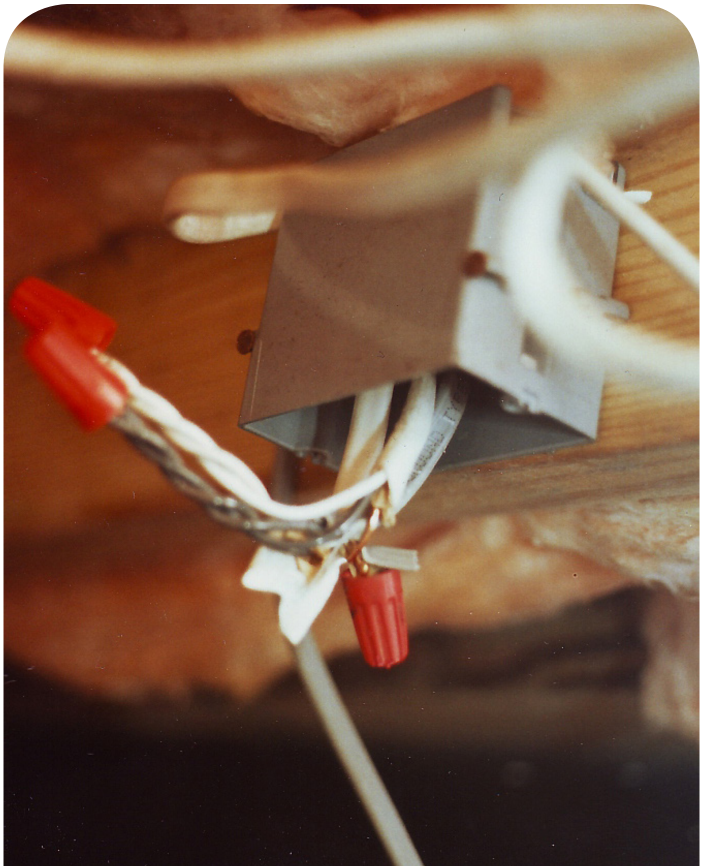

Photo 3. This image identifies the junction box found with the severed ground wire. Note the red wire-nut on the shortest wire, which is ground.

a shorter ground wire. I later learned from the town's electrical inspector that he had found this wire hanging out of the junction box, and it was severed at that point (**Photo 3**). Upon seeing this, he had reconnected it, to prevent any other ground issues.

The inspector stated that the dock was originally built without electricity, and whoever did the wiring never obtained an electrical permit. The grandfather recalled that a local contractor had completed the work, and did not recall if he had seen the permit (the dock had a certificate of occupancy but without electricity). I surmised there was no telling how long that ground wire had been severed.

The electrical inspector also informed me that he had located and opened a sealed standard plastic junction box under the wood dock and above the water line. He identified that the internal wires served the boat lift

