doesn't have to start for every glass of water. They work by squeezing a captive volume of air, since water doesn't compress. Pressure tanks are rated by their total volume. Draw-down volume—the amount of water that actually can be loaded into and withdrawn from the tank under ideal conditions—is typically about 40% of total volume. So a "20-gallon" pressure tank can really deliver only about 8 gallons before starting the pump to refill. Pressure tanks are one of the few things in life where bigger really is better. With a larger pressure tank, your pump doesn't have to start as often, it will use less power and live longer, your water pressure will be more stable, and if power fails, you'll have more pressurized water in storage to tide you over. Forty-gallon capacity is the minimum for residential use, and more is better.

Delivery Systems

A few lucky folks are able to collect and store their water high enough above the level of intended use that the delivery system will simply be a pipe or hose, and the weight of the water will supply the pressure free of charge. This is known as a gravity-fed system. (You need 46 vertical feet for 20 pounds per square inch. Said another way, for every foot the height of the water is above its destination, you gain 0.43 pounds per square inch of pressure.) For those using gravity to pressurize your water, avoid unnecessary constrictions in your distribution system that will reduce your pressure. For example, use full port valves that do not constrict to smaller interior diameters. (Search "full port valves" at HarvestingRainwater.com for more.) In addition, 1-inch-diameter pipe will give you better flow than smaller-diameter pipe in low-pressure situations. But most of us are going to need a pump, or two, to get the water up from underground and/or to provide pressure.

Water Conversions
1 gal. of water = 8.33 lb.
1 gal. of water = 231 cu. in.
1 cu. ft. of water = 62.4 lb.
1 cu. ft. of water = 7.48 gal.
1 acre ft. of water = 326,700 gal.
1 psi of water pressure = 2.31 ft. of head

We'll cover electrically driven solar and battery-powered pumping first, then water-powered and wind-powered pumps.

The standard rural utility-powered water system consists of a submersible pump in the well delivering water into a pressure tank in some location that's safe from freezing. A pressure tank extends the time between pumping cycles by saving up some pressurized water for delivery later. This system usually solves any freezing problems by placing the pump deep inside the well, and the pressure tank indoors. The disadvantage is that the pump must produce enough volume to keep up with any potential demand, or the pressure tank will be depleted and the pressure will drop dramatically. This requires a ⅓ hp pump minimally, and usually ½ hp or larger. Well drillers often will sell a much larger than necessary pump because it increases their profit and guarantees that no matter how many sprinklers you add in the future, you'll have sufficient water-delivery capacity. (And they don't have to pay your electric bill!) This is fine when you have large amounts of utility power available to meet heavy surge loads, but it's very costly to power with a renewable energy system because of the large equipment requirements. We try to work smarter and smaller while using less-expensive resources to get the job done.

Solar-powered Pumping

Where Efficiency Is Everything

PV modules are still not cheap, and water is still surprisingly heavy. These two facts define the solar-pumping industry. At 8.3 pounds per gallon, it takes a lot of energy to move water uphill. Anything we can do to wring a little more work out of every last watt of energy is going to make the system less expensive initially. Because of these economic realities, the solar-pumping industry tends to use the most efficient pumps available. For many applications, that means a positive-displacement type of pump. This class of pumps prevents the possibility of the water slipping from high-pressure areas to lower-pressure areas inside the pump. Positive-displacement pumps also ensure that even when running very slowly—such as when powered by a PV module under partial light conditions—water still will be pumped. As a general rule, positive-displacement pumps deliver four to five times the efficiency of centrifugal pumps, particularly when lifts over 60 feet are involved. Several varieties of positive-displacement pumps are commonly available. Diaphragm pumps, rotary-vane pumps, piston pumps, and the newest innovation, helical-rotor pumps, are all available from Real Goods.

Beware of Privatizing the Essence of Life

Just like air, water is precious and sustains all life on Earth. Increased demand for water by industry and agriculture is draining away the planet's rivers, lakes, and other freshwater sources. Meanwhile, a profit-driven industry increasingly controls our water supply. How we address the impending water crisis will have tremendous implications for people's health and the environment in the 21st century.

Though only a little less than 1% of Earth's water is available for human use, there is still more than enough fresh water to sustain every person on the planet—all 7 billion of us. Because of its essential, even sacred, role in life, many believe that water is a common resource to be shared by all.

In North America, most people receive water from a public utility. But not everyone in the world has access to the water they and their families need. The United Nations estimates that almost 800 million people lack access to safe drinking water. Hundreds of millions must walk miles every day to gather enough water to survive. The need to travel great distances to collect water is a leading reason that young girls are not able to attend school in many African countries. And 1.5 million children die every year of diseases caused by unsafe water. These situations are likely to worsen. According to the UN, by 2025 two-thirds of the world's population—more than 5 billion of us—will lack access to water and "could be under stress conditions." The World Bank has predicted that the wars of tomorrow will no longer be fought over oil but over water.

How is it possible that the water crisis could explode within a single generation?

There are many causes: the escalating use and abuse by water-intensive industries such as mining, paper production, and power generation; a growing population and an increasing need for irrigation; a spread of industrial pollution that fouls lakes and rivers, especially in developing countries; and spreading droughts induced by climate change. The World Bank estimates that rising temperatures and decreasing rainfall associated with climate change will reduce the amount of rain-fed farmland by approximately 10% within the lifetimes of today's children.

There's Huge Profit in Thirst

A limited water supply, coupled with the growing demand for water, is seen by corporations as a huge profit-making opportunity. *Fortune Magazine* maintains that "water will be to the 21st century what oil was to the 20th century," and corporations are racing to stake claims to this "liquid gold."

In fact, corporations have already been meeting behind closed doors for years, vying for control of the world's water resources. They have pushed officials at the World Bank and International Monetary Fund to make industry-friendly water policies a condition of debt assistance to developing countries. Water corporations have pushed trade ministers and officials at the World Trade Organization to craft industry-biased trade agreements. In March 2006, Coca-Cola sponsored the World Water Forum, where giant corporations met with representatives of the United Nations, governments, and the World Bank, to promote profit-oriented water policies around the world.

Nowhere is the corporate water grab more insidious than its escalating control of drinking water. Supplying water is already a $420-billion-a-year business. Throughout the world, powerful corporations are gaining control of public water systems, reducing a shared common resource into simply another opportunity to profit. For example, Suez—the corporation that built the Suez Canal—has recently been snatching up government contracts to take over municipal water systems.

And if controlling our taps were not enough, Coke, Pepsi, and Nestlé are bottling our water and selling it back to us at prices that are hundreds, even thousands, of times greater than what tap water costs. Today, water is one of the world's fastest-growing branded beverages.

Bottled Water: Is It Better?

In countries like the US, most water services are hidden from public view. We catch a glimpse of them when we turn on the shower or flush the toilet. Then they retreat into the background, and we go about our day.

Bottled water is an exception. Bottled water corporations aim to brand the water we drink and turn it into a status symbol. But these companies, led by Coke, Nestlé, and Pepsi, have sold us a bill of goods. Misleading advertising is fueling the explosive growth of the bottled water business. In 2005, bottled water corporations spent over $158 million to portray their products as "pure," "safe," "clean," "healthy," and superior to tap water. (Advertising for bottled water dropped to "only" $61 million in 2012.) Today, three out of four Americans drink bottled water, and one in five drinks *only* bottled water, even though it is much more expensive than tap water and can sometimes be less safe.

