

GUIDELINES ON

Rainwater Catchment Systems for Hawaii



College of Tropical Agriculture and Human Resources
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Important notice

Users of chemicals such as household bleach for water treatment do so at their own risk. Most of these products are not labeled for use in rainwater catchment systems. Use of a commercial product as a biocide for sanitation purposes is subject to the limitations, restrictions, precautions, and directions given on the product label.

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Patricia S. H. Macomber

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An estimated 30,000 to 60,000 people in the state of Hawaii are dependent on a rainwater catchment system for their water needs. The majority of those people are located on the island of Hawaii in the Puna, Kau, and Hamakua districts. With proper design, maintenance, and water treatment, a rainwater catchment system can provide water that is relatively free of contamination, soft, clear, and odorless; this water can be used for drinking, bathing, washing, flushing, laundry, and gardening.⁽¹⁾ But if the system is not properly designed and maintained, it can be a source of serious health risk and illness.

It is very important that those using water from a rainwater catchment system understand all of the potential dangers. In Hawaii, there are no government agencies overseeing the safety of your catchment system. It is up to you as the owner or user of the system to know how to maintain the water source and use it in a manner appropriate for yourself and your family.

This publication is for people who are building or maintaining a rainwater catchment system. It is intended to help them improve the quality of their water supply. While there are too many variables to make any system 100 percent safe, this publication should help you recognize problems, and it also suggests ways to minimize them. It starts with the premise that from the raindrop to your faucet, *the whole system* affects the quality of the

water you use. The information is organized into six sections, as follows:

- 1 Water collection—how to catch the water, how much water you need
- 2 Water storage—what to keep it in
- 3 Catchment system maintenance—identifying problems, keeping the tank clean
- 4 Water treatment—sources of water contamination, principles of water treatment
- 5 Water testing—keeping tabs on water quality
- 6 Firefighting concerns

Many people using a rainwater catchment system have never noticed a problem with their water system. This could be because they do not have any problems, but it may also be due to the fact that problems with water systems are not always obvious. Some problems may take years to show up, and then it is too late. Some people can be immune to many water-tank pathogens, or they may be infected but not show symptoms, but a visitor could drink the same water and become ill. Likewise, a healthy adult may not become ill, but an elderly person or an infant—people that are particularly susceptible to illnesses caused by contaminated water—could become deathly ill from drinking water from the same catchment system.

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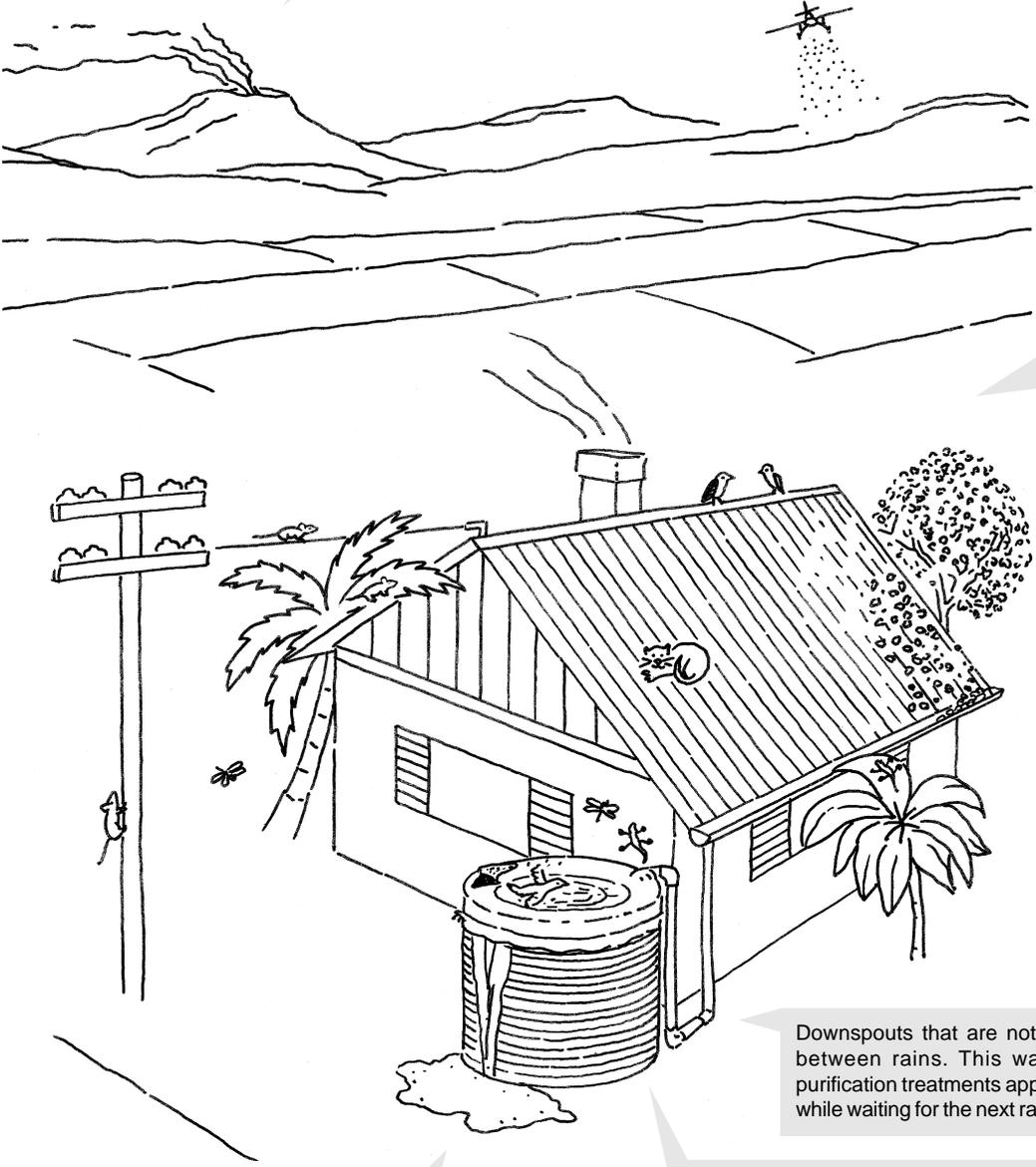
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Water pollution hazards for rainwater catchment systems

Many sources of pollution can affect rainwater catchment systems. A few of the contamination problems you need to consider when living on rainwater catchment are illustrated in this drawing. Few of these problems are insurmountable. With awareness, planning, and good catchment system management practices, your water supply can be improved.

Erupting volcanoes, fireplaces, and other sources of combustion produce smoke and fumes containing particulate matter that can land on your roof and wash into your water supply. Gasses from these sources also can combine with moisture in the atmosphere to produce acid rain.

Agricultural fields nearby can be sources of pesticide drift if sprays are applied incorrectly.



Trees and shrubs that touch or overhang the roof and gutters can cause several problems. Plant debris can block gutters and downspouts so water can't get to the tank. Decomposing organic materials provide nutrients for microorganisms and can taint the water so that its color and taste become unappealing. Plants also host insects, birds, and other animals whose wastes and corpses can contaminate your water supply. Rats in particular are a potential source of disease, and they are adept at getting onto roofs via branches and utility wires.

Downspouts that are not properly designed hold water between rains. This water is not affected by water purification treatments applied to the tank, and it stagnates while waiting for the next rain to flush it into the water supply.

Uncontrolled tank overflow can undermine a tank's foundations, resulting in eventual tank collapse. This runoff needs to be directed to avoid causing problems on your property or your neighbors'.

Birds delight in the baths formed by sagging mesh tank covers or blocked gutters. Many insects, particularly mosquitoes, find these pools perfect for breeding. Holes in the cover allow critters direct access to your stored water. Rodents and larger animals such as chickens and cats have fallen through holes in tank covers and drowned.

Section 1

Water Collection

Building materials

The key to choosing building materials for a rainwater catchment system is to select and use materials that will not leach toxins into the water under either normal or acid rain conditions. The material should be both non-toxic and inert (nonleaching). Acid rain, which is produced in Hawaii as rain mixes with volcanic emissions, causes certain metals and other materials to leach much more than normal rain would. The more acidic the rain at your location, the more likely you are to have a problem with chemicals leaching from materials the water touches.

Roofing

Ideally, only materials approved by the Food and Drug Administration or the National Sanitation Foundation would be used to catch drinking water. Unfortunately, no roofing materials have been approved for drinking water catchment use. The National Sanitation Foundation has approved epoxy coatings for drinking water use that can be painted over a surface, but these coatings are very expensive, have an effective life span of only about seven years, and were made for coating the interior of tanks rather than roofs and gutters.

The most common type of roofing material used for water catchment is galvanized metal that has been painted or enameled with a nontoxic paint. Other materials that could be used are concrete, terracotta tiles, slate, polycarbonate, and fiberglass.⁽²⁾ Paint used on the roofing material should not contain fungicides or other poisons that could leach into the water. Materials containing lead should not be used anywhere in the catchment system. Lead is a serious problem with older homes because not only the paint but also nails, flashings, sol-

ders, and gutters could contain lead. Lead-based paint was not manufactured in the United States after 1978, but these paints were still in circulation after that time, so if your home is an older home it would be wise to have the paint checked. Simple, inexpensive test kits can be purchased at local hardware stores to test paint or surfaces for lead. In addition to lead, avoid using roofs that contain uncovered zinc, asbestos (which used to be mixed with concrete tiles), tar, asphalt, or pesticide-treated wood.