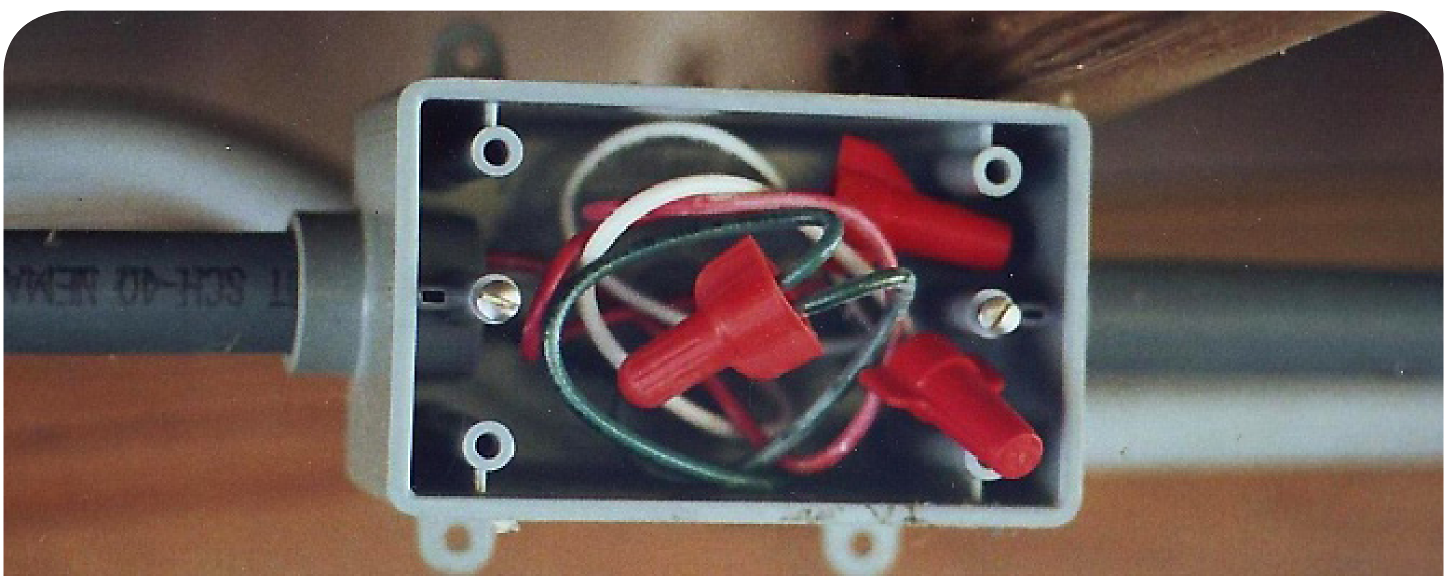

Photo 4. This image is of the under-deck plastic junction box with plastic conduits emerging on both sides. Water was released from the box when the inspector opened it.

motor and were spliced to the house wires with wire nuts. When he removed the cover screws, water poured out of the box. He identified that the ground (green) wire and the phase (black) wire of the 120V UF cable were on the bottom of the box. I noticed a line on the inside of the junction box, suspecting that this was identifying the water level inside the box, with the two wires clearly being below the line (**Photo 4** on page 15).

The house panel's circuit breaker for this circuit did not have a ground fault circuit interrupter (GFCI) as per the 1995-1998 NEC, Art. 555, Marina and Boatyards. I noted that the boat lift motor had two GFCI devices connected in series, in between the boat lift and the plastic junction box, located near the boat lift motor switch.

Photo 5. An image of the lift motor mounted on a metal plate, attached to the metal rod with the metal wires that are attached to the metal lift rods in Photo 2.

This made me ask myself: If there were two GFCI devices in series, how did the electricity get from the black (hot) wire to the metal rails of the boat lift? The motor casing was metal, and was directly attached to a metal plate, which was attached to metal cables supporting the metal rails. Therefore, an internal short in the motor's casing would energize everything back to the metal railings. Or maybe the two wires in the junction box below the water line were the source of the short. Either way, the severed ground wire under the house would not have allowed anything to flow back to the panel's ground bus.

A ground wire provides a safe return path to ground for any leakage or fault voltages. An internal motor short would result in tripping the circuit breaker, or leakage imbalance would trip the GFCI circuit. However, with the ground wire severed at the house, electricity could not flow on this wire. Therefore, there would not be a GFCI sensed voltage imbalance at the lift motor to trip the unit. Both GFCI circuits were on the up side of where the short to ground was located. Effectively, this said the GFCI became unusable as soon as the ground wire became severed.

If the GFCI circuitry was unusable, then the house circuit breaker was the only way for the electrical power to the motor to be interrupted from an overcurrent condition. But while not operating, there would be no current flowing for the house circuit breaker to trip.

Something else the grandfather said proved to be a useful clue in the case. Occasionally having a problem activating the boat lift, the grandfather said it had appeared sluggish to start and made buzzing noises in the past. This made me think that at these moments, the motor might not have been receiving sufficient voltage due to leakage into the lake; therefore, it could not turn the motor shaft to drive the boat lift.

I had to prove that the motor had an internal short to its casing, which would place 120V on the metal cabling and metal boat rails, or that the plastic junction box was filled with enough water to allow a conductive path between the black (hot) wire and the "floating" green (ground) wire. But how was I supposed to do this? The motor was hanging 15 ft to 20 ft over the water, with no means to place a ladder up to it and no way to prove that the water-filled plastic junction box was the conducive path (**Photo 5** on page 16).

The findings. I made a second trip back to the house and took along my digital meter and some hand tools. I decided that if I could prove or disprove one of the two possible causes, the answer would fall out. In order to examine the motor for an internal short, I disconnected the ground wire going from the house to the motor and then energized the motor via the power switch. I made a voltage measurement between the motor's ground wire and the ground wire going back to the house. I measured 0V, which told me that there was no voltage on the motor's casing. Therefore, the only other path would have to be through the water-filled plastic junction box, back to the motor's ground casing, and down the metal rails. No ground connection back at the house meant the metal rails remained energized until a grounding connection could be made somewhere.