Water bottling is one of the least regulated industries in the US. Tap water and bottled water are subject to similar standards, but tap water is tested far more frequently and is more rigorously monitored and enforced by the EPA. In contrast, there are significant gaps in FDA regulation of bottled water, and the agency largely relies on the corporations to police themselves. A comprehensive study conducted by the Environmental Working Group in 2008 found that 10 popular brands of bottled water, purchased from grocery stores and other retailers in 9 states and the District of Columbia, contained 38 chemical pollutants, with an average of 8 contaminants in each brand.

People are paying a high price for this deception, and price gouging is only the beginning. Bottled water corporations use their political and economic clout to secure sweetheart deals, block legislative efforts to protect local water rights, and pursue costly and time-consuming litigation against individuals and governments.

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Communities Resist Privatization

Imagine that you live in a town where some of the wells are contaminated with elevated levels of naturally occurring radiation. The contamination is known to the managers of the corporate-controlled water system, who shut down the wells when government inspectors arrive to take water samples. Their deception discovered, the managers are fired, indicted, and replaced with new managers. Months later, you turn on the tap while entertaining guests for a Memorial Day picnic, only to find it dry. You call the water company, but your call is disconnected after 40 minutes on hold because no one at the private water company could be reached. Welcome to Toms River, New Jersey, where Suez controls the water system.

Imagine residing in a town where the local water has become unfit to drink. The private corporation that supplies tap water refuses to repair the water system or to connect to another source and instead provides 25 gallons of bottled water a week to each household. Welcome to San Jerardo, California.

Imagine a major US city that spends $1 million on a marketing campaign to boost people's confidence in the public water system, which is widely regarded as one of the highest-quality systems in the country. Then imagine opening the newspaper one day to discover that the city has simultaneously been spending $2 million to provide expensive bottled water for city workers. Welcome to San Francisco.

In Stanwood, Michigan, concerned citizens fought Nestlé for 10 years. Nestlé has drained tens of millions of gallons of water from local water sources and ecosystems, causing significant damage to the local environment—a stream, two lakes, and rich diverse wetlands have been harmed. A local environmental group, Michigan Citizens for Water Conservation (MCWC), won a major court victory in 2003 that shut down the well field where Nestlé bottled water. But Nestlé retaliated. The corporation used its political and financial leverage to appeal the ruling and won temporary permission to continue to extract and bottle 218 gallons of water per minute. The citizens group appealed the case to the Michigan Supreme Court and in 2009 an out-of-court settlement forced Nestlé to reduce its extraction rate by half. This is a victory for the environment, but it came at great cost and the corporation continues to put stress on local water resources.

The reality behind this industry's slick public relations and marketing is that bottled water threatens our health and our ecosystems, costs far more than tap water, and undermines local democratic control of a common resource. Bottled water corporations take water from underground springs and municipal sources without regard to scarcity or human rights. Corporations are trying to make a profit-driven commodity out of a public resource that should not be bought or sold.

Courtesy of Corporate Accountability International, whose "Think Outside the Bottle" campaign aims to educate the public about the dangers of corporate water privatization. For more information, visit StopCorporateAbuse.org.

Bottled water brands in North America owned by Nestlé:		
Acqua Panna	Ozarka	San Pellegrino
Arrowhead	Perrier	Trade Winds
Deer Park	Poland Spring	Zephyrhills
Ice Mountain	Resource	
Nestlé Pure Life	Sweet Leaf	

Bottled water brands in North America owned by Coca-Cola:		
Alhambra	Spring! by Dannon	Malvern Water
Aquarius Spring	Dasani	(Schweppes)
Ciel (Mexico)	Dasani Nutriwater	**Pepsi's big brand:**
Crystal	Evian	Aquafina

Centrifugal pumps are good for moving large volumes of water at relatively low pressure. As pressure rises, however, the water inside the centrifugal pump "slips" increasingly, until finally a pressure is reached at which no water is actually leaving the pump.

Positive-displacement pumps have some disadvantages. They tend to be noisier, as the water is expelled in lots of little spurts. They usually pump smaller volumes of water, they must start under full load, most require periodic maintenance, and most won't tolerate running dry. These are reasons that this class of pumps is not used more extensively in the AC-powered pumping industry.

Most AC-powered pumps are centrifugal types. This type of pump is preferred because of easy starting, low noise, smooth output, and minimal maintenance requirements. Centrifugal pumps are good for moving large volumes of water at relatively low pressure. As pressure rises, however, the water inside the centrifugal pump "slips" increasingly, until finally a pressure is reached at which no water is actually leaving the pump. This is 0% efficiency. Single-stage centrifugal pumps suffer at lifts over 60 feet. To manage higher lifts, as in a submersible well pump, multiple stages of centrifugal pump impellers are stacked up.

In the solar industry, centrifugal pumps are used for pool pumping and for some circulation duties in hot water systems. But in all applications where pressure exceeds 20 psi, you'll find us recommending the slightly noisier positive-displacement pumps, which require occasional maintenance but are vastly more efficient. For instance, an AC submersible pump running at 7%–10% efficiency is considered "good." The helical-rotor submersible pumps we promote run at close to 50% efficiency.

For Highest Efficiency, Run PV Direct

We often design solar pumping systems to run PV direct. That is, the pump is connected directly to the photovoltaic (PV) modules with no batteries involved in the system so that it pumps when the sun is shining, which is usually when it's most needed. The electrical-to-chemical conversion in a battery isn't 100% efficient. When we avoid batteries and deliver the energy directly to the pump, 20%–25% more water gets pumped. This kind of system is ideal when the water is being pumped into a large storage tank or is being used immediately for irrigation. It also saves the initial cost of the batteries, the maintenance and periodic replacement they require, and the charge controllers and the fusing/safety equipment that they demand. PV-direct pumping systems, which are designed to run all day long, make the most of your PV investment and help us get around the lower gallon-per-minute output of most positive-displacement pumps. Why make things more complicated if you don't have to?

However (every silver lining has its cloud), we like to use one piece of modern technology on PV-direct systems that isn't often found on battery-powered systems. A linear current booster, or LCB, is a solid-state marvel that will help get a PV-direct pump running earlier in the morning, keep it running later in the evening, and sometimes make running a possibility on hazy or cloudy days. An LCB will convert excess PV voltage into extra amperage when the modules

A Brief Glossary of Pump Jargon

Flow: The measure of a pump's capacity to move liquid volume. Given in gallons per hour (gph), gallons per minute (gpm), or liters per minute (Lpm).

Foot Valve: A check valve (one-way valve) with a strainer. Installed at the end of the pump intake line, it prevents loss of prime and keeps large debris from entering the pump.

Friction Loss: The loss in pressure due to friction of the water moving through a pipe. As flow rate increases and pipe diameter decreases, friction loss can result in significant flow and head loss.

Head: Two common uses: 1) the pressure or effective height a pump is capable of raising water; 2) the height a pump is actually raising the water in a particular installation.