With a new roof, always divert the first flush of rainfall away from the catchment system. The first rain will help flush away dust and debris such as metal shavings from the new building materials and keep these materials out of your tank. Also, new acrylic paint used on roofing and gutters can leach substances including detergent into your catchment water, which could cause the water to froth.⁽²⁾

In designing a roof for catchment purposes, keep its pitch relatively low to maximize the amount of water that gets into your gutter. A steep roof can cause water to splash out of the gutter.

Gutters

Like roofs, gutters should be made of inert materials. PVC or plastic gutters are the most common. Because gutters are not likely to be made of food-grade material, try to select materials that are as inert as possible. Be wary of colored materials that could contain toxic dye or fungicide.

When installing gutters, make sure that there is a *continuous downward slope* toward the catchment tank. Low areas that cause a backflow or puddling must not

be allowed. Standing water can collect insects, attract animals, and catch organic materials, such as leaves. Decaying organic material can ruin the taste and color of the water and cause health problems.

Screens

One method to keep large debris such as leaves out of your catchment system is to place screens over the gutters. The screens then have to be maintained to remove any build-up of debris that would block water from entering the gutter.

It has been suggested that screens be placed at an angle so that leaves and other things caught on the screens will slide off. However, most gutter systems have outer lips that are too high to accommodate such an angle. Various types of gutter netting and screening are available; some arch over the gutters, which allows greater access for water when leaves get caught around the sides, but these types still have to be cleaned regularly.

Some people block the downspouts with screens. This catches large debris, but like all other screens, regular cleaning is needed to prevent clogging. Most homes have multiple downspouts, so this cleaning may require a lot of effort. Before screening gutters or downspouts, decide if you are willing to clean the screens regularly, perhaps as often as every two weeks, depending on the season and nearby vegetation.

One innovative homeowner buys bulk packages of knee-high nylon stockings to use as large-particle filters. She attaches a sock to the end of her pipe, just before the water tank. Every two weeks she changes the sock, tossing out the old one with its collected debris.

If you are considering putting screens on your system, or have already put them on but find the need for regular maintenance to be a problem, you might consider using a first-flush diverter system instead. While screens keep large debris out of the system, small particles and microorganisms are still passing through the mesh and into the tank. With a first-flush diverter, this contamination is reduced.

First-flush diverters

A first-flush diverter is a device placed between the roof gutter and the storage tank that allows most of the dust and debris accumulated on the roof between rainfalls to be diverted away from the storage tank. Tests have shown this initial flow of water to be the most contaminated.



One example of a flat screen over the gutter to keep large debris out of the tank. A problem with gutter screens is that they require a lot of maintenance to keep leaves and debris from piling up and blocking the screens. Also, dirt on the leaves can still be washed into the storage tank.

Among the contaminants that can be washed off the roof during the first part of a rainfall are bird and animal droppings, dust, volcanic particles, molds, and pollen. After the first flush of water is diverted, the rest of the rainfall will flow into the tank. In dry areas, the initial runoff from a first-flush diverter can be stored separately for appropriate uses.

So far, most first-flush diverters to be seen in Hawaii are devices created by individuals. As of the date of publication, not many water-system supply stores on the island of Hawaii had experience with first-flush devices. Various types of first-flush diverters are available

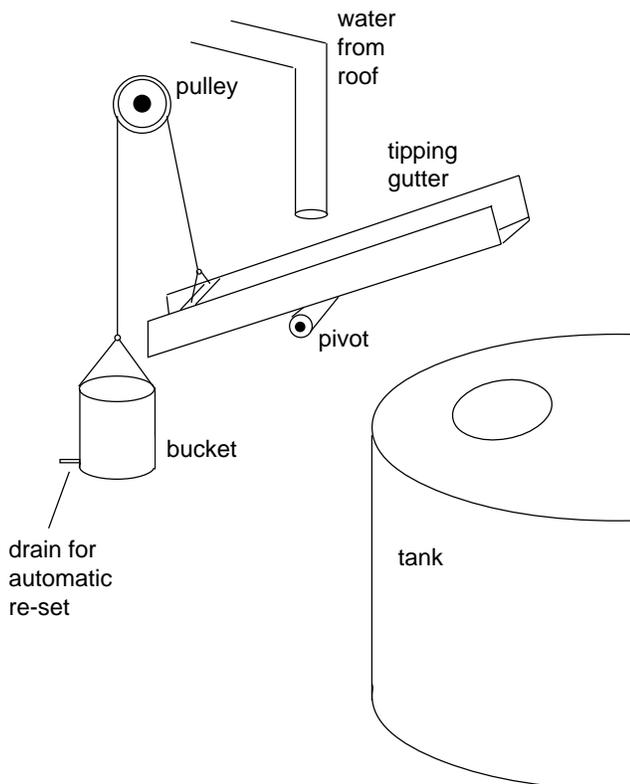
for import from outside the USA, but they are generally expensive. As demand for these devices grows, it is hoped that inexpensive models will become more widely available. Use of a first-flush diverter is highly recommended for rainwater catchment systems in Hawaii.

One possible first-flush diverter begins with a T-joint, placed either in the pipe leading to the storage tank or at the downspout. From this T-joint, a length of pipe drops down and ends in a screw closure. This length of pipe is filled first with the first wash of water from the roof and its load of contaminants. Once the pipe is filled, water flows into the tank. A bend in the pipe hinders the contaminated water from back-flushing into the tank. A drainage hole can be drilled above the screw closure to allow slow drainage of water, so that the pipe empties by the next rainfall. The screw cap is periodically removed to clean out leaves and other materials. Various



This simple and inexpensive first-flush diverter is a passive device. PVC pipe drops from the downspout, before the water tank (this can also work on a U-shaped downspout system). The pipe has a small hole near the screw closure at the end. The hole lets water slowly drain between rains. The screw closure can be opened periodically to remove leaves and other debris. A bend in the pipe reduces back flushing once the pipe is filled. The length of the pipe along the ground can vary according to the amount of water you want to divert.

A first-flush diverter using a tipping gutter. The initial flow of water from the roof fills a bucket; the weight of diverted water pulls the gutter upward, tipping it toward the tank.



configurations are possible to increase the device's ability to trap debris, drain as completely as possible, prevent clogging of the drain hole, and minimize backflow into the storage system.

Another idea for a first-flush diverter is a diversion valve operated by a 5-gallon bucket or similar container. When the bucket is empty, the valve is open and any new rainfall will be diverted into the bucket. When the bucket is filled by the first flush, its weight pulls the diversion valve closed, and water can enter the storage tank. Small holes in the bucket allow it gradually to drain, reopening the valve. The tipping-gutter device shown here is a variation on this concept.

Downspouts

The pipes that carry water from the gutter to the storage tank should have a continuous downward slope from the roof to the tank. There should not be any sections where the water pools or does not drain completely. Most homes are built with gutters that empty into a vertical downspout. When a rainwater catchment system is incorporated into this traditional downspout design, it usu-



The U-shaped downspout-to-tank configuration at left is typical but undesirable. The pipe runs down from the roof, across the ground, then up and over the tank. Between rains, water is left standing in the pipe. In the system at right, the downspout is completely drained by gravity.

ally results in water flowing down the downspout, across or under the ground to the storage tank, then up and over the top of pipe that is left filled with standing water between rains. This creates a large U-shaped section of pipe that is left filled with standing water between rains. This is undesirable, because sludge can collect and bacteria can grow as this water stagnates, resulting in poor water quality. The widespread occurrence of catchment systems with this design flaw may be due to a lack of information available to homeowners and contractors informing them of the problem. If you are building a new home, make it clear to the architect and contractor that you do not want a system in which standing water can collect. If you have a U-shaped downspout design already, you can either modify the design or install a first-flush device after the U with enough diversion capacity to handle both the water held in the U section and the first flush.

Water use

Before you build a water storage tank, you need to know some basics about how much water you will use. The three factors that determine the size of tank needed to meet your water needs are

- the number of people using the water
- the rainfall
- the dimensions of the system's catchment surface.

How many people are in your household using the water? Don't forget to consider visitors if you have a lot of them. Heavy use of a dishwasher and washing machine can also use up a lot of water. Some sources state that the average person uses about 100 gallons of water each day.⁽³⁾ Studies done in Hawaii in 1959 found that families living on rainwater catchment systems are much more conservative in their water use and average closer to 30–50 gallons per day; even less during dry periods.⁽⁴⁾ Another study estimated that a typical family of four using rainwater catchment will use about 200 gallons a day in the following manner⁽⁵⁾:

| <i>Purpose</i> | <i>Gallons per day</i> |
|---------------------|------------------------|
| cooking/dishwashing | 20 |
| laundry | 35 |
| bathing | 65 |
| flushing | 80 |

In this case, with 10,000 gallons of stored water, a family of four using 50–75 gallons of water per person per day would have enough water for 35–40 days without rain.

