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BILGE PUMP SYSTEMS

Part I

SELECTION, INSTALLATION & USE

STORY AND PHOTOGRAPHY BY STEVE D'ANTONIO

In this installment of our two-part series on bilge pumps, we investigate the different types of pumps that are available, factors that influence their efficiency, calculating flow rates, and how pumps are affected by varying installations. In the next issue, we'll discuss electrical installation issues, manual and automatic switches, and methods of monitoring bilge pumps.

"The sound of the engine changed slightly, which made me glance at the instruments. The tachometer needle rested limply at the zero mark, and the voltmeter showed about 11 volts. If the boat was trying to get my attention, it had succeeded. I slowed to an idle, handed the helm to a shipmate, and went below to check the engine. When I opened the compartment, it was as humid and foggy as a London street, and a faint smell of burning electrical components permeated the air. There was obviously a leak; I could see that water had risen to the level of the engine's crankshaft pulley and flywheel and was being slung everywhere, including [into] the alternator, killing its charge capability and the tachometer output along with it."

The above excerpt, part of a missive sent to me by a client, graphically details the aftermath of a comparatively small leak caused by a failed stuffing box injection hose. I had been planning to write an article about bilge pumps for some time, and this note leant a new sense of urgency to the task.

When it comes to bilge pumps and their associated wiring and plumbing, many face a challenge that can be characterized as the "you don't know what you need until you *need* it" scenario. Though it may seem difficult, there is a way to avoid this problem. Like most systems-related tasks aboard a well-found cruising vessel, it simply requires a bit of planning and forethought.

PUMP VARIETIES AND THE MATH OF FLOODING

Before delving into the minutiae of the various types of bilge pumps that exist, a reality check is in order. Many cruisers are under the impression that a bilge pump is their first line of defense against catastrophic flooding. They believe, for instance, that if they strike that shipping container with their name on it or if they run aground, their trusty 2,000gph bilge pump(s) will stem the flow until they make it to the nearest boatyard or can effect adequate repairs. In truth, the rate at which water is likely to enter your boat makes this an unlikely possibility.

Consider these sobering figures, taken from my 2000 edition of the *U.S. Navy Salvor's Handbook:* A 1-inch hole 1 foot below the waterline will admit 1,200gph (that's more than 5 *tons* of water), a 3-inch hole 1 foot below the waterline will admit 10,620gph, a 1-inch hole 3 feet below the waterline will admit 2,040gph, and a 3-inch hole 3 feet below the waterline will admit 18,360gph. Add to these already frightening numbers the fact that, as water enters what the Navy calls the "hull envelope," the hole sinks farther below the surface, increasing the flooding rate. (To learn how to calculate flood rates, see the sidebar below.)

It's clear to see that even under the best of pumping circumstances—which virtually never exist aboard a boat, and I'll explain why below—most electric bilge pumps would have trouble keeping up with even the smallest hole.

TYPES OF PUMPS

Electric bilge pumps fall into three basic categories: rubber impeller, diaphragm, and centrifugal. Rubber impeller pumps can be discounted from the start. Whoever thought that this type of pump could be used effectively and reliably as a bilge pump probably spent too much time at a drafting table or in a marketing boardroom.

Rubber impeller pumps are self-priming, but beyond that, they have few positive attributes when pressed into service as bilge pumps. The problem with these pumps (which, incidentally, are the same type used to supply water to your engine and generator) is that they don't cope well with running dry for more than a minute or so, and often less. American Boat & Yacht Council requirements call for bilge pumps to be able to withstand dry running for seven hours without creating a fire hazard. This requirement really applies to the electric portion of the pump, and it's possible an impeller pump could run for this long without catching fire. However, it won't be of much use as a pump after operating this way for seven minutes, much less seven hours. Therefore, this style of pump is best avoided as a bilge pump.

Diaphragm pumps, in spite of the fact that they use rubber components, are much more resilient than rubber impeller pumps. The most familiar variety of diaphragm pump consists of an exposed crankshaft and connecting rod actuating a flexible diaphragm (most use a cogged belt, as well). The reciprocating motion of the diaphragm, coupled with two built-in check valves, creates suction, making it self-priming. The problem with diaphragm bilge pumps is their pitifully small capacity. In perusing a marine supply catalog on my bookshelf, the largest capacity diaphragm pump I could find moved a mere 600gph and cost over $500, or 83 cents per gph. That's not very cost effective compared with other kinds of bilge pumps.