Lift: Same as head. Contrary to the way this term sounds, pumps do not suck water, they push it.

Prime: A charge of water that fills the pump and the intake line, allowing pumping action to start. Centrifugal pumps will not self-prime. Positive-displacement pumps will usually self-prime if they have a free discharge—no pressure on the output.

Submersible Pump: A pump with a sealed motor assembly designed to be installed below the water surface. Most commonly used when the water level is more than 15 feet below the surface or when the pump must be protected from freezing.

Suction Lift: The difference between the source water level and the pump. Theoretical limit is 33 feet; practical limit is 10–15 feet. Suction lift capability of a pump decreases 1 foot for every 1,000 feet above sea level.

Surface Pump: Designed for pumping from surface water supplies such as springs, ponds, tanks, or shallow wells. The pump is mounted in a dry, weatherproof location less than 10–15 feet above the water surface. Surface pumps cannot be submerged and be expected to survive.

aren't producing quite enough current for the pump. The pump will run more slowly than if it had full power, but if a positive-displacement pump runs at all, it delivers water. LCBs will boost water delivery in most PV-direct systems by 20% or more, and we usually recommend a properly sized one with every system. It's well worth the small additional investment.

Direct Current (DC) Motors for Variable Power

Pumps that are designed for solar energy use DC electric motors. PV modules produce DC electricity, and all battery types store DC power. Direct current motors have the great advantage of accepting variable voltage input without distress. Common AC motors will overheat if supplied with low voltage. DC motors simply run slower when the voltage drops, slowing the flow of water but keeping it coming nonetheless. This makes them ideal partners for PV modules. Day and night, clouds and shadows; These all affect the PV output, and a DC motor simply "goes with the flow"!

Which Solar-powered Pump Do You Want?

That depends on what you're doing with it and what your climate is. We'll start with the most common and easiest choices and work our way through to the less common.

Pumping from a Well

Do you have a well that's cased with a 4-inch or larger pipe, and a static water level that is no more than 750 feet below the surface? Perfect. We carry several brands of proven DC-powered submersible pumps with a range of prices, lift, and volume capabilities. The SHURflo Solar Sub is the lowest-cost system with lift up to 230 feet and sufficient volume for most residential homesteads. The bigger helical-rotor-type sub pumps like the Grundfos and SunPumps are available in over a dozen models, with lifts up to 750 feet or volume over 25 gallons per minute, depending on the model. Performance, prices, and PV requirements can be found on our website, realgoods.com. The SHURflo Solar Sub is a diaphragm-type pump, and unlike almost any other submersible pump, it can tolerate running dry. The manufacturer says just don't let it run dry for more than a month or two! This feature makes this pump ideal for many low-output wells. One that we highly recommend is ITT Goulds' three-phase 240-volt AC submersible pump with an ABB reactor and variable frequency drive (VFD). It's a simple matter to invert the DC to AC, and this way you get an industrial-quality pump for less money than a Grundfos, which cannot be serviced if it fails prematurely, which does happen.

Complete submersible pumping systems—PV modules, mounting structure, LCB, and pump—range from $1,900 to $12,000 depending on lift and volume required. Options such as float switches that will automatically turn the pump on and off to keep a distant storage tank full are inexpensive and easy to add when using an LCB with remote control, as we recommend.

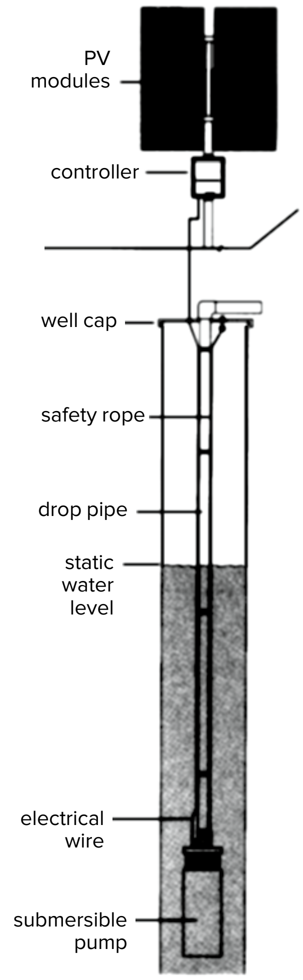
Because many solar pumps are designed to work all day at a slow but steady output, they won't keep up directly with average household fixtures, like your typical AC sub pump. This often requires some adjustment in how your water supply system is put together. For household use, we usually recommend the following, in order of cost and desirability:

- **Option 1.** Pumping into a storage tank at least 50 feet higher than the house (21 psi by gravity feed), if terrain and climate allow.
- **Option 2.** Pumping into a storage tank at house level, if climate allows, and using a booster pump to supply household pressure.
- **Option 3.** Pumping into a storage tank built into the basement for hard-freeze climates, and using a booster pump to supply household pressure.
- **Option 4.** Using battery power from your household renewable energy system to run the submersible pump, and using a big pressure tank (80 gallons minimum).

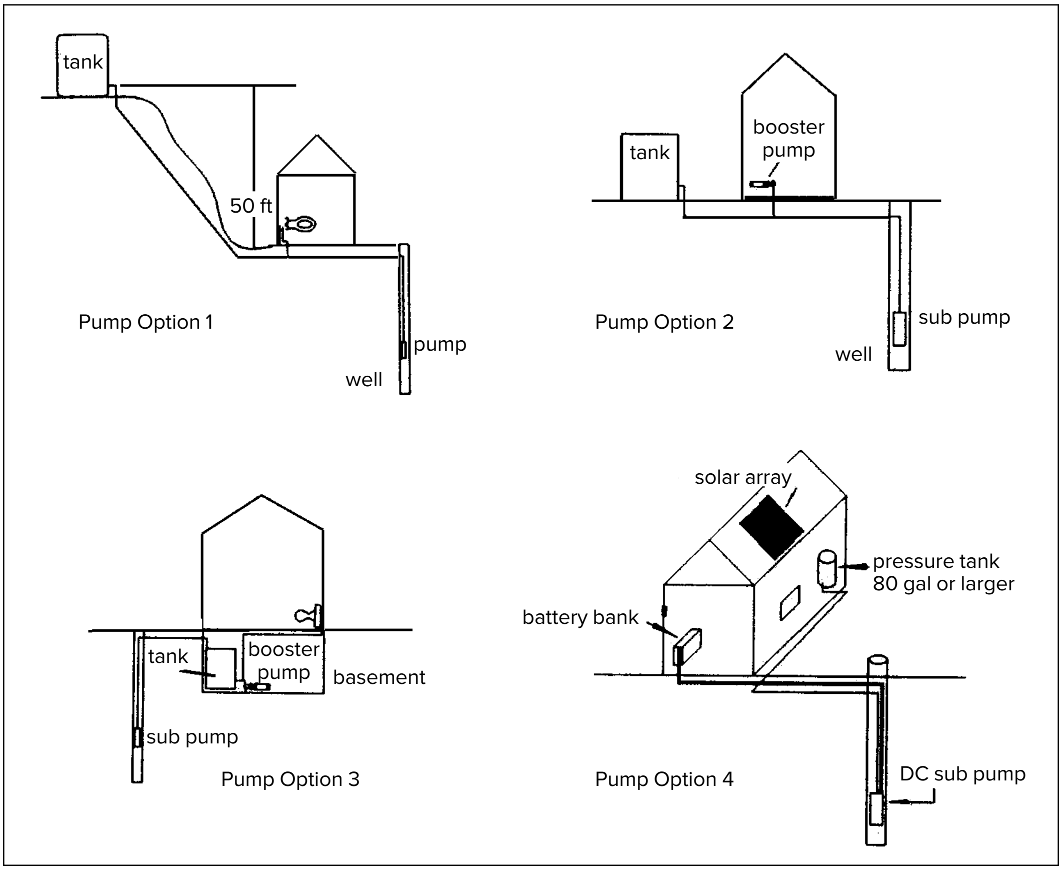
Q: Will Solar Pumps Run Only During Direct Sunlight?