Rainfall

If you plan on living in an area where you must depend on rainwater catchment, you should find out if the area receives enough rainfall to meet your needs. In some locations where no public water utilities are available, there is not enough rainfall to sustain a household. Just because you see water tanks in a neighborhood, don't assume that enough water is available from rainfall. In some areas of the island of Hawaii, such as Ocean View, tanks are used as much as for storage of purchased, trucked-in water as they are for rainwater collection.

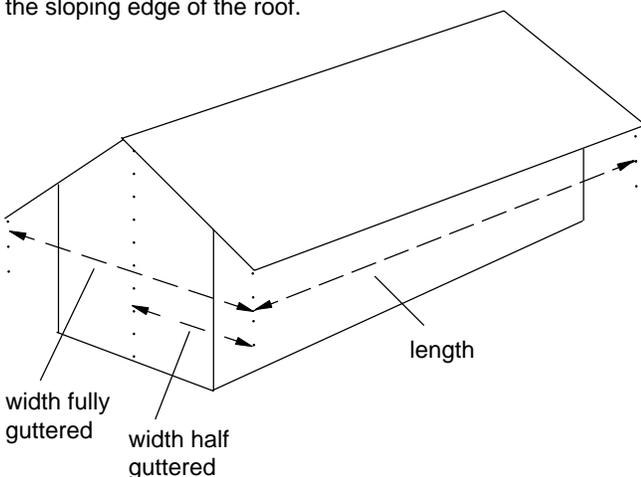
You have to plan for the dry seasons and have enough water storage capacity to get you through them. Always allow for the fact that weather can be unpredictable, and have a contingency plan in case you don't have enough water.

The table on page 12 shows rainfall data for various areas for 1998, which was a relatively dry year. Note that the areas have different rainfall patterns. It is very important to understand the weather patterns and the dry seasons that might be expected. Plan for the worst case, not for the average.

How much rain can you catch?

A square foot of horizontal surface receives approximately 0.625 gallons of water with each inch of rainfall.⁽⁶⁾ Surfaces that slope, like your roof, catch less wa-

To calculate catchment area of a roof that is guttered only on one side, multiply the length times half the width; if it is fully guttered, use the total width. It is not necessary to measure the sloping edge of the roof.



ter per square foot of surface area. So it is not the area of roof surface that you need to measure, but the roof's "footprint," the area of ground under it. To get the effective square footage of your roof for catchment purposes, measure the sides of your house from eave to eave. Multiply the length times the width to get the square footage of the catchment surface. Multiply that amount times 0.625 and to find the total gallons the roof can catch per inch of rain. If only part of the roof is used for catchment, calculate only for that area.

For example, an HPM-1056 package home is 32 x 32 feet. The eaves add 2 feet on all sides, so the roof covers an area of 36 x 36 feet.

$$36' \times 36' = 1296 \text{ square feet of catchment area}$$

$$1296 \text{ ft}^2 \times 0.625 \text{ gallons of water per inch of rain} =$$

$$810 \text{ gallons caught per inch of rain}$$

This calculation provides theoretical value, a general estimate of the amount your rainwater catchment system can capture. Some rain will evaporate, splash off, or overflow the gutters; some water will be lost if you have a first-flush diverter; and if it rains a lot, the tank may overflow.

Once you know the effective roof area, take a look at the rainfall chart. Let's say you live in Mountain View and you had to get through a period like February 1998, when only 3.44 inches of rain fell. How much water would that provide for your family? The roof area calculated above will catch 810 gallons of water per inch of rain. If 3.44 inches of rain falls, you have

$$810 \text{ gal} \times 3.44 \text{ inches of rain} = 2786.4 \text{ gallons.}$$

A family using 200 gallons of water per day for 30 days would need 6000 gallons per month. So, the rainfall that February would not be enough. In fact, with a system capturing 810 gallons per inch of rain, that family would need at least 7.4 inches of rainfall that month to meet its water needs ($6000 / 810 = 7.4$). Of course, that calculation considers only one month, and it doesn't take into account the existence of stored water available for use.

The next step is to consider the tank's storage capacity. We've seen that there wouldn't be enough rain in that February in Mountain View for an average family of four. However, if you had a storage tank that could hold 10,000 gallons of water, you would have enough stored water to get through more than one month with a shortage of rainfall. The drier your area, and the more

Monthly rainfall (inches) during 1998 at selected locations on the island of Hawaii

| STATION | JAN | FEB | MAR | APR | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | YEAR |
|---------------------------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Hwn. Bchs. | 1.43 | 1.07 | 5.26 | 9.82 | 13.36 | 11.14 | 6.28 | 8.77 | 8.69 | 14.20 | 11.42 | 10.35 | 101.79 |
| HI Volcanoes Natl. Pk. | 0.63 | 1.31 | 5.20 | 13.90 | 12.90 | 7.08 | 1.69 | 4.91 | 4.21 | 7.59 | 12.19 | 12.41 | 84.02 |
| Hawi | 2.86 | 3.30 | 6.69 | 8.42 | 8.48 | 9.86 | 4.20 | 3.78 | 5.10 | 4.14 | 5.36 | 5.51 | 67.7 |
| Hilo Airport | 0.13 | 2.40 | 3.67 | 8.86 | 15.65 | 11.27 | 6.09 | 8.48 | 10.76 | 16.01 | 15.57 | 9.89 | 108.78 |
| Holualoa | 0.26 | 1.78 | 0.10 | 0.50 | 1.56 | 1.46 | 3.03 | 2.23 | 1.81 | 3.53 | 1.10 | 0 | 17.36 |
| Honokaa Town | 2.25 | 3.39 | 7.18 | 15.29 | 15.48 | 7.47 | 8.11 | 14.11 | 10.93 | 6.94 | 10.69 | 5.19 | 107.03 |
| Kahuku Mill Coop | 1.05 | 0.12 | 0.51 | 0.97 | 1.14 | 3.18 | 0.99 | 1.67 | 2.28 | 2.20 | 3.31 | 1.48 | 19.17 |
| Kahuna Falls | 1.82 | 4.43 | 7.71 | 25.57 | 28.37 | 22.56 | 9.57 | 23.69 | 16.69 | 25.51 | 27.95 | 17.81 | 211.68 |
| Kainaliu | 1.63 | 0.09 | 0.94 | 2.21 | 1.49 | 2.04 | 2.67 | 6.20 | 5.57 | 1.74 | 4.76 | 1.33 | 30.67 |
| Kapoho Bch. | 0.69 | 1.00 | 3.54 | 5.04 | 7.83 | 5.65 | 3.55 | 6.20 | 6.75 | 5.93 | 10.98 | 5.32 | 62.39 |
| Kapoho Lndg. | 2.61 | 1.18 | 2.83 | 6.86 | 11.47 | 7.73 | 6.55 | 6.19 | 7.55 | 9.98 | 12.07 | 9.40 | 84.42 |
| Keaau | 0.61 | 1.55 | 3.99 | 9.81 | 14.64 | 12.96 | 6.99 | 7.27 | 12.40 | 18.40 | 19.28 | 13.43 | 121.33 |
| Kulani Camp | 0.10 | 0.14 | 0.79 | 3.52 | 1.67 | 0.64 | 0.40 | 1.36 | 0.67 | 1.77 | 2.84 | 13.25 | 27.15 |
| Laupahoehoe | 1.95 | 1.00 | 2.00 | 3.05 | 2.05 | 3.15 | 2.45 | 1.23 | 11.44 | 14.36 | 17.43 | 7.52 | 67.63 |
| Milolii | 0.61 | 0.09 | 1.55 | 0.45 | 0.43 | 0.37 | 0 | 0 | 0.50 | 0 | 1.15 | 0 | 5.12 |
| Mountain View | 0.95 | 3.44 | 8.41 | 21.72 | 25.85 | 20.03 | 14.01 | 16.32 | 15.73 | 23.65 | * | * | * |
| Naalehu | 0.89 | 0.12 | 0.18 | 1.14 | 1.09 | 1.75 | 0.13 | 0.52 | 3.14 | 3.33 | 4.20 | 1.13 | 17.62 |
| Opihihale | 1.27 | 0.18 | 1.24 | 0.71 | 1.37 | 1.68 | 3.77 | 3.22 | 3.31 | 4.70 | 2.80 | 0.57 | 24.82 |
| Paauilo | 1.11 | 2.64 | 5.10 | 12.74 | 15.32 | 5.53 | 6.09 | 11.71 | 10.38 | 5.08 | 13.25 | 7.73 | 96.68 |
| Pahala Mauka | 0.70 | 0.05 | 0.43 | 0.52 | 0.97 | 1.39 | 0.11 | 0.66 | 1.41 | 1.58 | 2.31 | 0.92 | 10.75 |
| Pahoa | 1.89 | 1.68 | 1.97 | 12.61 | 16.91 | 11.17 | 8.00 | 5.11 | 11.68 | 18.26 | 13.35 | 15.41 | 118.04 |
| Sea Mountain | 0.31 | 0.01 | 0.22 | 0.31 | 0.42 | 0.71 | 0.01 | 0.33 | 1.18 | 2.86 | 2.26 | 1.04 | 10.29 |
| S. Glenwood | 1.47 | 3.97 | * | * | * | * | 10.64 | 12.64 | 13.00 | 8.19 | 25.2 | 17.52 | * |
| S. Kona | 0.83 | 0 | 0.78 | 3.36 | 0.29 | 0.74 | 0.21 | 1.71 | 0.42 | 1.00 | 0.78 | 0.22 | 10.34 |
| Waiakea SCD | 1.02 | 2.82 | 6.57 | 21.12 | 27.34 | 19.8 | 14.57 | 19.93 | 16.69 | 26.31 | 25.92 | 18.24 | 200.33 |
| Waikaloa | 0.94 | 0.07 | 0.06 | 0.50 | 0.22 | 0.32 | 0 | 0.31 | 2.01 | 0.20 | 1.49 | 0.08 | 6.20 |
| Waikaloa Bch. Rsrst. | 0.51 | 0.04 | 0 | 0.16 | 0.12 | 0.33 | 0.03 | 0.38 | 0.08 | 0.15 | 0.23 | 0.05 | 2.08 |