Because the boat dock is made of wood, anyone standing on it would be isolated and would not receive a shock by touching the metal cables during normal boat lifting operation. This also was true if you were to stand inside a boat supported by the rails — a person would have to make direct contact between any metal and the water.

Unfortunately, when the boy hung from the rails with his feet in the water, he provided a direct path for current to flow.

When the grandfather lifted the rails out of the water, he disconnected the leakage path, allowing the electricity to remain on the rails. Unfortunately, when the boy hung from the rails with his feet in the water, he provided a direct path for current to flow.

However, how the water got into the gasketed, sealed, junction box remained somewhat of a mystery. The wiring feeding the junction box was encased in two plastic conduits, but they were not sealed from the outside humid environment, possibly accumulating condensation over time. The section routed toward the house stopped about halfway along its length. The other section was routed vertically partially up to the GFCI connector. Therefore, both ends were open to the elements.

Don’t assume that because you see a GFCI circuit interrupter in-circuit that you are protected from a ground fault.

I also noticed that the plastic junction box was located directly under a seam in the deck boards. If the cover was not sealed completely, its location would be ideal for water to drip into the box. Either way, it was likely that the internal water buildup took a long time, possibly starting from the first day that the uninspected wiring was installed.

The verdict. The final outcome of this case against the grandfather (my client) was settled out of court for an undisclosed amount. The outcome of litigation between the boy’s father and the electrician is unknown.

The recommendations. First of all, an electrical permit should have been obtained by the electrician. The inspection would have uncovered the missing GFCI at the house, and the connection under the house would have been installed to NEC regulations, preventing the severed wire. Eventually, water buildup in the plastic junction box would have tripped the GFCI. Then, the subsequent troubleshooting would have uncovered the problem and led to the fix, which sealed the conduits and the plastic junction box.

The quirky piece of this puzzle is that individually the severed ground wire and the water buildup would not have caused this fatality. But together, a dangerous electrical condition was lurking under the surface, waiting for someone to provide the grounding connection.

Lessons learned. Don’t assume that because you see a GFCI circuit interrupter in-circuit that you are protected from a ground fault. Always insist that anyone doing electrical work for you gets an electrical permit. Although this does cost money, in the end, the customer can rest assured knowing that a qualified electrical inspector will make sure the electrical installation is completed within the confines of the NEC.

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The Case of Stray Voltage in a Lake

Faulty concentric neutrals on high-voltage underground cables lead to one teenage swimmer's drowning and two others' brain injuries.

By Donald R. Johnson, P.E., Johnson Engineering

When six teenagers gathered at a friend's lake house to hang out for a casual evening, the group quickly decided to enjoy the cool night in an outdoor hot tub. When they'd had enough heat in the Jacuzzi, several of them decided it would be refreshing to run down to the homeowner's small dock and take a dip in the lake. Unaware of any underlying danger, the teens had no reason to believe their spontaneity would soon trigger an unthinkable tragedy.

The accident. After swimming near the dock for several minutes, the teenagers began to notice a strange sensation — what would later be identified as electric current flowing through their bodies. One boy, who experienced the phenomena, recalls being unable to swim, sinking in the water as he lost muscle control.

Seeing the swimmers' plight, the remaining teenagers standing on the dock called to the adults in the house for help. Several of them came running out, called 911, and dove into the water, trying to retrieve the kids who were underwater. (*Note*: It was determined later during testing that the currents in the water were intermittent, thus not causing any harm to the adults.) After multiple dives, the adults retrieved the two boys and one girl who had been submerged for some time.

CPR was immediately administered, until the paramedics arrived. At the hospital, one boy was pronounced dead (cause of death was drowning), and the other two received brain damage due to lack of oxygen caused by the near-drowning experience.

The investigation. After the accident, the first thought by many at the scene was that the dock wiring was somehow faulty, which, in turn, had caused the electric current to flow

Photo 1. After conducting a forensic investigation and analysis, the electrical engineering expert on this case determined that the dock wiring was not the cause of electric currents in the lake water.

through the water. Tasked with determining the cause of the electric current in the lake water, I was retained as a professional electrical engineer by the attorneys representing the plaintiffs (parties who filed suit against the electric utility and others).