A. No. While we often run pumping systems directly off solar electric modules without batteries, battery-based systems can be used for round-the-clock pumping. Direct pumping is usually the better option (approximately 20% more efficient), but this works only during sunny times of day. PV direct is usually the preferred power delivery if you're pumping to a storage tank, doing direct irrigation, or running the backyard fountain. A PV-direct pump controller often is needed to help start the pump earlier in the day, keep it running later in the afternoon, or make any pumping possible on cloudy days.

A simple PV-direct solar pumping system.



WATER DEVELOPMENT



- **Option 5.** Using a conventional AC-powered submersible pump, large pressure tank(s), and your household renewable energy system with large inverter. There is some loss of efficiency in this setup, but it's the standard way to get the job done in freezing climates, and your plumber won't have any problems understanding the system. We strongly recommend the variable frequency drive agricultural pumps, which have no start-up surge, similar power use to a DC pump per amount of water pumped and pressure, and are long-lasting. Start-up surge will be kind to your inverter, output is 5–9 gpm, and power use is a quarter that of conventional AC pumps.

Many folks, for a variety of reasons, already have an AC-powered submersible pump in their well when they come to us but are real tired of having to run the generator to get water. For wells with 6-inch and larger casings, it's usually possible to install both the existing AC pump and a submersible DC pump. If your AC pump is 4 inches in diameter, the DC pump can be installed underneath it. The cabling, safety rope, and ½-inch poly delivery pipe from the DC submersible will slip around the side of the AC pump sitting above it. Just slide both pumps down the hole together. The redundancy offers peace of mind and a little security for emergencies. It's often comforting to have backup for those times when you need it, like when it's been cloudy for three weeks straight, or the fire is coming up the hill and you want a lot of water fast!

Pumping from a Spring, Pond, or Other Surface Source

Your choices for pumping from ground level are a bit more varied, depending on how high you need to lift the water and how many gallons per minute you want. Surface-mounted pumps will not tolerate freezing temperatures. If you live in a freezing climate, make sure that your installation can be (and is!) completely drained before freezing weather sets in. If you need to pump through the hard-freeze season, we recommend a submersible pump as described above.

Pumps Don't Suck! (They Push)

Pumps don't like to pull water up from a source. Or, put simply, Real Goods' #1 Principle of Pumping: Pumps don't suck; pumps push. To operate reliably, your surface-mounted pump must be installed as close to the source as practical. In no case should the pump be more than 10 feet above the water level. With some positive-displacement pumps, higher suction lifts are possible but not recommended. You're simply begging for trouble. If you can get the pump closer to the source, such as the post for a pier or dock, for example, and still keep it dry and safe, do it! You'll be rewarded with more dependable service, longer pump life, more water delivery, and most importantly, less power consumption.

Low-cost Solutions

For modest lifts up to 50 or 60 feet and volumes of 1.5–3 gpm, we have found the SHURflo diaphragm-type pumps to be moderately priced and tolerant of abuses that would kill other pumps. They can tolerate silty water and sand without distress. They'll run dry for hours and hours without damage. But you get what you pay for. Life expectancy is usually two to five years, depending on how hard and how much the pump is working. Repairs in the field are easy, and disassembly is obvious. We carry a full stock of repair parts, but replacement motors don't cost much less than a new pump. Diaphragm pumps will tolerate sand, algae, and debris without damage, but these may stick in the internal check valves and reduce or stop output, necessitating disassembly to clean out the debris. Who needs the hassle? Filter your intake! Our customers love this pump, and people who don't mind doing periodic maintenance have used this low-cost solution for years.

Longer-life Solutions

For higher lifts, or more volume, we often go to a pump type called a rotary vane. Examples include the Slowpump and Flowlight Booster pumps. Rotary-vane pumps are capable of lifts up to 560 feet and volumes up to 5.59 gpm depending on the model. Of all the positive-displacement pumps, they are the quietest and smoothest. But they will not tolerate running dry, or abrasives of any kind in the water. It's very important to filter the input of these pumps with a 10-micron or finer filter in all applications. Rotary-vane pumps are very long-lived but will eventually require a pump head replacement or a rebuild.

Household Water Pressurization

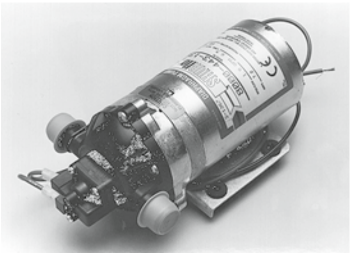
We promote two pumps that are commonly used to pressurize household water: The Chevy and Mercedes models, if you will.

The Chevy model. SHURflo's 5000 series is our best-selling pressure pump. It comes with a built-in 54 to 60 psi pressure switch. With a 5 gpm flow rate, it will keep up with most household fixtures, garden hoses excluded. The diaphragm pump is reliable and easy to repair, but it's somewhat noisy and has a limited life expectancy. We recommend 24-inch flexible plumbing connectors in a loop on both sides of this pump, and a pressure tank plumbed in as close as possible to absorb most of the buzz.

Need Pump Help?

If you would like the help of our technical staff in selecting an appropriate pump, controller, power source, etc., we have a Solar Water Supply Questionnaire at the end of this chapter. It will give our staff the information we need in order to thoroughly and accurately recommend a water supply system for you. You can mail, fax, or scan and email your completed form. Please give us a daytime phone number if at all possible! Call us at 888-567-6527.

The Mercedes model. Flowlight's rotary-vane pump is our smoothest, quietest, largest-volume pressure pump. It delivers 3–4.5 gpm at full pressure and is very long-lived but quite expensive initially. This pump will keep up easily with garden hoses, sprinklers, and any other normal household use. Brushes are externally replaceable and will last 5 to 10 years. Pump life expectancy is 15 to 20 years.


Diaphragm-type pump.

Any household pressure system requires a pressure tank. A 20-gallon tank is the minimum size we recommend for a small cabin; full-size houses usually have 40-gallon or larger tanks. Pressure tanks are big, bulky, and expensive to ship. Get one at your local hardware or building supply store.

Solar Hot Water Circulation

Most of the older solar hot water systems installed during the tax-credit heydays of the early 1980s used AC pumps with complex controllers and multiple temperature sensors at the collector, tank, plumbing, ambient air, etc. This kind of complexity allows too many opportunities for Murphy's Law.