* no data

Source: National Oceanic and Atmospheric Administration (NOAA)

subject it is to seasonal dry periods, the larger the tank needed to get through the dry times. Some areas always get plenty of rain, and some never get enough no matter how big the storage tank is. For example, if the area receives 100 inches of rain annually but it all falls in a period of three months, you had better think about an alternative way to get water.

In considering the size of water tank for a rainwater catchment system, you also should plan to have extra water storage for fire protection (see p. 45). In fact, some insurance companies require homes to have at least a 10,000 gallon tank.

To determine how much accessible water you have, don't just measure the tank height. Measure the depth of the water from the bottom of the uptake pipe to the beginning of the overflow pipe. Then do the calculations below. (When measuring tank volume for the purpose of calculating water purification treatments, you need to know not just amount of accessible water but the total amount of water, including the water below the intake pipe; in that case, measure from the bottom of the tank up to the overflow pipe.)

To determine how much accessible water you have in your tank, use the following formulas:

For a round tank, tank diameter (feet) (squared) x depth of water (feet) x 5.9 gallons/foot = volume (gallons). For example, if your tank measures 8 feet across and the depth of water you are calculating for is 6 feet:

$$8^2 = 8 \times 8 = 64$$

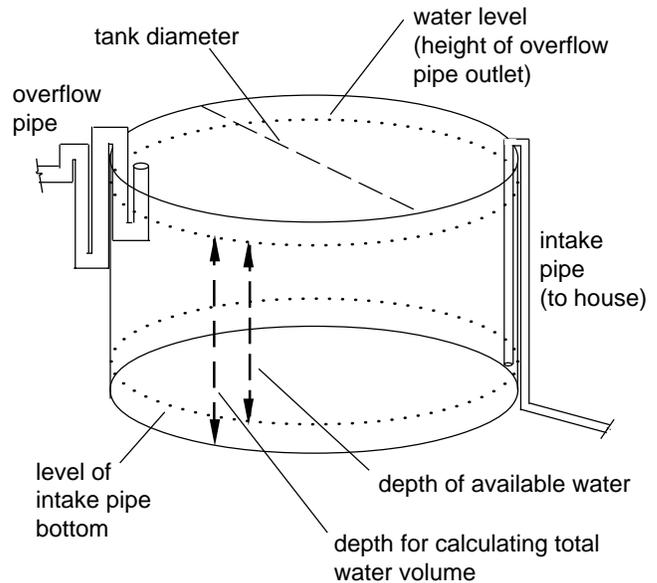
$$64 \times 6 \times 5.9 = 2265.6 \text{ gallons.}$$

For a rectangular tank, tank length (feet) x tank width (feet) x depth of water (feet) x 7.5 gallons/foot = volume (gallons). For example, if your tank is 8 feet square and the water depth is 6 feet, then

$$8 \times 8 \times 6 \times 7.5 = 2880 \text{ gallons.}$$

On page 14 are two charts that will help you determine the approximate usable capacity or total volume of a tank. Remember to measure water depth from the intake pipe to the overflow pipe if you are calculating accessible water capacity for use purposes; measure from the bottom of the tank to the overflow pipe if you are calculating total water volume for treatment purposes.

To calculate the volume of available water, measure from the water surface to the opening of the intake pipe. To calculate the total volume of water in the tank, measure to the bottom of the tank.



Water collection highlights

- Use non-toxic building materials.
- Wash all surfaces before using them to catch or hold water.
- Make sure there are no low spots or puddles in the gutter system and that there is a continuous downward slope to the catchment tank.
- First-flush systems improve water quality and should be installed.
- Install a by-pass valve so you can paint or clean your roof and gutters without the rinse water going into the tank.
- Make sure your system will catch and hold enough water for your family's needs
- Calculate the amount of water in your tank—a full 5000-gallon tank does not mean you have 5000 gallons of accessible water.
- When building your home, consider the water catchment as a whole system rather than a series of parts.

Calculating the capacity (gallons) of a rectangular water tank

| | | Depth (feet) | | | | | | | | | | | | |
|---|------|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Floor area (length x width = square feet) | 16 | 360 | 480 | 600 | 720 | 840 | 960 | 1080 | 1200 | 1320 | 1440 | 1560 | 1680 | 1800 |
| | 25 | 563 | 750 | 938 | 1125 | 1313 | 1500 | 1688 | 1875 | 2063 | 2250 | 2438 | 2625 | 2813 |
| | 36 | 810 | 1080 | 1350 | 1620 | 1890 | 2160 | 2430 | 2700 | 2970 | 3240 | 3510 | 3780 | 4050 |
| | 49 | 1103 | 1470 | 1838 | 2205 | 2573 | 2940 | 3308 | 3675 | 4043 | 4410 | 4778 | 5145 | 5513 |
| | 64 | 1440 | 1920 | 2400 | 2880 | 3360 | 3840 | 4320 | 4800 | 5280 | 5760 | 6240 | 6720 | 7200 |
| | 81 | 1823 | 2430 | 3038 | 3645 | 4253 | 4860 | 5468 | 6075 | 6683 | 7290 | 7898 | 8505 | 9113 |
| | 100 | 2250 | 3000 | 3750 | 4500 | 5250 | 6000 | 6750 | 7500 | 8250 | 9000 | 9750 | 10500 | 11250 |
| | 144 | 3240 | 4320 | 5400 | 6480 | 7560 | 8640 | 9720 | 10800 | 11880 | 12960 | 14040 | 15120 | 16200 |
| | 169 | 3803 | 5070 | 6338 | 7605 | 8873 | 10140 | 11408 | 12675 | 13943 | 15210 | 16478 | 17745 | 19013 |
| | 196 | 4410 | 5880 | 7350 | 8820 | 10290 | 11760 | 13230 | 14700 | 16170 | 17640 | 19110 | 20580 | 22050 |
| | 225 | 5063 | 6750 | 8438 | 10125 | 11813 | 13500 | 15188 | 16875 | 18563 | 20250 | 21938 | 23625 | 25313 |
| | 256 | 5760 | 7680 | 9600 | 11520 | 13440 | 15360 | 17280 | 19200 | 21120 | 23040 | 24960 | 26880 | 28800 |
| | 289 | 6503 | 8670 | 10838 | 13005 | 15173 | 17340 | 19508 | 21675 | 23843 | 26010 | 28178 | 30345 | 32513 |
| | 324 | 7290 | 9720 | 12150 | 14580 | 17010 | 19440 | 21870 | 24300 | 26730 | 29160 | 31590 | 34020 | 36450 |
| | 361 | 8123 | 10830 | 13538 | 16245 | 18953 | 21660 | 24368 | 27075 | 29783 | 32490 | 35198 | 37905 | 40613 |
| 400 | 9000 | 12000 | 15000 | 18000 | 21000 | 24000 | 27000 | 30000 | 33000 | 36000 | 39000 | 42000 | 45000 | |