After numerous investigations by myself and other experts, we concluded that the dock wiring was not the cause of the electric currents in the lake water (**Photo 1**). However, I later discovered that the electric utility had major corrosion problems with the bare concentric neutrals of its high-voltage underground cables, which were buried under and around the lake where the accident occurred. To get a better idea of what a cable with a good and bad concentric neutral looks like, see **Photo 2** on page 21. Although these shots come from another case — one in which the corroded neutrals caused a dairy farmer to lose many cows to disease/death as well as suffer significant loss of milk production in the remaining cows — they clearly demonstrate the difference between normal and deteriorated products.

Up to nine years prior to the accident, the electric utility realized through concentric neutral testing procedures that the bare concentric neutrals were in a serious state of deterioration throughout the lake area and housing subdivision around the lake. Despite this discovery, the electric utility did not take immediate steps to fix the problem. Instead, it began a multi-year program of replacing the bare concentric neutral cables with new jacketed concentric neutral cables in the area. However, due to difficulty in installing new cable in two particular sections of

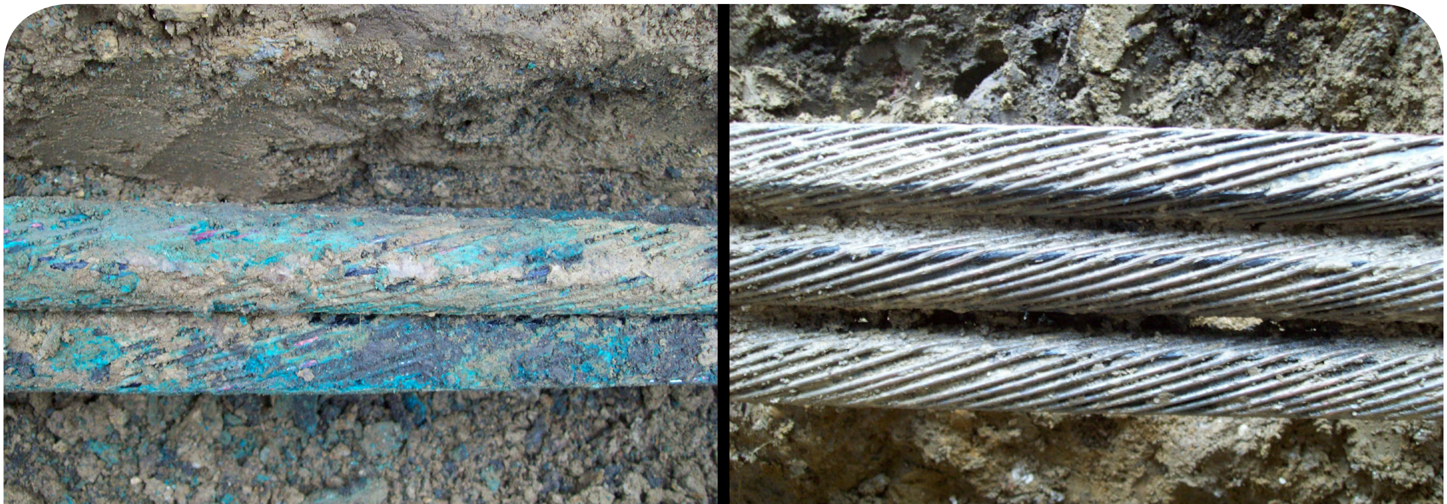

Photo 2. The images above show a badly corroded concentric neutral (left) as well as one that is in good shape (right). In the case of the bad neutral, you can see the extreme oxidation (green color) on the tin-coated copper strands.

underground cable under and around the lake, these sections were not replaced.

It turned out that these two particular sections of cable were the primary paths for the neutral current return for the entire lake area subdivision back to the electric utility substation source. This meant that the electrical load within the subdivision was essentially on an “island” in terms of an adequate return current path. Because of this island effect, the currents took the least-resistant path into the lake water heading to the dock — a structure that was more than adequately grounded to the electric utility system overhead neutral, which was then tied directly to the utility substation source.

To verify the above scenario, we completed numerous on-site tests. During one visit, we installed a recording multimeter at the dock where the accident occurred, leaving it to record for eight to 10 consecutive days. (The wiring to the dock was totally disconnected and removed during this time.) The voltages were recorded by placing a ground rod off the end of the dock into the lake water where one meter probe was attached. The other probe was attached to the house ground, which was, in turn, attached to the electric utility ground. A 500-ohm shunt resistor was included in the voltage measuring circuit. The currents were measured using the same technique without the 500-ohm resistor in the testing circuit.