The smarter solar hot water systems simply use a small PV panel wired directly to a DC pump. When the sun shines a little bit, producing a small amount of heat, the pump runs slowly. When the sun shines bright and hot, producing

Hot water circulation pump.

lots of heat, the pump runs fast. Very simple, since the pump only runs when it needs to without temperature sensors. System control is achieved with an absolute minimum of gadgetry or points of failure. We carry several hot water circulation pumps for systems of various sizes.

For solar hot water systems with long, convoluted collection loops creating a lot of pipe friction, we can use multiple pumps. If some amount of lift is involved, we have to look at more robust pumps like the Dankoff SunCentric series with high-temperature pump heads, which will require substantially more PV power.

Ram pump.

Swimming Pool Circulation

Yes, it's possible to live off the grid and still enjoy luxuries like a swimming pool. In fact, pool systems dovetail nicely with household systems in many climates. Houses generally require a minimum of PV energy during the summer because of the long daylight hours, yet the maximum of energy is available. By switching a number of PV modules to pool pumping in the summer, then back to battery charging in the winter, you get better utilization of resources. Currently we are recommending a high-quality AC variable frequency pump and controller (like the Pentair Intelliflo system) as the best choice for swimming pool circulation, whether on-grid or off. We've found customers to be unhappy with the quality of the available DC pool pumps.

Direct current pumps run somewhat more efficiently than AC pumps, so a slightly smaller DC pump can do the same amount of work as a larger AC pump. We also strongly recommend using a low-back-pressure cartridge-type pool filter. Diatomaceous earth filters are trouble. They have high back pressure and will greatly slow circulation or increase power use.

Ram-type water pumps use the energy of falling water to force a portion of that water up the hill to a storage tank.

Water-powered Pumps

A few lucky folks have access to an excess supply of falling water. This falling-water energy can be used to pump water. Both the High Lifter and ram-type water pumps use the energy of falling water to force a portion of that water up the hill to a storage tank. That's right, no PV necessary, just let gravity do the work for you.

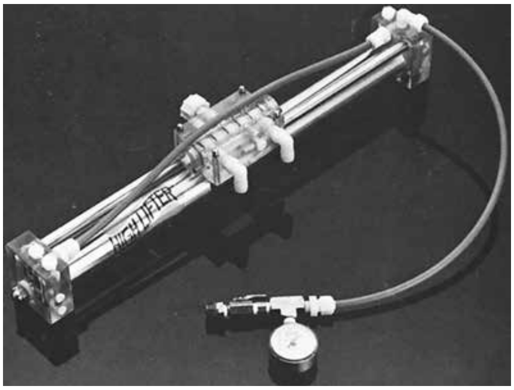
Ram Pumps

Ram pumps have been around for many decades, providing reliable water pumping at almost no cost. They are more commonly used in the eastern US, where modest falls and large flow rates are the norm, but they will work happily almost anyplace their minimum flow rate can be satisfied. Rams will work with a minimum of 1.5 feet to a maximum of about 20 feet of fall feeding the pump. Minimum flow rates depend on the pump size.

Here's how ram pumps work: A flow is started down the drive pipe and then shut off suddenly. The momentum of moving water slams to a stop, creating a pressure surge that sends a little squirt of water up the hill. How much of a squirt depends on the pump size, the amount of fall, and the amount of lift. (Our technical staff can provide you with pump output data.) Each ram needs to be tuned carefully for its particular site. Ram pumps are not self-starting. If they run short of water, they will stop pumping and simply dump incoming water, so don't buy too big. Rams make some noise—a lot less than a gasoline-powered pump, but the constant 24-hours-a-day chunk-chunk-chunk is a consideration for some sites. Ram pumps deliver less than 5% of the water that passes through them, and the discharge must go into an unpressurized storage tank or pond. But they work for free, and you can expect them to last for decades. If you're lucky enough to have a site with falling water, go for it!

The High Lifter Pump

This pump is unique. It works by simple mechanical advantage. A large piston at low water pressure pushes a smaller piston at higher water pressure. High Lifters recover a much greater percentage of the available water than ram pumps do, but they generally require greater fall into the pump. This makes them better suited for more mountainous territory. They are available in two ratios, 4.5:1 and 9:1. Fall-to-lift ratios and waste-



High Lifter pump.

water-to-pumped-water ratios are either 4.5:1, 9:1, or 22:1 (with 2,000 feet of net lift). Note, however, that as the lift ratio gets closer to theoretical maximum, the pump is going to slow down and deliver fewer gallons per day. High Lifters are self-starting. If they run out of water, they will simply stop and wait, or slow down to match what water is available. This is a very handy trait for unattended or difficult-to-attend sites. The only serious disadvantage of the High Lifter is wear caused by abrasives. O-rings are used to seal the pistons against the cylinder walls. Any abrasives in the water wear out the O-rings quickly, so filtering of the intake is strongly encouraged. High Lifter pumps can be overhauled fairly easily in the field, but the O-ring kit costs a lot more than filter cartridges. Output charts for this pump are included in the product section.

Selecting a Ram

Estimate amount of water available to operate the ram. This can be determined by the rate the source will fill a container. Make sure you've got more than enough water to satisfy the pump. If a ram runs short of water, it will stop pumping and simply dump all incoming water.

Estimate amount of fall available. The fall is the vertical distance between the surface of the water source and the selected ram site. Be sure the ram site has suitable drainage for the tailing water. Rams splash big-time when operating! Often a small stream can be dammed to provide the 1½ feet or more of head required to operate the ram.

Estimate amount of lift required. This is the vertical distance between the ram and the water storage tank or use point. The storage tank can be located on a hill or stand above the use point to provide pressurized water. Forty or 50 feet of water head will provide sufficient pressure for household or garden use.

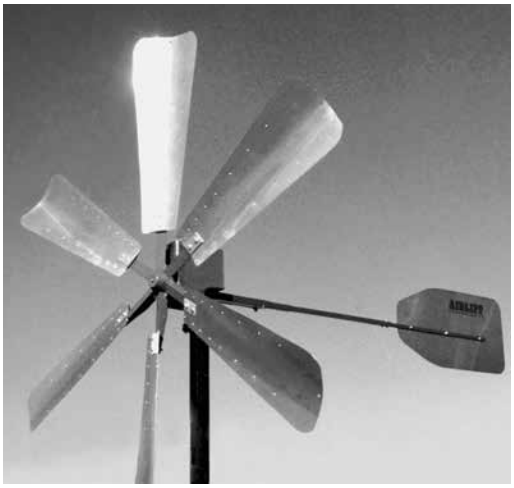
Estimate amount of water required at the storage tank. This is the water needed for your use in gallons per day. As examples, a normal two- or three-person household uses 100–300 gallons per day, or much less with conservation. A 20 × 100-foot garden uses about 50 gallons per day. When supplying potable water, purity of the source must be considered.

These estimates will help you figure out which ram to select. The ram installation will also require pouring a small concrete pad, a drive pipe 5 to 10 times as long as the vertical fall, an inlet strainer, and a delivery pipe to the storage tank or use point. These can be obtained from your local hardware or plumbing supply store. Further questions regarding suitability and selection of a ram for your application will be promptly answered by our technical staff.