Calculating the capacity (gallons) of a circular water tank

| | | Depth (feet) | | | | | | | | | | | | |
|-----------------|----|--------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Diameter (feet) | 4 | 283 | 378 | 472 | 566 | 661 | 755 | 835 | 944 | 1038 | 1133 | 1227 | 1322 | 1416 |
| | 5 | 443 | 590 | 738 | 885 | 1033 | 1180 | 1305 | 1475 | 1623 | 1770 | 1918 | 2065 | 2213 |
| | 6 | 637 | 850 | 1062 | 1274 | 1487 | 1699 | 1879 | 2124 | 2336 | 2549 | 2761 | 2974 | 3186 |
| | 7 | 867 | 1156 | 1446 | 1735 | 2024 | 2313 | 2558 | 2891 | 3180 | 3469 | 3758 | 4047 | 4337 |
| | 8 | 1133 | 1510 | 1888 | 2266 | 2643 | 3021 | 3341 | 3776 | 4154 | 4531 | 4909 | 5286 | 5664 |
| | 9 | 1434 | 1912 | 2390 | 2867 | 3345 | 3823 | 4228 | 4779 | 5257 | 5735 | 6213 | 6691 | 7169 |
| | 10 | 1770 | 2360 | 2950 | 3540 | 4130 | 4720 | 5220 | 5900 | 6490 | 7080 | 7670 | 8260 | 8850 |
| | 11 | 2142 | 2856 | 3570 | 4283 | 4997 | 5711 | 6316 | 7139 | 7853 | 8567 | 9281 | 9995 | 10709 |
| | 12 | 2549 | 3398 | 4248 | 5098 | 5947 | 6797 | 7517 | 8496 | 9346 | 10195 | 11045 | 11894 | 12744 |
| | 13 | 2991 | 3988 | 4986 | 5983 | 6980 | 7977 | 8822 | 9971 | 10968 | 11965 | 12962 | 13959 | 14957 |
| | 14 | 3469 | 4626 | 5782 | 6938 | 8095 | 9251 | 10231 | 11564 | 12720 | 13877 | 15033 | 16190 | 17346 |
| | 15 | 3983 | 5310 | 6638 | 7965 | 9293 | 10620 | 11745 | 13275 | 14603 | 15930 | 17258 | 18585 | 19913 |
| | 16 | 4531 | 6042 | 7552 | 9062 | 10573 | 12083 | 13363 | 15104 | 16614 | 18125 | 19635 | 21146 | 22656 |
| | 17 | 5115 | 6820 | 8526 | 10231 | 11936 | 13641 | 15086 | 17051 | 18756 | 20461 | 22166 | 23871 | 25577 |
| | 18 | 5735 | 7646 | 9558 | 11470 | 13381 | 15293 | 16913 | 19116 | 21028 | 22939 | 24851 | 26762 | 28674 |
| | 19 | 6390 | 8520 | 10650 | 12779 | 14909 | 17039 | 18844 | 21299 | 23429 | 25559 | 27689 | 29819 | 31949 |
| | 20 | 7080 | 9440 | 11800 | 14160 | 16520 | 18880 | 20880 | 23600 | 25960 | 28320 | 30680 | 33040 | 35400 |

Section 2

Water Storage

Type of tank

Water tanks can be made of a variety of materials. Most are specially designed for the purpose, but sometimes containers meant for other purposes are used, such as horse troughs and “kiddie pools.” Many people believe that anything that holds water can be used as a catchment tank⁽⁷⁾, but they are mistaken. As with the other parts of a catchment system, the tank should be chosen with careful consideration of your water needs and awareness of the materials that your water comes in contact with. Just like roofing materials, tank materials can leach into the water. Different tanks have different problems and benefits. Whichever type of tank you use, you should rinse it well before using it for the first time.

Preferences for the type of tank have changed over the years in Hawaii, due mostly to the materials cost and availability. Technology and market competition also influence what people are buying and using.

Fifty years ago, the popular tanks were redwood tanks. They were easily obtainable and inexpensive. As availability of redwood diminished and prices increased, swimming pool tanks were marketed by local suppliers and became popular. This popularity gave way to the sturdier corrugated steel tanks that lead the market in sales today. Concrete tanks of one form or another have existed for a long time, but their high price limits their popularity. The newer ferroconcrete tank is the tank market’s fastest growing alternative, and if prices come down, they could come to dominance. Polyethylene and fiberglass tanks are also relatively new to the market but have yet to demonstrate the longevity of comparative priced concrete tanks; high price also limits their popularity.

The table on page 16 gives a brief overview of the various types of tanks, which are discussed in more detail in the following paragraphs.

Swimming pool tanks

Sometimes referred to as “portable swimming pools,” these tanks have metal sides and plastic (polyethylene) liners. Doughboy® is probably the most familiar trade name, but there are many companies making this type of swimming pool. Some have a plastic framework rather than metal, some have elaborate siding, and some have no siding. These pools are the most common type of rainwater catchment storage tank in use now.

The greatest advantage of swimming pool tanks is low cost. Also, homeowners can install them, and they are readily available from various sources including discount stores.

Among their disadvantages, they are not as sturdy or as durable as some other types of tank. The liners that come with the pools are not food-grade quality. The liners only come up to the top edge of the tank and often



A large swimming pool tank with pipe arches holding up a mesh cover. These tanks are popular for their price and ease of assembly.

pull out of their clips and droop into the pool, particularly when the water level is low and the liners shrink with drying. The biggest problem with swimming pool tanks can be the liner material itself. Some liners contain biocides designed to reduce fungal and bacterial growth in the pool. This material can be very toxic. These types of liner are *NOT* designed for storing water for consumption and should not be used for holding household water⁽⁸⁾. It is very important to buy a liner approved by the Food and Drug Administration if you use a swimming pool for a rainwater catchment system water tank. Another problem with swimming pool tanks is that the large diameter pools are difficult to cover without the cover sagging into the water (see *Tank covers*, p. 21)

Corrugated steel tanks

The second most popular type of tank material currently is corrugated metal. They are more durable than swimming pool tanks and usually have a narrower diameter, which makes covering them easier. They are more expensive than swimming pools but are still relatively in-



A typical corrugated steel tank with a mesh cover. This type of tank is the second most common in use today.

expensive. They can be easy to assemble, although they may require more skill than a swimming pool tank; different types vary in construction difficulty. Corrugated steel is a popular choice of tank material for its convenience, price, and reasonable durability. Liners for these tanks, as with swimming pool tanks, should be FDA approved.

Information on selected tank types

| Type | Approx. price ^w | Cover type | Purchasing trends | | Structural integrity ^x | Longevity ^x | Notes |
|---------------------|----------------------------|------------|-------------------|------------|-----------------------------------|------------------------|-------------------------------------|
| | | | Past 5 years | In use now | | | |
| Swimming pool | \$2,000 | mesh | 6% | 57% | ** | ** | Low cost; limited durability |
| Corrugated steel | \$3,500 | mesh | 85% | 23% | *** | *** | Good balance of cost and durability |
| Poly-ethylene | \$5,500–6,000 ^y | solid | 1.5% | 1% | **** | **** | Should be food-grade, UV protected |
| Hollow tile | \$6,000 | solid | 1% | z | ** | ***** | Subject to leaks |
| Ferro-concrete | \$5,500–8,000 | solid | 2% | z | ***** | ***** | Reduces acidity of acid rain |
| Solid-pour concrete | \$7,500–8,000 | solid | 1.5% | z | **** | ***** | Reduces acidity of acid rain |
| Fiberglass | \$4,500–10,000 | solid | 1.5% | 5.5% | **** | **** | Should be food-grade |
| Redwood | \$7,000–10,000 | solid | 1% | 11% | **** | **** | Needs wet environment |

^w Price in year 2000 for a 10,000-gallon system installed with cover.

^x Five stars = excellent

^y Four tanks without installation

^z A survey (1999) showed 16% of 91 tanks were concrete tanks, but there was no differentiation among the types of concrete.

Enclosed metal tanks

These tanks are not common these days in Hawaii. An advantage is that they usually have solid covers, which make them less susceptible to the introduction of contaminating materials. But their disadvantages have resulted in their seldom being used. Many of these tanks are too small to meet the needs of most families, particularly in locations not in a rain belt. Rust and deterioration inside the tank has often been a problem. Some of the older tanks found in Hawaii had been painted on the inside with lead paint, possibly to discourage the growth of fungus. This can be a serious health problem, because lead leaches out of the paint into the water.

Elsewhere, in Australia for example, enclosed galvanized steel tanks are more common and have newer designs. These newer tanks have a couple of problems you should be aware of. The initial corrosion of galvanized steel normally leads to the production of a thin, adherent film that coats the surface of the metal and provides protection against further corrosion. It is important when cleaning such tanks not to disturb this film.⁽⁹⁾ New galvanized steel tanks also may leach excess concentrations of zinc, which could affect the taste of stored rainwater. Finally, these tanks need to be flushed before use.⁽⁹⁾ At present (Dec., 2001), we are not aware of any source for these tanks in Hawaii.

Concrete tanks (“cement” tanks)

The three main types of concrete tank are ferroconcrete, solid-pour concrete, and hollow tile. These tanks may be freestanding or built into a house’s structure, or they may be partially underground. They can be made to blend into the house design—covered with a lanai, for example. The biggest advantage of concrete is its durability. A second advantage is that calcium in the cement helps to deacidify water from acid rain. On the other hand, high pH can make traditional chlorine treatments ineffective, and alternative purification techniques are recommended.

Concrete tanks usually are more costly and are much more difficult to install than metal or swimming pool types of tank. Once they are built, they are not portable and cannot be relocated. Because of the occurrence of earthquakes on the island of Hawaii, owners of concrete tanks should be vigilant about checking their tanks for cracks and leaks.

Over the years, acid rain can deteriorate concrete. If water gets through the concrete and to the metal support



These enclosed metal tanks are well maintained on the outside, but problems may arise if there is deterioration on the inside.

structure, the metal could rust and ultimately cause tank failure. This is more common with large commercial tanks than it is with smaller tanks, but it is something to be concerned about if you notice your tank cracking or the concrete flaking off. Concrete will sometimes flake off if metal is rusting and swelling inside of it.