Neither impeller pumps nor diaphragm pumps are submersible; they must be installed well above bilgewater or any other water accumulation or exposure. The final nail in the coffin for both flexible impeller and diaphragm pumps is their propensity to become clogged with debris

Debris is a bilge pump's worst enemy, and this is particularly true of diaphragm pumps. This fingernail clipping prevented the pump from operating.

HOW FAST WILL IT FLOOD?

If you want to figure out how much water will enter your boat through a hole of any given size at any given depth below the waterline, the formula is $Q = CA\sqrt{H}$, where Q is the flow rate, C is 8 (to measure flow in cubic feet per minute) or 3,600 (to measure flow rate in gallons per minute), A is the hole area in square feet (or any fraction thereof), and H is the depth of the center of the hole below the water's surface.

and then fail. These pumps, when used for bilge dewatering, must be equipped with an inline strainer or screen that, if clogged, will diminish or stop flow altogether. If debris makes its way into the pump, it's likely to have the same effect, because the check valves are particularly sensitive. I've seen diaphragm pumps fail as a result of ingesting a single fingernail clipping.

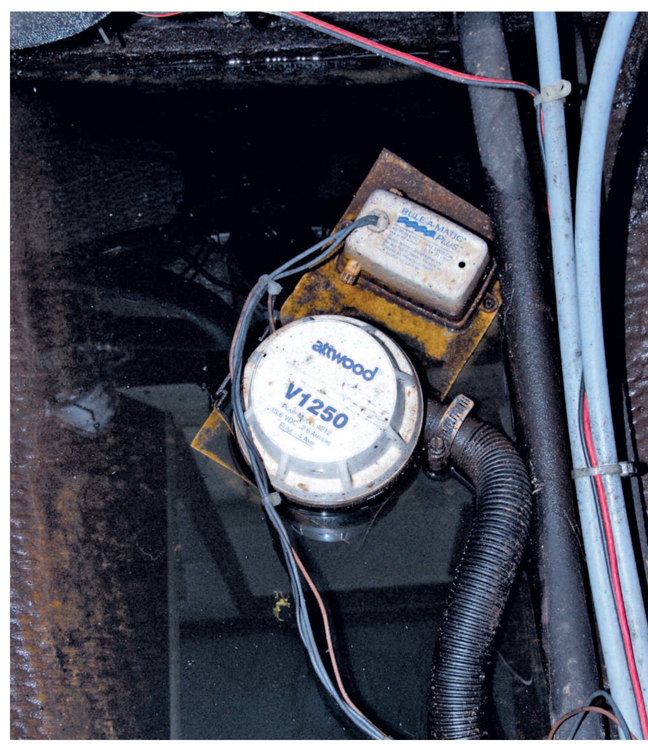
Keeping the bilge free of debris is a prerequisite for ensuring that your boat's bilge pump will run reliably and efficiently. Don't assume that a bilge is clean just because a vessel is new; this detritus was removed from a recently delivered boat.

Centrifugal bilge pumps are by far the most familiar and, generally speaking, the most effective for bilgewater removal. They operate by means of a rigid impeller that spins in a chamber, drawing water into its center and slinging it out the sides, where it is then channeled into a hose. This type of pump is submersible. In fact, this is one of the primary differences between centrifugal bilge pumps and the previous two kinds. A centrifugal bilge pump won't work unless it's submerged—it won't pump air, whereas the other pumps will. This makes its installation somewhat simpler; it has only one discharge hose, and the pump will be primed as long as it's submerged when it's actually pumping (the only time priming matters). The fact that the pump works while submerged raises the bar somewhat for its electrical and watertight integrity. The wire entry into the pump must be absolutely waterproof. Most manufacturers rise to this occasion with well-sealed housings and wire entries.

Centrifugal pumps can be further delineated into small and large varieties. The demarcation I establish between these two categories has more to do with the design or size of the pump body than with its capacity, although capacity is indirectly affected by the former. In small centrifugal pumps, or those whose rated capacity is at or below approximately 1,000gph, the impeller is closer to the bottom of the bilge, albeit only slightly. The effect is that smaller pumps typically are capable of removing more water from the bilge than are larger, 1,000gph-plus pumps. (They may not remove a greater volume, but they draw water to a lower level.) Larger pumps have larger impellers with higher intakes, which means they will start drawing in air at a higher water level. Once the intakes begin to suck air, the pump stops pumping.