High Lifters recover a much greater percentage of the available water than ram pumps do, but they generally require greater fall into the pump.

Wind-powered Water Pumps

If you've been reading this far because you want to buy a nostalgic old-time jack-pump windmill, we're going to disappoint you. They are still made but are very expensive, typically $3,000 and up. We don't sell them and don't recommend them. They are quite a big deal to set up and install into the well and require routine yearly service at the top of the tower. This is technology that largely has seen its day and is not worth the upkeep. Submersible pumps powered by PV panels are a much better choice for remote locations now.



Wind-powered pump.

There are a couple of effective ways to run a pump with wind power.

Compressed-air Water Pumps

Airlift pumps use compressed air. Three models are available, depending on lift and volume needs. They all use a simple pole-mounted turbine that direct-drives an air compressor with a wind turbine. The air is piped down the well and runs through a carefully engineered air injector. As it rises back up the supply tube, it carries slugs of water in between the bubbles. The lift/submergence ratio of this pump is fairly critical. Lift is the vertical rise between the standing water level in the well and your tank. Approximately 30% of the lift is the recommended distance for the air injector to be submerged below the standing level. As lifts edge over 200 feet, the submergence ratio rises to a maximum of 50%. Too little submergence and the air will separate from the water; too much and the air will not lift the water, though considerable latitude exists between these performance extremes. This pump isn't bothered by running dry. Output depends on wind speed, naturally, but the largest model is capable of over 20 gpm at lower lifts, or can lift a maximum of 315 feet. The air compressor requires an oil change once a year.

In most areas of the country, freezing is a major consideration when installing plumbing and water storage systems. For outside pipe runs, the general rule is to bury the plumbing below frost level.

Wind Generators Running Submersible Pumps

Some manufacturers offer wind generators that allow the three-phase turbine output to power a three-phase submersible pump directly. These aren't residential-scale systems and are mostly used for large agricultural projects, or village pumping systems in less industrialized countries. They are moderately expensive to buy. Contact our technical staff for more information on these options.

Freeze Protection

In most areas of the country, freezing is a major consideration when installing plumbing and water storage systems. For outside pipe runs, the general rule is to bury the plumbing below frost level. For large storage tanks, burial may not be feasible, unless you go with concrete. In moderate climatic zones, simply burying the bottom of the tank a foot or two along with the input/output piping is sufficient. In some locations, due to climate or lack of soil depth, outdoor storage tanks simply aren't feasible. In these situations, you can use a smaller storage tank built into a corner of the basement with a separate pressure-boosting pump, or you can pump directly into a large pressure-tank system.

The usual rule for sizing PV-direct arrays is to add about 20% to the pump wattage in a mild climate, or 30% in a hot climate.

Other Considerations and Common Questions

We hope that, by this point, you've zeroed in on a pump or pumps that seem to be applicable to your situation. If not, our technical staff will be happy to discuss your needs and recommend an appropriate pumping system—which may or may not be renewable-energy powered. Filling out the Solar Water Supply Questionnaire that follows will supply all the answers we're likely to need when we talk with you. At this point, another crop of questions usually appears, such as…

How Far Can I Put the Modules from the Pump?

Often the best water source will be deep in a heavily wooded ravine. It's important that your PV modules have clear, shadow-free access to the sun for as many hours as practical. Even a fist-size shadow will effectively turn off most PV modules. The hours of 10 AM to 2 PM are usually the minimum your modules want clear solar access, and if you can capture full sun from 9 AM to 3 PM, that's more power for you. If the pump is small, running off one or two modules, then distances up to 200 feet can be handled economically. Longer distances are always possible, especially when Linear Current Boosting MPPT pump controllers are installed, but consult with our tech staff or check out the wire-sizing formula on page 427 first, because longer distances require large (expensive!) wire. Many pumps routinely come as 24- or 48-volt units now, as the higher voltage makes long-distance transmission much easier. The Grundfos sub pump accepts DC input up to 300 volts. If you need to run more than 300 feet for sunshine, this may be just the ticket. Give us a call, and we'll make sure you're not selecting the wrong wire size and thereby depriving your pump of useful energy, wasted due to voltage drop.

What Size Wire Do I Need?

This depends on the distance and the amount of power you are trying to move. See the Wire Sizing Chart on page 427 and formula that can properly size wire for any distance, at any voltage, AC or DC. Or just give our tech staff a call—we do this kind of consultation all the time. Going down a well, 10-gauge copper submersible pump wire is the usual, although some of the larger sub pumps we're using now require 8-gauge, or even 6-gauge, for very deep wells. If you need anything other than common 10-gauge wire, we'll let you know.

What Size Pipe Do I Need?

Many of the pumps we offer have modest flow rates of 4 gpm or less. At this rate, it's okay to use smaller pipe sizes such as ¾ inch or 1 inch for pumping delivery without increasing friction loss. However, that's for pumping delivery only. There's no reason you can't use the same pipe to take the water up the hill to the storage tank and also bring it back down to the house or garden. Pipes don't care which way the water is flowing through them. But if you do this, you'll want a larger pipe to avoid friction loss and pressure drop when the higher flow rate of the household or garden fixtures comes into play. We usually recommend at least 1¼-inch pipe for household and garden use, and 2-inch for fire hose lines. See the pipe friction loss charts on page 245 to be sure.

What Size PV Modules Do I Need?

A number of the pumps Real Goods sells have accompanying performance and wattage tables. For instance, the Dankoff Solar Slowpump model 1403-24 lifting 440 feet will deliver 3.1 gpm and require 413 watts of PV. Because module ratings are based on ideal laboratory conditions, and you want your pump to work on hot or humid days, you should add 30% to the pump wattage. Heat reduces PV output; water vapor cuts available sunlight. So, in our example, we actually need 537 watts, which means buying two 280-watt modules. The usual rule for sizing PV-direct arrays is to add about 20% to the pump wattage in a mild climate, or 30% in a hot climate. And, of course, an LCB (linear current booster) of sufficient amperage capacity is practically standard equipment with any PV-direct system.

Can I Automate the System?

Absolutely! Life's little drudgeries should be automated at every opportunity. The LCBs that we so strongly recommend with all PV-direct systems help us in this task. These units are all supplied with wiring for a remote control option. This allows you to install a float switch at the holding tank, and a pair of tiny 18-gauge wires can be run as far as 5,000 feet back to the pump/controller/PV modules area. Float switches can be used either to pump to or pump from a holding tank and will automatically turn the system off when satisfied. The LCBs, float switches, and other pumping accessories can be found on our website, realgoods.com. LCBs can also be used on battery-powered systems when remote sensing and control would be handy.

Where Do We Go from Here?

If you haven't found all the answers to your remote water pumping needs yet, please give our experienced technical staff a call. They'll be happy to work with you to select the most appropriate pump, power source, and accessories for your needs. We run into situations occasionally where renewable energy sources and pumps simply may not be the best choice, and we'll let you know if that's the case. For 95% of the remote pumping scenarios, there is a simple, proven, cost-effective, long-lived renewable energy-powered solution, and we can help you develop it.