Underground tanks are susceptible to leaks that allow contaminants to enter. Compared to above-ground tanks, leaks in underground tanks are more difficult to detect. If there is sewage seepage or another contaminant nearby, leaks in the tanks could result in health problems. Because most tanks in Hawaii are above ground, leakage into tanks is not often a concern.

Concrete tanks are usually left unlined. Epoxy sealant is often painted around the seams and on the bottom. Epoxy or paint should be checked for its suitability for drinking water use before application.

Some plaster coatings that can be applied to the inside of concrete tanks have been approved for water storage by the National Sanitation Foundation. These coatings help seal the tank and reduce etching while still providing the minerals needed for neutralizing acid rain.

It is possible that older tanks have been painted with lead-based paint, so if you are buying a property with a concrete tank in place, the water should be tested. If a liner is used, it should be an FDA approved liner.

Another benefit of concrete tanks is that they can easily support a solid cover.

Hollow tile tanks

The biggest difference between hollow tile tanks and



Hollow tile tanks have lost popularity mainly due to their price and tendency to leak.

the other types of concrete tank is that hollow tile tanks are notorious for springing leaks. Owners often find themselves lining the tank within a few years, which negates the beneficial effect of calcium contacting the water. Solid covers are not always included in the construction of these tanks. Many owners of hollow tile tanks cover them with wood, metal roofing, or mesh. A solid cover is preferable.

Solid-pour concrete tanks

Solid-pour concrete is more expensive than other concrete types, but due to its strength, tanks of this material can be incorporated into the design of the house, providing the home with an aesthetic quality that isn't always available with other options. The tank can be made to look like a room in the house, or it can support a deck. These tanks are sometimes put underground or partially underground.



The front of this house is a lanai (interior view at right) built over a solid concrete tank. While high-priced, solid-pour concrete tanks such as this offer attractive architectural design options.



Ferroconcrete tanks, also known as ferrocement tanks, are new to the local market and growing in popularity. Like solid concrete tanks, they can be designed into a home's structure.

Earthquakes can be a concern, particularly for underground tanks. Contaminant leakage into underground tanks is a more serious problem than water leaking out.

Ferroconcrete tanks

Ferroconcrete is one of the newer tank materials to be used in Hawaii. It provides a sturdy framework that can be used as part of the house design, such as under a patio or lanai. The framework of these is reinforced and seems to hold up well during earthquakes. Ferroconcrete tanks are built with a solid cover and are becoming popular with those who can afford them. Currently most of these tanks are being built above ground.





An older redwood tank. Beware of redwood tanks that were painted on the inside with lead paint to discourage algae.

Redwood tanks

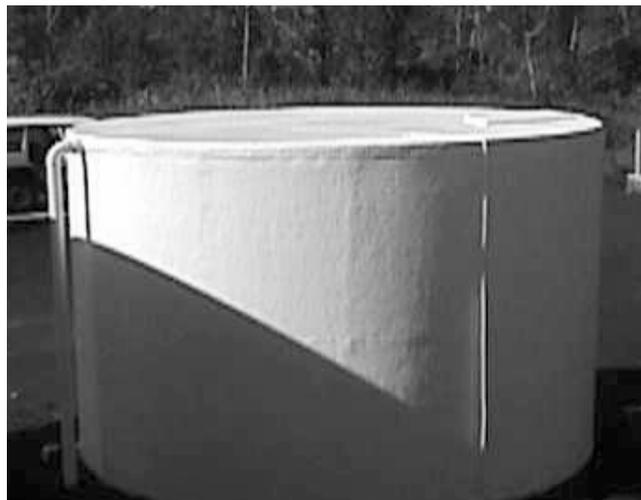
Once popular a few decades ago was the round, redwood tank. The tanks were easy to obtain, and redwood was considered an ideal material because the wood is resistant to insect damage. A few old redwood tanks are still in use today. Some contemporary versions are available, but relatively few new redwood tanks are used today due to their relatively high cost.

Normally, wooden tanks should not be painted, because the paint reduces the ability of the wood to swell and seal the tank's joints. But years ago people often painted the interior of redwood tanks with lead-based paint to keep fungal growth down. Lead leaching from these old paints into the water has been a serious contamination problem. If you are buying a home with an older wooden tank, you should have the water analyzed, especially if the tank is painted on the inside.

Redwood tanks do not work well in areas that are dry. They need moisture to keep their joints swollen shut, and if the wood dries out too much they will leak.

Among the other problems with redwood tanks is that they are almost impossible to decontaminate once they have become contaminated. Many of the early redwood tanks were elevated to create a gravitational flow of water into the home, and elevated tanks are very susceptible to damage or destruction by earthquakes.

Wooden tanks, like concrete tanks, can readily support a solid cover.



Fiberglass tanks offer solid covers. The fiberglass must be cured on the inside to avoid bad tasting water. The tanks can be made of food-grade materials, so no liner is necessary.

Fiberglass tanks

Fiberglass is a new material for water tanks in Hawaii, and tanks made of it are as yet relatively rare. Fiberglass tanks have advantages. The material is lightweight and the tank is portable when empty. The tanks are molded with a cover to make an enclosed system. The composite fiberglass material can be relatively inert when made to food-grade quality specifications, in which case a liner is not needed to protect the water supply. They can also be made with UV protection to hinder their degradation from sunshine.

The fiberglass used for a water-storage tank or cover must be properly cured. If the inner layer of fiberglass is not cured, the water may start to taste bad, or the tank's interior may develop an odor. During fiberglass manufacture, layers of the material are added to each other. With each successive layer, unattached molecules of styrene monomers wait on the surface to bond with the next layer. A layer of waxy material is usually added to the outside layer of fiberglass to bind those molecules and thus "cure" the fiberglass. Improper curing can result in release of the styrene monomer molecules into the water. An easy way to check whether or not a fiberglass surface is cured is to put some acetone on your finger and rub it on the tank. (Nail polish remover that contains acetone will work.) After the acetone has evaporated, touch the spot with a dry finger. The spot should not be sticky; if it is sticky, then the fiberglass is not cured.



Polyethylene tanks are new to the market. They are lightweight, easy to relocate, and can be made out of food-grade materials. Their small size often requires joining multiple units to provide ample water storage. They can be molded with a solid cover.

Don't buy a fiberglass tank from an unknown source. Beware of cheaper grades of fiberglass that are made of materials not suitable for containing potable water. Unsuitable materials can contain chromium dyes, for example.

It is wise to rinse or steam-clean the interior of a fiberglass tank before using it, to remove loose manufacturing materials.

Polyethylene (plastic) tanks

Like fiberglass tanks, polyethylene tanks are also relatively new to Hawaii. They are now manufactured on the island of Hawaii, so buyers there no longer have to pay high shipping costs. These tanks generally are enclosed systems with solid covers. They are lightweight and easy to clean and move around when empty. They can be made of food-grade quality materials that are safe for potable water.

There are some drawbacks to polyethylene tanks. They are still expensive, even when manufactured locally. They are not structurally sound enough to be made in large sizes, so the largest size for a water tank is around 2500 gallons. This means that to have a 10,000 gallon system you would need four tanks connected together with valves. This would allow for easy cleaning, because each tank could be isolated from the others, but the

multiple tanks on your property may not be pleasing in appearance. There is also a question about their longevity in sunlight, as UV eventually breaks down the material. The newer materials with UV protection probably have greater longevity, but they have not been in the field long enough or in great enough numbers to make a durability evaluation.

It is important to have confidence in the source of fiberglass and polyethylene tanks, because they might be constructed with toxic materials and unsuitable for drinking water storage. Don't buy a tank unless you can confirm that it is made of food-grade material.

Undesirable storage containers

Because there are no limits to the imagination of homeowners, many different types of container are used for water storage. Our survey of 91 tanks found that about 10 percent were small containers, including horse troughs, plastic food containers, metal drums, kiddie pools, plastic trash cans, etc. Use of such undesirable storage containers for water storage can lead to many problems. The most obvious problem with small containers is storage capacity, particularly during a drought. More important, the containers are not often food-grade quality and might contain various chemicals harmful to water quality. For example, plastic trash cans and kiddie pools may contain biocides to cut down on growth of algae. These biocides are toxic and could leach into the water. The materials may also contain toxic dyes, such as those containing cadmium. Some containers may be safe for a short time but not for long-term storage because of the material's permeability. Another problem with small containers is that contaminants introduced to the tank are present in a higher concentration than they would be if diluted in a larger volume of water. In high concentration, they may present a greater health risk. Although dilution is not the solution to pollution, it can help.

Tank liners

Tank liners should be food-grade quality liners approved by the U.S. Food and Drug Administration. They are available at local water catchment equipment and supply stores. Water usually has longer contact with the liner than any other part of the catchment system, so it is imperative that the liner surface is pure. The surface that your liner rests on should be free of sharp objects that could puncture the fabric. If a sand-bottomed tank is



Water collected and held in containers that haven't been approved for water storage can be deadly. Plastic garbage containers, for example, can contain toxic dyes and biocides that could leach into the water.

undermined by improperly directed overflow runoff, the liner could bulge out the bottom and rip. Therefore, tank bases should be inspected regularly.