Of course, the smaller centrifugal pumps can't remove water as quickly, but in most cases, that's not the issue. Keeping the bilge as dry as possible reduces odors and corrosion, so having less water sloshing around is always desirable. The dilemma is deciding whether you want to sacrifice overall pumping capacity for a drier bilge. Thankfully, you don't always have to make that choice. In many applications, you can use both a small "drying" pump and a larger, higher capacity pump. The small pump does the day-to-day water removal, while the large pump is triggered only when the small pump either can't keep up with the demand or fails.

In short, the submersible centrifugal pump represents the highest capacity, most reliable, most efficient method of removing water from the bilge. In addition, this type of pump offers the most pumping capacity for the cost. A



A fouled bilge, a low-budget bilge hose, and sloppy wiring add up to bilge pump unreliability. Bilge pump installations must be engineered well and with the greatest attention to detail, and they must incorporate the highest quality materials.

2,000gph pump costs about $100, or 5 cents per gph, which, when compared with the aforementioned diaphragm pump, is quite attractive.

EFFICIENCY

Regardless of the type of pump you choose, a variety of factors will influence its efficiency. It's important to note that most bilge pump manufacturers rate their pumps, or at least brand them, in what's known as open-flow capacity. This translates to the pump being rated for pumping water only—not through a hose and with no "lift." To be fair, it's probably the only way different pump manufacturers can rate their products on a level playing field. If some rated their pumps in real-world conditions of, say, pumping through 20 feet of hose out a bilge that's 5 feet deep and others did not, the results would be skewed. Most manufacturers do provide additional pumping capacities based on "heads" (more on this term later) of 3.3 and 6.7 feet (1 and 2 meters, respectively). The difference, however, may not be clear to the consumer who is simply seeking the highest "rated" capacity pump. The upshot is, when mulling over flood rates, don't conclude that a pump with an advertised 2,000gph capacity will keep up with that 1-inch hole that's 3 feet below the waterline, because it plainly will not.

The plumbing inefficiency alone that must be factored into any pump installation may be considerable. "Static head," or the height to which water must be raised from the bilge to reach the discharge point—including the highest point in the hose run—is among the most significant. Remember that, in many installations, the pump's outlet hose rises above the discharge. I'll discuss why this is so in a moment.

Let's use a 2,000gph pump as an example. (I repeatedly refer to this size pump, because it's the best-selling small centrifugal bilge pump in the world.) Its open-flow rating is, not surprisingly, 2,000gph. However, if the distance between the pump and the highest point in the hose run is increased to about 3.5 feet, the pump's revised flow is just 1,620gph, a 20 percent decrease in capacity. If the head is increased to 6.7 feet, the pump's output drops to 1,300gph. Neither of these scenarios takes into account resistance imparted by hose length or turns, pipefittings, or valves, collectively referred to as "dynamic head." I've made these calculations on a number of occasions, and the results are chilling. It's not unusual to find a pump's output reduced by half or, in some cases, almost completely. Nearly all submersible centrifugal pumps possess a maximum head against which they'll pump. Exceed it, and they simply will no longer work. Insidiously, this often will occur when voltage drops slightly. The pump will run and sound as if it's pumping; it won't trip a circuit breaker or blow a fuse, but it will not move any water. I've encountered this situation on several boats, some of them fresh from the factory. Just because a pump installation is new, don't necessarily assume it's correct.

Calculating static head is relatively easy, while calculating dynamic head is a bit more challenging. As far as I know, there's no "calculator" per se that takes into account hose friction as well as 90- and 45-degree turns, seacocks, vented loops, etc. A Google search of "total dynamic head" yields a variety of methods for determining head losses caused by pipe/hose friction, fittings, valves, and so forth. To the best of my knowledge, however, there is no one source for carrying out these calculations using materials and equipment found on small recreational boats.

If you care to do the research and calculations, in essence, all hose and pipe 90- and 45-degree bends and sweeps, plus valve friction losses, are simply converted to additional head. This figure, when added to static head, can then be compared to graphs of pump output versus head that are available from most pump manufacturers. Just to keep things interesting, water flow rate or velocity plays a role, too.