Water Pumping Truths and Tips

1. Pumps prefer to *push* water, not *pull* it. In fact, most pumps are limited to 10 or 15 feet of lift on the suction side. Mother Nature has a theoretical suction lift of 33.9 feet at sea level, but only if the pump could produce a perfect vacuum. Suction lift drops 1 foot with every 1,000 feet rise in elevation. To put it simply, **Pumps Don't Suck, They Push. Choose your pump location wisely!**
2. Water is heavy, 8.33 pounds per gallon. It can require tremendous amounts of energy to lift and move.
3. Direct current electric motors are generally more efficient than AC motors. If you have a choice, use a DC motor to pump your water. Not only can it be powered directly by solar modules, but your precious wattage will go further.
4. Positive-displacement pumps are far more efficient than centrifugal pumps. Most of our pumps are positive-displacement types. AC-powered submersibles, jet pumps, and booster pumps are centrifugal types.
5. As much as possible, we try to avoid batteries in pumping systems. When energy is run into and out of a battery, 25% is lost. It's more efficient to take energy directly from your PV modules and feed it right into the pump. At the end of the day, you'll end up with 25% more water in the tank.
6. One pound per square inch (psi) of water pressure equals 2.31 feet of lift, a handy equation.

Water-saving Showerheads

Showers typically account for 32% of home water use

A standard old-style showerhead uses about 3 to 5 gallons of water per minute, so even a five-minute shower can consume 25 gallons. Since the 1990s, all showerheads sold in the US must use 2.5 gpm or less. The average for the low-flows that we sell (realgoods.com), however, is even less, a highly efficient 1.4 gpm! According to the US Department of Energy, heating water is the second-largest residential energy user. With a low-flow showerhead, water use, energy use, and costs for heating water for showers may drop as much as 50%. A recent study showed that changing to a low-flow showerhead saved 27¢ worth of water and 51¢ of electricity per day for a family of four. So, besides being good for Earth, a low-flow showerhead will pay for itself in about two months! Add one of our instantaneous water heaters for even greater savings.

Solar Water Supply Questionnaire

To thoroughly and accurately recommend a water supply system, we need to know the following information about your system. Please fill out the form as completely as possible. Please give us a daytime phone number, too.

Name: ____________________

Address: ____________________

City: ____________________ State: ________ Zip: ____________

Email: ____________________ Phone: ______________

DESCRIBE YOUR WATER SOURCE

Depth of well: ________

Depth to standing water surface: ________

If level varies, how much? ____________

Estimated yield of well (gallons/minute): ________

Well casing size (inside diameter): ________

Any problems? (silt, sand, corrosives, etc.) ____________________

____

WATER REQUIREMENTS

Is this a year-round home? ________ How many people full-time? ________

Is house already plumbed? ________ Conventional flush toilets? ________

Residential gallons/day estimated: ________

Is gravity pressurization acceptable? ________

Hard-freezing climate? ________

Irrigation gallons/day estimated: ________ Which months? ______________

If you have a general budget in mind, how much? ____________

Do you have a deadline for completion? ____________________

DESCRIBE YOUR SITE

Elevation: ________

Distance from well to point of use: ________

Vertical rise or drop from top of well to point of use: ________

Can you install a storage tank higher than point of use? ________

How much higher? ________ How far away? ________

Complex terrain or multiple usage? ________ (Please enclose map)

Do you have utility power available? ________ How far away? ________

Can well pump be connected to nearby home power system? ________

How far? ________ Home power system power battery voltage: ________

Mail your completed questionnaire to:

Tech Staff/Water Supply, Real Goods, 13771 South Highway 101, Hopland, CA 95449.

Questions? Call us at 888-567-6527.

Real Goods' Homestead Plumbing Recommendations

Types of Pipe

Metals

Black iron and galvanized iron—used for gas (propane or natural gas) plumbing but little else. It is slow and difficult to cut and thread, and requires special, expensive tools. (Consider renting tools if needed.) A special plastic-coated iron pipe is used for buried gas lines. The insides of galvanized pipe corrode when used for water supply and eventually restrict water flow. Older houses often suffer from this affliction, which causes ultrasensitivity of shower temperature and other exciting problems.

Cast iron—used to be the material of choice for waste plumbing, but ABS plastic thankfully has replaced it. Simple conversion adapters to go from cast iron to ABS are available if you find yourself having to repair an existing older system.

Copper—the most common material for water supply plumbing in new home construction. Most plumbing codes require copper for indoor work. Type M, the most common grade for interior work, comes in 20-foot rigid lengths. Houses typically use ¾-inch lines for feeders and ½-inch lines for fixtures. If gravity-fed water pressure will be lower than the 20 to 40 psi city standard, consider increasing your supply pipes one size. This cures many low-pressure woes by eliminating pressure loss within the house (and provides a shower that's nearly immune to temperature fluctuations). The thicker-walled flexible tubing L and K grades can be used legally in some localities, but they generally cost considerably more. Copper does not tolerate freezing at all! Copper is relatively easy to work with, and you need only simple, inexpensive tools. Joints must be "sweat soldered," which takes about 10 minutes to learn and is kind of fun afterward. Be sure to use lead-free solders for water supply piping! Some states allow the use of flexible copper tubing for gas supply lines, in which case special compression-type fittings are used.

Bronze/Brass—beautiful stuff, but too expensive for common use. Pre-cut, pre-threaded nipples are used occasionally for dielectric water tank protection (5 inches of brass qualifies as protection under code). Use brass only where plumbing will be exposed and you want it to look nice.

Plastics

Poly (polyethylene)—this black, flexible pipe is used widely for drip and irrigation systems. Available in utility or domestic grades. Never use utility grade for drinking water! It's made with recycled plastics, and you don't know what will leach out. Poly is almost totally freeze-proof. It's easy to work with (when warm) and only requires common hand tools. It's sold in 100-foot or occasionally longer rolls. Barbed fittings and hose clamp fittings *will* leak (why do you suppose it's used in *drip* systems?). Do not use this cheap plumbing for any permanently pressurized installations, unless you can afford to throw water away. Poly also degrades fairly rapidly in sunlight. Two to three years is the usual unprotected lifespan. One good use for poly is with submersible well pumps where the flexibility makes for easy installations. Poly pipe is the usual choice for sub pumps unless they're pumping hundreds of feet of lift at very high pressure. Special 100 and 160 psi high-pressure versions of poly pipe are used for sub pumps.

PVC (polyvinyl chloride)—one of the wonders of chemistry that makes homesteading easy. This is the white plastic pipe that should be used for almost everything outside the house itself. It's easy to work with and requires only common hand tools (although if you're doing a lot of it, a PVC cutter is a real timesaver over the hacksaw). PVC usually can survive mild freezing. Hard freezes will break joints, however, so use protection. It comes in 20-foot lengths. Sizes 1 inch and up generally are available with bell ends, saving you the expense and extra gluing of couplings. Use primer (the purple stuff), then glue (the clear stuff) when assembling. PVC must be buried or protected. If exposed to sunlight, it will degrade slowly from the UV, but it will also grow algae inside the pipe!

PVC grades: Schedule 40 is the standard PVC that is recommended for most uses. Some lighter-duty agricultural types are available. Class 125, class 160, and class 200 are graded by the psi rating of the pipe. Don't use these cheaper thin-wall classes if you're burying the pipe! Leaks from stones pushing through thinner walls are too hard to find and fix.