The results of the testing indicated that both the voltage and current levels followed the electric loads of the utility in that the measured peaks were at the highest levels during the morning and evening hours. (*Note:* The accident occurred during the evening hours when electric loads were at their highest.) In addition, the frequency of all voltage and current measurements were measured at 60 Hz, a direct indication that the electric utility was the source of these measured voltages

UNWANTED VOLTAGE UNCOVERED

Stray voltage is a popular term resulting from electrical currents flowing through the earth or other conductive surfaces not normally expected to carry electric currents. Small amounts of electric currents traveling through the earth are prevalent throughout the nation, primarily due to electric utilities using the earth as a grounding medium for grounded wye distribution systems.

Even though these grounded wye systems feature a neutral conductor return current path — because the neutral conductor is grounded to the earth at multiple locations (as required by the National Electrical Safety Code) — the result is the earth acts as a parallel path for these currents. Typically, depending upon the conductivity of the earth and the amount of return neutral current on the electric distribution system, the amount of current flowing through the earth is small. However, as electric loads across the country continue to increase, these earth currents are increasing as well.

These earth currents became noticeable many years ago on dairy farms when farmers noticed a significantly higher mortality rate among dairy cows along with a major loss of milk production. The culprit was directly tied to the amount of earth currents flowing through the dairy facilities. Electric utilities across the nation have found out the hard way (through multi-million dollar lawsuits) that they must reduce these earth currents to non-damaging levels.

and currents. The highest currents measured during this test period reached 0.5A, and the highest voltage reached 6.2V.

During another site visit — with the electric utility present to allow access to its underground cable junction enclosures — numerous readings were conducted to measure the current on both the underground electric utility energized phase conductors and the concentric neutrals. Voltage measurements were also taken from the ground system in the enclosures to a remote ground. In one particular section (right near the lake), the neutral current on the concentric neutral was less than one-tenth of an ampere, whereas the energized phase current was in excess of 6A. Obviously, the remainder of the return current was flowing through the earth, and, in this case, the lake water. In addition, the voltage measured from these same junction enclosures was in excess of 7V to a remote ground test point. These measurements were a clear indication that the concentric neutrals on these underground sections were likely absent due to corrosion.

The findings. Using an assumed human body resistance of 300 ohms when immersed in fresh water — and assuming a current range through the human body where muscle control is lost in the range of 6mA to 30mA — and applying Ohm's law, the voltage necessary to cause a drowning in fresh water is in the range of 1.8V to 9V, 60 Hz AC. The above testing results show that the necessary voltage and current levels were at a level well within the range to cause the drowning and near-drowning of the victims.

After going to trial, a jury awarded the plaintiffs a total judgment of $2,325,000. No appeal was filed by the electric utility defendant.

Demonstrating the dramatic effects of stray voltage (**Unwanted Voltage Uncovered** on page 22) in a wet environment, this case serves as a reminder to all electric utilities about the importance of being vigilant in maintaining their distribution systems — in order to keep stray voltages at extremely low levels, levels that do not pose a danger to humans or animals. As electric loads continue to increase across the nation, many experts are even encouraging electric utilities to modify their distribution systems so that the earth is not used as a current-carrying medium.

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The Case of the Hot Marina

An inadequate grounding system on a docked boat leads to a rare form of electrocution that disguises itself as drowning.

By Jim Shafer, CAM Components/Harbor Marine Consultants

While enjoying the Memorial Day weather on the sundeck of their moored houseboat on a lake in the Southeast, a mother and her adult daugher decided to go for a brief swim to cool off. Aside from a couple splashes and a shout that the water was cold, neither woman gave any indication that anything was wrong, but as a second daughter prepared to follow them a short time later, she looked down and saw her mother floating face down near the swim ladder; her sister was nowhere to be seen.

The subsequent frantic efforts to resuscitate the mother were to no avail. Despite administering CPR, a witness was unable to save her. Rescuers found the daughter several minutes later more than 50 feet below the surface of the water, but it was too late to save her. The post mortem suggested both had drowned because neither body had suffered any physical trauma, but the surviving daughter reported that they were both good swimmers. What could have possibly happened?

Combining electricty and water always creates the potential for danger. If the grounding system at this marina had been working properly, these deaths could have been avoided.

As the investigation into their deaths continued, it became increasingly evident that the women were the victims of a phenomenon that has become known as electric shock drowning.