If you want to test your existing system, you can determine the time it takes to pump a known quantity of water from your bilge. You can do this by allowing your

It's important to remember that the labeling or "rating" of a bilge pump often has little to do with its actual pumping capacity. A variety of factors affect just how much water a pump can move, including wire size, hose diameter and length, installed valves, and bends and turns.

pump to clear the bilge of as much water as possible. Then, turn off the pump, pour a known quantity of water into the bilge (several 5-gallon bucketfuls, for example), turn on the pump, and time how long it takes the pump to remove the water. Some simple arithmetic will determine your pump's capacity in gallons per hour.

SELECTING A PUMP: HOW MUCH CAPACITY DO I NEED?

As discussed earlier, even large pumps will have a hard time keeping up with catastrophic flooding. Add to that the reality of static and dynamic head, and it's clear to see that most bilge pump installations are not capable of keeping a sinking vessel afloat unless the leak is a mere trickle. Nevertheless, it doesn't hurt to try to do everything you can to keep up with the water that is flooding into your boat, and in some cases, a few minutes can make a difference.

In the event of a flooding emergency, your primary mission is to reestablish the aforementioned watertight "hull envelope." A well-found bilge pump system may buy you the time to do this; it's essentially a two-pronged assault. The *Salvor's Handbook* emphasizes the importance of stemming the flow of water. These folks understand that pumps are for removing water once the flow has been halted, not for holding back the sea, stating, "If the situation allows, start watertight envelope restoration immediately. If restoration is delayed, a flooded casualty can be lost through loss of reserve buoyancy (causing sinking) or stability (causing capsizing). Focus initial watertight envelope restoration efforts on stopping and containing the flooding."

'Nuf said, right? The lesson here is: don't hit anything, and make sure your damage-control kit is well stocked and easily accessible.

With that established, no one would argue with the potential benefits of having more bilge pump capacity. As a bare minimum, the rule of thumb I've devised calls for 100gph of pump capacity for every 10 feet of overall boat length, rounding up to the nearest 10. Therefore, a 38-foot boat should have *at least* 4,000gph of pump capacity. Remember that this is a minimum. In all likelihood, your pump will contend with nothing more than the normal accumulation of bilgewater, particularly if it's handicapped by excessive head, as so many installations are. If you'd like to be prepared to deal with a serious leak—to buy those precious minutes that may enable you to stop or slow down the flooding—then this figure should be doubled.

The number of bilge pumps that you have is as important as their collective capacity. If, using the above formula, you installed one 4,000gph pump beneath the V-berth sole, you would meet the requirement. However, if your 2-inch propeller shaft separates from the transmission coupling and goes spinning out of the stuffing box as you back into your slip, the far-forward location of your lone pump will have sealed your fate. (The hole, by the way, will admit 136gpm, or 8,100gph, assuming it is 3 feet below the waterline, which means the pump will be able to handle only half the incoming water under perfect operating conditions.) The leaking water will drag the stern down, and even if water could flow forward to the pump, it would likely be impeded by bulkheads and stringers. Thus, the preferred approach is equipping your boat with multiple pumps—at least one in each compartment, say two 2,000gph models—even if they are smaller. The small "drying" pumps, if present, should be left out of this equation as a reserve.

Because I'm asked so frequently about the "engine as an emergency bilge pump" option, it's worth discussing here. This arrangement enables the engine's own raw-water pump, via an engine room selector valve, to be used as a bilge dewatering pump. The pumps used on moderately sized marine diesel engines move approximately 60gpm, or 3,600gph, at "high" rpm, which, initially, appears to be a fair quantity of water. The notion is, you already have this pump and it's already pumping water, so why not use it to save the boat in the event of catastrophic flooding?

There is one overarching reason *not* to take the engine-as-a-bilge-pump approach. In such an emergency, your best allies are a running engine (because it may be getting you closer to help or to a beach) and a fully charged battery bank (because it's enabling your electric pumps to operate at full capacity). If you allow your engine to draw water from the bilge and it loses prime, gets clogged from the inevitable flooding-induced flotsam, or sucks air, the impeller will melt almost instantly, and the exhaust system will turn to toast, often long before your engine's overheat alarm sounds. (It's interesting to note that melted or burned exhaust systems have accounted for more than a few sinking casualties.) The only way to avoid this situation is to station a crew member in the engine compartment so that he or she can switch the valve back to seawater intake if the bilge intake stops drawing water—a *Poseidon Adventure*-like job that I would not readily volunteer for aboard a sinking vessel.