CPVC (chlorinated polyvinyl chloride)—a PVC formulation specifically made for hot water. The fittings and the pipe are a light tan color so you can tell the difference from ordinary PVC. Some counties and states allow the use of CPVC; most don't. It works just like PVC.

ABS (acrylonitrile butadiene styrene)—a black rigid pipe universally used for unpressurized waste and vent plumbing. It's easy to work with, requires common hand tools, and glues up quickly just like PVC. Make sure that the glue you use is rated for ABS. Some glues are universal and will work on both PVC and ABS; others are specific. Buy a big can of ABS glue—these larger pipes use a lot more glue. Also, the bigger cans come with bigger swabs, which you'll need on larger pipe.

PB (polybutylene)—a flexible plastic pipe that is used occasionally for home plumbing, but mostly for radiant-floor heating systems. It requires special compression rings and tools for fittings. PB will survive considerable abuse during construction without springing leaks. It makes no reaction with concrete floors. PB is the best choice for radiant floors and has nearly infinite life expectancy when buried in concrete.

Try to arrange your house plan so that bathrooms, laundry room, and kitchen all fit back to back and can share a common plumbing wall. This saves thousands of dollars in materials costs, lots of time during construction, hours of time waiting for the hot water, and many gallons of expensive hot water.

Other Tips

Don't go small on supply piping. Long pipe runs from a supply tank up on the hill can produce substantial pressure drop. The typical garden needs 1¼-inch supply piping for watering and sprinklers. We recommend *at least* 1½-inch supply for most houses, and a 2-inch or larger line for a fire hose is often a very good idea.

Keep plumbing runs as short as possible. Try to arrange your house plan so that bathrooms, laundry room, and kitchen all fit back to back and can share a common plumbing wall. This saves thousands of dollars in materials costs, lots of time during construction, hours of time waiting for the hot water, and many gallons of expensive hot water.

Insulate *all* hot water pipes, even those inside interior walls before the walls are covered up. The savings and comfort over the life of the house quickly make up for the initial costs.

Store your glue cans upside down. This sounds wacky, but it works. Tighten the cap first, obviously. The glue seals any tiny air leaks and keeps all the glue inside and on the cap threads from drying solid. Don't store your primer upside down, though; it can't seal the tiny leaks and will disappear.

Friction Loss Charts for Water Pumping

How to Use Plumbing Friction Charts

If you try to push too much water through too small a pipe, you're going to get pipe friction. Don't worry, your pipes won't catch fire. But friction will make your pump work harder than it needs to, and it will reduce your available pressure at the outlets, so sprinklers and showers won't work very well. These charts can tell you if friction is going to be a problem. Here's how to use them:

PVC or black poly pipe? The rates vary, so first be sure you're looking at the chart for your type of supply pipe. Next, figure out how many gallons per minute you might need to move. For a normal house, 10–15 gpm is probably plenty. But gardens and hoses really add up. Give yourself about 5 gpm for each sprinkler or hose that might be running. Find your total (or something close to it) in the "Flow GPM" column. Read across to the column for your pipe diameter. This is how much pressure loss you'll suffer for every 100 feet of pipe. Smaller numbers are better.

Example: You need to pump or move 20 gpm through 500 feet of PVC between your storage tank and your house. Reading across, 1-inch pipe is obviously a problem. How about 1¼ inches? 9.7 psi times 5 (for your 500 feet) = 48.5 psi loss. Well, that won't work! With 1½-inch pipe, you'd lose 20 psi…still pretty bad. But with 2-inch pipe, you'd lose only 4 psi…ah! Happy garden sprinklers! Generally, you want to keep pressure losses under about 10 psi.

Friction Loss in PSI per 100 Feet of Scheduled 40 PVC Pipe								
Flow GPM	Nominal Pipe Diameter in Inches							
	½"	¾"	1"	1¼"	1½"	2"	3"	4"
1	3.3	0.5	0.1					
2	11.9	1.7	0.4	0.1				
3	25.3	3.5	0.9	0.3	0.1			
4	43.0	6.0	1.5	0.5	0.2	0.1		
5	65.0	9.0	2.2	0.7	0.3	0.1		
10		32.5	8.0	2.7	1.1	0.3		
15		68.9	17.0	5.7	2.4	0.6	0.1	
20			28.9	9.7	4.0	1.0	0.1	
30			61.2	20.6	8.5	2.1	0.3	0.1
40				35.1	14.5	3.6	0.5	0.1
50				53.1	21.8	5.4	0.7	0.2
60				74.4	30.6	7.5	1.0	.03
70					40.7	10.0	1.4	0.3
80					52.1	12.8	1.8	0.4
90					64.8	16.0	2.2	0.5
100					78.7	19.4	2.7	0.7
150						41.1	5.7	1.4
200						69.9	9.7	2.4
250							14.7	3.6
300							20.6	5.1
400							35.0	8.6

Friction Loss in PSI per 100 Feet of Polyethylene (PE) SDR-Pressure Rated Pipe								
Flow GPM	Nominal Pipe Diameter in Inches							
	½"	¾"	1"	1¼"	1½"	2"	2½"	3"
1	0.49	0.12	0.04	0.01				
2	1.76	0.45	0.14	0.04	0.02			
3	3.73	0.95	0.29	0.08	0.04	0.01		
4	**6.35**	1.62	0.50	0.13	0.06	0.02		
5	9.60	2.44	0.76	0.20	0.09	0.03		
6	13.46	3.43	1.06	0.28	0.13	0.04	0.02	
7	17.91	4.56	1.41	0.37	0.18	0.05	0.02	
8	22.93	**5.84**	1.80	0.47	0.22	0.07	0.03	
9		7.26	2.24	0.59	0.28	0.08	0.03	
10		8.82	2.73	0.72	0.34	0.10	0.04	0.01
12		12.37	**3.82**	1.01	0.48	0.14	0.06	0.02
14		16.46	5.08	1.34	0.63	0.19	0.08	0.03
16			6.51	1.71	0.81	0.24	0.10	0.04
18			8.10	2.13	1.01	0.30	0.13	0.04
20			9.84	2.59	1.22	0.36	0.15	0.05
22			11.74	**3.09**	1.46	0.43	0.18	0.06
24			13.79	3.63	1.72	0.51	0.21	0.07
26			16.00	4.21	1.99	0.59	0.25	0.09
28				4.83	2.28	0.68	0.29	0.10
30				5.49	**2.59**	0.77	0.32	0.11
35				7.31	3.45	1.02	0.43	0.15
40				9.36	4.42	1.31	0.55	0.19
45				11.64	5.50	1.63	0.69	0.24
50				14.14	6.68	**1.98**	0.83	0.29
55					7.97	2.36	0.85	0.35
60					9.36	2.78	1.17	0.41
65					10.36	3.22	1.36	0.47
70					12.46	3.69	**1.56**	0.54
75					14.16	4.20	1.77	0.61
80						4.73	1.99	0.69
85						5.29	2.23	0.77
90						5.88	2.48	0.86
95						6.50	2.74	0.95
100						7.15	3.01	**1.05**
150						15.15	6.38	2.22
200							10.87	3.78
300								8.01