Dangerous currents. Electric shock drowning is often the result of a situation similar to a hair dryer falling into a bathtub; in these cases the hair dryer is a boat, and the bathtub is a lake. The cause is often an undetected ground fault that energizes the hull and causes a low-level current to flow through the swimmers, thereby disabling muscle function. It's referred to as electric shock drowning and not electrocution because there is no physical injury. The victims either lose muscle control if the current level is in the 0.01A to 0.02A range or suffer ventricular fibrillation at 0.05A to 0.06A current levels. Because victims typically show no sign of injury, many electric shock drownings are mislabeled as deaths attributable to alcohol intoxication or heart attack. Oftentimes, those drownings that are attributed to electric shock are classified that way because of circumstantial evidence like great distress, multiple deaths, and a tingling sensation reported by the survivors.

How does the hull become energized? What happens to the safety bonding system? American Boat and Yacht Council (ABYC) recommended practices require that the AC shore cord's green bonding wire be joined on a boat to the DC negative bus and the underwater gear bonding system. Should a fault develop on the boat, the fault current in the ground wire will initiate a breaker trip or at least prevent a potential (voltage) rise on the hull or underwater gear. However, there's no way to know if the ground wire is OK under normal operating conditions.

The grounding system in this dockside service panel was called into question in the investigation.

Current takes all paths back to the source, so even with a good ground system there still may be a small voltage rise on the hull as a fault establishes a parallel current path in the water. The boat may become lethal, however, if the ground return is damaged and located in fresh water.

Regardless of the size of the AC fault, the potential may rise to lethal levels as low as 15VAC. Even with a poor ground, a boat in salt water won't develop enough potential to cause a problem for a swimmer, making this an unheard of phenomenon with boats in the ocean. However, lakes are a different

The investigation revealed that the boat owner failed to connect the grounding (bonding) wire to the female plug, which ultimately led to an ineffective ground-fault return path.

story. Fresh water is a very poor conductor by comparison, so an ungrounded fault will raise the potential on the hull as it attempts to enter the water. A swimmer represents a much lower resistance fault path, even if only in the electric field and not touching anything.

The common elements in all of the accidents for which information is available always include a fault to ground below the breaker trip point, a high resistance or open ground, fresh water, and a swimmer near the faulted boat. Possibilities include:

• Neutral ground connections, open ground, reverse polarity.

• Motor or heating element insulation failure and open ground.

• Metal conduit on dock, not bonded and water soaked.

A preventable disaster. As more evidence was uncovered, the investigation into the deaths of the two women began to focus on the electrical system. On the day of the incident, the resort at which the boat was docked had put into service new power pedestals that required boat owners to use new shore power cords. The owner of the boat in question — and the husband and father of the two victims — had been working that morning on converting his existing Type SOW 600V power cord, which required nothing more than discarding the pig-tail adapter that had been used for the old service and plugging the cord into the new pedestal.

However, in making the conversion, he also altered the female plug connector at the boat. In doing so, he miswired the ground and hot wire, thus energizing the boat's aluminum hull, railing, and ladder. In addition,

Closer inspection showed that the boat owner connected a hot conductor to the ground connection.

the wiring within the boat had been altered. Additional circuits had been added, and the incoming power had been changed from 125V (as designed) to 125/250V, which had exceeded the listed rating of the houseboat's female receptacle.

Without complete GFCI or isolation transformer protection, the safety grounding system had to be intact to protect the boat.

The underwater metal hull of every boat in a marina is electrically connected through the shore power grounding system while moored. So while most of these accidents occur when both the fault and missing ground are on the boat, as was the case in this incident, the marina operator must ensure that his dock power system is in good condition. Sec. 3.21 of the NFPA 303 Fire Protection Standard for Marinas and Boatyards describes a visual inspection and a ground integrity test the marina operator should be aware of. Many don't even know this document exists. Lawsuits initiated in response to electric shock drownings have involved the marina operator at least to some extent if they weren't making the proper effort to comply with existing standards. It goes without saying that ignoring NFPA recommended practices increases the marina's exposure to liability.

The NFPA 303 ground integrity test should be conducted under load. One major manufacturer's test instrument locks the circuit momentarily to 15A and displays the ground impedance. Dock personnel can then log the readings for later review by an electrician.

Since most of the problems that cause these drownings originate on the boat — and many are generated by nonqualified workmanship — it may be necessary to implement around-the-clock monitoring of the marina shore power system to detect ground faults. Such a system is available and currently in use in nine marinas.

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