Instead of potentially handicapping your vessel with such an arrangement, install an ultrahigh-capacity, submersible centrifugal electric bilge pump. Rule Industries (rule-industries.com) offers 3,700gph and 4,000gph pumps that are ideally suited for this role, and their output is roughly equal to that of most engines. If you're looking for the mother of all emergency bilge pumps, there's a tandem 8,000gph model. I installed one of these pumps once. Its discharge was located near the boat's waterline, and when the pump was activated, it shot out a 3-inch water column that acted like a water-jet bow thruster, moving the boat sideways as it pumped.

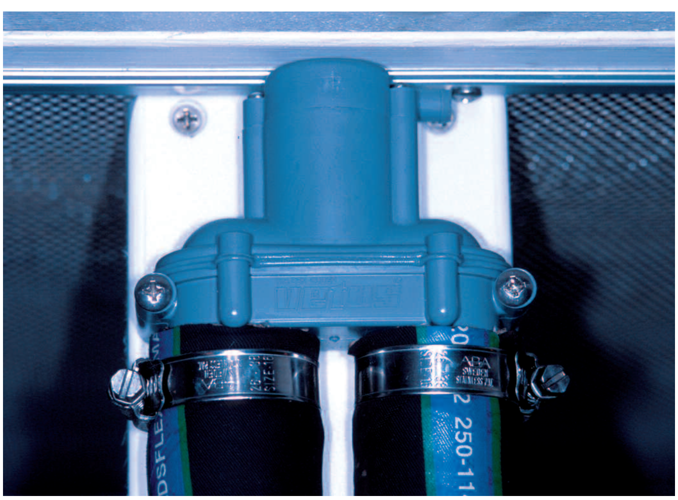
INSTALLATION

The key to obtaining maximum reliability and efficiency from a bilge pump is a proper, manufacturer-compliant installation. A bilge pump is not an appliance unto itself; it must be thought of as a component in a system. Therefore, you must look at the big picture, rather than just the pump itself. The system starts at the pump intake and electrical connections and ends at the overboard discharge.

Although this sounds obvious, care should be taken to install bilge pumps as low in the bilge as possible. Many vessels include a prepared pad for pump installation; however, in some cases, the pad is not in the lowest section of a bilge compartment when the vessel is afloat. The pump should be securely fastened to the hull, but avoid screwing the pump's base plate directly to the hull. I've seen more than one hole drilled all the way through the bottom of a boat, even though the installer was certain the hull was "very thick." The pump should rest on a perfectly flat surface (not necessarily level, although that's also desirable) to prevent the base from distorting when it's fastened in place. Distortion of the base is the number one cause of pumps releasing themselves from their mounts and drifting around the bilge. If a suitable or properly placed base pad does not exist, one can be epoxied in place. Because of its propensity to rot, avoid using wood for this component. My preference is for a solid fiberglass laminate product known as GPO or Garolite.

Choose your hose wisely. The familiar bilge pump hose of the black or white corrugated plastic variety is simply too delicate for use aboard seagoing vessels. It crushes and kinks at the mere hint of deformation and will spring lawn-sprinkler-like leaks if repeatedly stressed. Because of their propensity to trap debris and increase resistance, hoses with corrugated interiors also should be avoided. (Only use hoses whose interiors are completely smooth.) Ideally, your bilge pump hose should be kink resistant, and you should be able to step on it without crushing or damaging it. Several manufacturers offer dedicated bilge pump and "live well" hose that meets these criteria. Because it will be connected to a through-hull fitting that's likely to be located near the waterline, it is absolutely vital that the hose you select be specifically designed and rated for below-the-waterline applications.

The hose run between the pump and the overboard discharge fitting should be as short and as straight as possible. As a former marine mechanic, I realize that's easier said than done. However, the best effort should be made to keep hose length, as well as sharp bends, to a minimum. Also, avoid dips in the hose that will trap water; these can act as air locks, preventing the pump from establishing its initial pumping action. Ideally, the path taken by the hose from the pump to the discharge or riser should be a continuous, uphill run.



Left: An anti-siphon valve installation. It's imperative that the manufacturer's guidelines be followed during installation to ensure proper operation. If, for instance, the valve is not installed far enough above the vessel's waterline, it may not work properly. Right: Anti-siphon valves prevent potentially catastrophic flooding of a vessel that can occur when water siphons into the hull. This valve has been opened for service, exposing a small spring and rubber valve. These parts should be cleaned regularly.