Tank covers

Water storage tanks should be completely covered with a solid material. Good covering will keep out

sunlight—reducing growth of algae and other photosynthetic organisms

dirt and air-borne particles—excluding dust from entering through mesh and holes

mammals, birds, insects, amphibians, and reptiles—keeping their waste products and their carcasses from reducing water quality and, in some cases, spreading serious diseases

mosquitoes—limiting their access to a breeding habitat

organic rubbish—excluding leaves, branches, and other organic sources of nutrients that support biological growth and taint the taste.

The more you do to protect stored water from contamination, the better will be its quality and the safer it

will be. Contaminants can get into a rainwater catchment tank by washing off the roof, but as described earlier, a first-flush system can eliminate the majority of the roof's contribution to debris entering the tank. Then, if the tank is covered with a solid cover, airborne contamination cannot get in.

Mesh covers made from woven polypropylene groundcover cloth or similar products are inexpensive, but unfortunately they are not an acceptable choice of cover as far as water quality is concerned. The mesh allows dirt, small insects, bird and animal wastes, and sunlight through. Keeping the mesh out of contact with the water in the tank is a major problem. If the cover is not properly supported, or as the material ages, stretches, and sags into the water, the resulting "pond" allows birds, insects, and other animals direct access to your water supply. Using a mesh cover is almost the same as having an open tank.

If the tank is equipped with an overflow device to keep the water level below the top, it may be possible to pull a mesh cover tight enough to keep it above the water. The larger the diameter of the tank, the more difficult it is to keep the fabric tight.

Some people who use a mesh cover combat the sagging problem by supporting the mesh above the water with a flotation device or with a structure such as pipe arches. Flotation devices should be made of material that is nontoxic and preferably food-grade quality. For example, do not use rubber inner tubes, which leach toxic petroleum products that turn the water black, and termite-treated lumber, which releases the insect poison into the water. Sharp-edged items can rip the fabric. Some pool toys contain biocides, toxic dyes, or release fumes that enter the water.

Mesh covers usually have to be changed every three to five years, depending on their composition, because they wear out and are susceptible to degradation by the sun.

Mosquitoes have been a problem with stored water in Hawaii since their introduction in the late 1800s, and they are a particular problem when tanks are covered with sagging mesh. A very hazardous old-time method to eliminate mosquitoes was to cover the water surface with a film of kerosene, assuming that it would kill the larvae and then evaporate. Kerosene is toxic to humans and should **never** be used in a water catchment system. Mineral oil has also been used in the same fashion to



Pipe arches supporting a mesh cover keep it from sagging into the water.



Mesh covers often sag into the water when the tank is full or the mesh stretches in the sun. The resulting puddle attracts birds, insects, and debris, which contaminate the water.

kill mosquito larvae, but the oil residue left on the tank will support the growth of undesirable microorganisms. There is a commercially available larvicide for potable water. It works by coating the water surface with a thin film. The larvae cannot break through the surface to breathe, and they suffocate. The best way to avoid mosquitoes is to eliminate any opening large enough to admit them, filter the intake, and eliminate exposed, ponded, or standing water anywhere in the catchment system.

Everyone should strive to have a solid tank cover to maintain water quality. Putting a solid cover on a typical tank that was not designed with a solid cover can be costly and problematic. For example, swimming pool tanks and corrugated steel tanks often are not strong enough to support a solid cover. Fiberglass covers for these types of tank might be available, but they may be more expensive than the tank itself, and usually some type of support frame is needed to hold an added cover. Also, side openings need to be sealed too. If you buy a fiberglass cover, make sure the material is cured (see the section on fiberglass tanks).

Tank overflow devices

Tanks should be fitted with overflow devices so that water doesn't spill over the sides and wash out the tank's foun-



Sagging and broken covers like this one are very common. The storage tank is where water sits the longest, and keeping it covered is important to reducing water contamination.

dation or cause any other damage to your or your neighbors' property. Most overflow devices are simple gravitational devices made out of looped PVC pipe. The overflow pipes should be at least as large or larger than the intake pipes. It is unlikely that animals and insect will enter the tank through the overflow device, but a flapper or screen on the outside end can help prevent this.



An overflow device that will keep the water level as indicated. The pipes on the near side of the fence hang outside the tank. In this design, a hole must be made on the top of the pipe in the foreground for the system to function properly. If a T joint is used instead of an elbow, the hole is not needed.



Even though surrounding your tank with plants may look nice, it can cause major pollution problems for your water supply, particularly if the tank cover is not solid.

Drain pipes

Some solid-pour concrete and ferroconcrete tanks have a drain at the bottom that can be opened up for complete drainage. Rounding the bottom of a tank and placing the drain at the low spot facilitates this process. Most other types of tanks do not have bottom drainage. To get complete drainage, water has to be siphoned out with a hose or pumped out. It is a good idea to rinse a tank and drain it before using it to store water for the first time. This is to wash out any manufacturing materials that could contaminate the water.

House intake pipes

The pipe that carries the water from the tank to the pump should be above the bottom of the tank. There are two reasons for this. One is to keep the suction from pulling up the sludge that collects on the bottom of the tank or on its liner. The second reason is to have water below the pipe available for firefighting. Concrete tanks may have these pipes going through a side hole, while other types of tanks usually have the pipes going over the top of the tank.

Adding other water to tanks

To add water to your tank (from a tank truck, for example), it is usually easier to run the truck hose over the

top of the tank. Build your tank with some type of top access. Solid-covered tanks should be built with a top hatch you can open. With most tanks that do not have solid covers, the hose is put over the side and under the cover. Be sure the tank frame can support a heavy hose before doing this. Tank trucks do not have standardized hoses, so making a connection specifically to fit a tank truck hose is not recommended. For more information on water haulers and the standards they should conform to, see the section on trucked-in water on page 43.

Tank location

When setting up a storage tank, you need to take a number of things into consideration, some of which may be in conflict with one another. The tank should be close enough to the house to be able to run a down-sloping pipe from the roof to the tank. Water runoff should not enter septic system drainfields or cesspool locations. The tank should be in a location where overflow and drainage does not affect the foundations of any structures or adversely impact neighboring property. The slope of the land should influence where you put your tank. If the tank collapsed, would you suddenly have a flood of water gushing through your living room? If prevailing winds blow mostly from one direction, you may want to shelter the tank on the leeward side of the house. If you need

to bring in water to supplement rainfall, the tank should be in a location that is accessible to water haulers. For firefighting purposes, the tank should be well away from your buildings and located in front of the house (more about firefighting will be discussed in the last section).

Tank foundations

The type of foundation needed under a tank varies with the type of tank you put in. If the tank liner sits on the ground, a base of compacted soil covered with sand is the most common foundation. A concrete base is preferable but more expensive. The most important thing is that the ground is level and the foundation is free of sharp objects that could puncture a tank or liner. Undermining of the sand and base-course foundations is a common problem when tank overflow devices are insufficient or the tank is leaning. If the foundation is not solid, the tank may begin to tilt, which could lead to its collapse. Make sure that whatever type of base you use, it won't be washed away by runoff from tank overflow or runoff from other parts of the property. It is almost impossible to avoid occasional tank overflow during torrential downpours, particularly if the cover is not solid. Be sure to check your base for damage if this should occur. Inspect the foundation for damage after earthquakes. When installing overflow devices, make sure they are situated so that they will not cause the overflow water to undermine the foundation.

Pumps

To get water from the tank into your house, you need a pump system. People usually want the water system to be pressurized, so along with a pump you need a pressure tank, check valves, and a pressure gauge. These items are usually connected onto the pump or next to it. (See pages 49–50 for more information about pump systems.) Most systems also have a coarse filter with the pump. The filter should be changed once a month, or more often if needed. If the filter gets clogged with sediment, the water pressure will be reduced and more contaminants can be forced through the filter. Organic material harbored and decaying in the filter can provide a suitable environment for bacteria to grow and thrive. The coarse filter should be one of the first things to check if the water pressure drops or water quality decreases. In some systems the coarse filter is before the pump, in others, after the pump.



A small but typical electric pump. The pump sits below a pressure chamber. A coarse filter hanging from the inlet pipe filters the water before it enters the house.

Earthquakes

In the 1950s when elevated redwood tanks were the norm on the island of Hawaii, research was done on the best way to prevent a tank from collapsing during a large earthquake.⁽¹⁰⁾ Since tanks are now more commonly set on the ground, this is no longer considered as great a problem. Still, because earthquakes are a common occurrence, it is good to take them into consideration when designing and building a water storage tank. Concrete tanks, particularly those that are underground or partially underground, can be cracked by earthquakes, and cracks both let water out and let contaminants in. Cracks in underground tanks can be so small that you might not notice a water loss, but they still can allow introduction of soil-bound contaminants and, more significantly, fecal material. To the extent possible, check your tank for leaks after any earthquake activity.

Water storage highlights

- Liners must be food-grade quality; many swimming pool liners contain toxins.
- All tanks should have a cover.
- The tank cover should be solid.
- Covers and liners need to be maintained regularly.
- Plan for and direct overflow water to an area where it will not do any damage to your property, the neighboring property, or the environment.