Do not, under any circumstances, use a hose whose inside diameter is smaller than the outlet size of the pump. Many pumps possess outlets that require a hose with an inside diameter of 1-1/8 inches. That's an unusual hose size, to be sure, and one that tempts some installers to try to force the use of a 1-inch hose. At one time this transgression was forgivable, because the only 1-1/8 inch hose available was the aforementioned corrugated bilge pump hose. Today, that's no longer the case. Several manufacturers offer high quality hose in this once-rare size.

The through-hull discharge should be located above the maximum heeled waterline, and never below the resting waterline. (Bilge pump manufacturers typically call for the discharge to be installed a minimum of 12 inches above the waterline.) For power vessels, the maximum heeled waterline is defined at 7 degrees of heel; any fitting that's submerged on the low side of the boat when it is heeled 7 degrees is considered to be below the waterline.

If this installation condition cannot be met or if, for cosmetic reasons, a below-the-waterline discharge is desired, then the plumbing portion of the installation *must* include a "riser" (simply a hose loop) that is located well above the heeled waterline, as well as an anti-siphon device. A check valve is *not* considered an anti-siphon device and must not be used to prevent back flooding in the event that the discharge becomes submerged (which may occur when the vessel lists or rolls, or as a result of grounding or stranding). Furthermore, the use of check valves is prohibited by some pump manufacturers, and the ABYC specifically indicates in its *Standards & Technical Information Reports for Small Craft* that "a check valve shall not be used for this [siphoning prevention] purpose."

The reason for the concern is straightforward enough: check valves commonly become stuck in the open or closed position, both of which can have catastrophic results. Check valves also present a flow restriction; my own experiments indicate that check valves can reduce flow by as much as 50 percent. Additionally, if the valve is installed adjacent to the pump, the head of water that remains on its outlet side may be too great for the pump to overcome upon start up, effectively rendering it useless. The pump will run, but it will not pump water.

An acceptable anti-siphon device is one that admits air into the bilge pump discharge hose whenever a vacuum is present. This prevents siphoning from occurring. A variety of anti-siphon valves, sometimes called "siphon breaks" or "vented loops," are commercially available. Choose one that incorporates a replaceable or serviceable/cleanable valve assembly (the device that allows air to enter while preventing water from leaking out often uses a small rubber flap or spring-loaded ball). This component is prone to becoming encrusted with salt or debris, and as such it must be serviced at least annually. This service requirement holds true for *all* of your boat's anti-siphon valves, often found on engines and generators and in sanitation systems. It's important for you to know how many you have aboard and where they are located.

I once inspected a 60-foot cruising vessel that was equipped with a large, submersible electric bilge pump in each of its four bulkhead-separated compartments. At first glance, the arrangement seemed to meet or exceed the bilge pump rule of thumb, as the smallest pump possessed a 2,000gph capacity. Upon closer inspection, I discovered that three of the pump's discharges were routed to the bilge served by the fourth pump, and thus the effective pumping ability of the entire vessel's bilge pump system was limited to this one pump's capacity.

Pumping water from one compartment to another and then overboard is a bilge pump faux pas if ever there was one. Likewise, plumbing multiple pump outputs to a single manifold is also less than desirable if the manifold cannot support the full output capacity of all pumps operating simultaneously without imparting *any* restriction. Additionally, if the manifold arrangement requires check valves to prevent back flooding, then it's not only a liability but also in violation of American Boat & Yacht Council standards.

Ideally, each pump should be plumbed with its own overboard discharge hose, vented loop, and seacock if warranted. Until recently, ABYC guidelines called for the use of a seacock on any discharge installed below the heeled waterline, although this changed with the July 2008 revision of the Standards. Discharges within the 7-degree heel range now may use "reinforced piping or hose that resists kinking or collapse" in lieu of a seacock. My preference is for the pre-amendment protocol, which calls for the installation of an ABYC-compliant seacock on every hull penetration below the heeled waterline. (ABYC-compliant seacocks are capable of withstanding 500 lb. of static force applied to the inboard end of the assembly for 30 seconds.)

The manner in which a bilge pump is installed and plumbed will make or break its effectiveness. High-capacity pumps that are poorly installed are sure to offer a vessel owner only one thing: a false sense of security.

Steve owns and operates Steve D'Antonio Marine Consulting (stevedmarineconsulting.com), providing consulting services to boat buyers, owners, and the marine industry.