Section 3

Rainwater Catchment System Maintenance

Tank maintenance

It is important to clean the water-storage tank periodically to remove any sludge that has built up on the bottom. Federal guidelines suggest that water storage tanks be cleaned every three years.⁽¹¹⁾ You may want to do it more often if the tank gets dirty or less often if you have a closed system with good screening devices and little dust. All tanks build up sludge, but the amount depends on the system and what gets washed into the tank. If you drain the system, do not release the water in an area where it could harm the environment or cause property damage.

The reason it is important to clean the sludge and organic material out of your tank is because it is an environment in which microorganisms grow. Also, lead and heavy metals can accumulate in sludge and create a health hazard.

Sludge removal

If you do not want to drain your tank to remove the sludge from the bottom, you can clean the bottom of the tank using a pump and hose. Or, you can siphon the sludge using a hose with an inverted funnel at the end. Create a gravitational suction, then move the funnel carefully and slowly across the bottom of the tank. Professional cleaners provide sludge removal. Some people worry that a professional tank-cleaning service will use up all their water supply. New technologies enable professionals to vacuum sludge from the bottom of a tank with minimal use of water.

Dead animals in the tank

If you discover a dead animal in the tank, the tank and water delivery system should be decontaminated,

cleaned, and drained. Remove the carcass and add a strong chlorine solution to decontaminate the water. Purge all the system's pipes and faucets with this chlorine-treated water. Then drain the entire system and flush it with clean, chlorinated water. Replace or clean and decontaminate any filtering devices. Then, repair or seal places of entry so that other animals cannot get into the tank. Professional tank cleaners are trained to deal with this kind of problem if you do not wish to do it yourself.

Leaf and organic decomposition

In addition to providing nutrients for microorganisms to grow in, the breakdown of plant and animal materials may affect the color and taste of water. Although not considered a major concern, trihalomethanes can be produced when chlorine is added to decaying organic materials. While trihalomethanes are carcinogenic, the quantity produced in a home water system is probably less than what would be considered a harmful amount and should not deter you from using chlorine as a disinfectant. If you suspect your tank has decaying organic matter inside, clean it.

Other problems with catchment water

The sources of contamination that threaten water quality are either biological, chemical, or metallic. Each type of contamination provides good reason why you should treat stored rainwater to disinfect or purify it.

The biological threats include the various pathogens that cause diseases. Leptospirosis, giardiasis, and cryptosporidiosis are three examples of diseases that come from organisms carried in the gastrointestinal or urinary tracts of mammals; birds and reptiles may also

carry some pathogens, such as those causing campylobacteriosis and salmonellosis. Carcasses of insects, animals, and reptiles, as well as other decaying organic materials, can cause water to become polluted or tainted. While not all microorganisms are pathogenic (disease causing), some may make the water undrinkable due to taste or turbidity.

The chemical threats come from many sources. Chemicals can be introduced from catchment system materials. The swimming pool liners sometimes used in catchment tanks contain biocides that can be extremely toxic. Petroleum products can leach from some composite roofing and tank cover materials. Inner tubes that are sometimes used as floats to keep tank covers out of the water leach toxic petroleum products that can turn the water black. Pesticides in the form of aerosols or dust can be carried into the system from agricultural and domestic applications. (If you live near an agricultural area, pesticide drift should be of particular concern to you, and use of a first-flush diversion device is strongly recommended.) Excessive intake of chlorine can cause gastrointestinal illness. Nearby volcanic activity can cause acid rain, and the lower pH can increase the reactivity of other chemicals in the system's materials.

Heavy metals are the third main source of potential contamination. These primarily come from building materials leaching such elements as lead, zinc, or copper into the water. Galvanized steel can leach cadmium. Heavy metals might also come from volcanic emissions and pesticide drift. Most of the problems with heavy metal identified in Hawaii are associated with lead leaching from paint, nails, flashings, and other building materials. Acid rain accelerates leaching of metals and various other chemicals from building materials. Acid rain also affects copper piping, and the leaching reaction is greater when the pipes carry hot water. Copper leached into water leaves a blue-green stain on your sink, iron leaves a brown stain, but lead is not likely to leave any discoloration.

Bacterial, viral, and parasitic worm diseases

Most biological pathogens can be eliminated by chlorination. The table on pages 28–31 lists some of the more common types that might be encountered in your catchment system. It does not list some of the more commonly known diseases that affect water quality and human health, such as amoebic dysentery, hepatitis A,

Norwalk virus, and Asiatic cholera. These are diseases caused by human feces contamination, and they are more often associated with water contamination in public utilities. They are not likely to be a problem in your water supply unless you allow people to swim in your tank or if there are leaks in the tank that allow contaminants to seep in. However, any nearby occurrence of a sewage problem, such as an overflowing cesspool, should be a clue to be concerned about possible contamination of your rainwater catchment system.

Protozoans

Protozoans are one-celled animals that normally inhabit water and soil, feeding on bacteria and small nutrient particles. Only a few of the 20,000 species of protozoans cause disease. Some protozoans produce a protective capsule, called a cyst, which allows the organism to survive for a long time in adverse conditions. In the cyst stage they can even survive a chemical environment such as chlorinated water.

Intestinal protozoans are a health threat when ingested; they enter the body when swallowed in drinking water or contaminated food. Protozoan cysts are usually spread from the digestive system of one host to another in contaminated water. Once inside a digestive tract, the protozoan changes to an active form (trophozoite), which can reproduce, usually in the intestines, to form more cysts to be excreted by the new host.

Protozoans are a problem for rainwater catchment systems because the cysts of some species survive chlorination. The cysts also can be quite small, such as the 4–6 micron *Cryptosporidium* cysts, which can get through most filter systems. This is why chlorination alone will not solve all your drinking water problems. The National Safety Foundation lists products that can eliminate these cysts; these include “absolute 1-micron” filters, some types of ultraviolet radiation, and solar pasteurization. For more information, see page 48 for NSF contact information and Section 4, *Water treatment*.

Lead

Lead contamination has been a particular problem for people using rainwater catchment systems. There is a misperception that this problem exists only in older plantation homes, where lead paint was often used both on the roof and inside the water tank. Lead can come from lead solder, paint, flashings, gutters, nails, etc. Lead-

containing products should be replaced. While older homes often are singled out as having high lead readings due to the larger use of building materials containing lead in the old days, new homes also can have lead problems. For example, faucets can be a source of lead in newer homes, particularly if the water is acidic due to acid rain.

In 1988 the Hawaii Department of Health reported that more than 70 percent of the homes in the South Kona district with lead in their catchment or distribution systems had water containing over 20 µg/liter lead.⁽¹²⁾ These high levels can lead to serious health problems, especially for children.

The more acidic the water the greater the problem with leaching of lead into the water. Hot water also can increase leaching of lead and other contaminants, so hot water from the tap should not be used for consumption.

Acid rain

Rain is considered acidic when it has a pH less than 5.6. Acid rain is often associated with man-made pollution, usually where burning of fossil fuels releases excessive amounts of nitrogen oxides into the atmosphere, but it can occur anywhere in the world. In Hawaii, the greatest cause of acid rain is fumes from volcanic activity. Erupting volcanoes release gases, particularly sulfur dioxide (SO₂). In a series of reactions in the atmosphere, the SO₂ combines with water molecules, forming a dilute sulfuric acid that returns to the earth as acid rain. Kilauea volcano releases 350 metric tons per day of SO₂ during eruptive pauses, and 1850 metric tons per day during active eruption.⁽¹³⁾

In nature, rain with a pH a bit less than 5 can sometimes fall to the earth without causing much damage. This is because the rocks, soil, and vegetation act as buffers to neutralize the acidity. If the rain's pH is too low for the earth to buffer, severe damage to the ecology of an area can occur.⁽¹⁴⁾ Farmers near the town of Volcano have had crops destroyed because the acidity of the rain was too strong for the plants. Acid rain caught in catchment systems does not have the opportunity to benefit from the earth's natural buffers. The water in catchment tanks has been reported to be as low as pH 4 in areas such as Kau and South Kona.⁽¹²⁾

The pH scale

| | | |
|---------|----|--------------|
| Basic | 12 | Oven cleaner |
| | 11 | Hair remover |
| | 10 | Soap |
| | 9 | Bleach |
| Neutral | 8 | Sea water |
| | 7 | Pure water |
| | 6 | Urine |
| Acidic | 5 | Acid rain |
| | 4 | Tomato juice |
| | 3 | Orange juice |
| | 2 | Lemon juice |
| | 1 | Stomach acid |

System maintenance highlights

- Keep your catchment system—and especially the tank—clean.
- Acid rain increases leaching of metals and other system materials into the water.
- Bacteria, viruses, protozoans, heavy metals, and chemical contaminants all threaten the quality of your drinking water—and your health.

Some bacterial illnesses associated with water

| Illness | Bacteria name | Where harbored | Notes or nature of the disease | Example methods of water contamination |
|--|----------------------------------|--|--|--|
| Listeriosis ⁽¹⁵⁾ | <i>Listeria monocytogenes</i> | Fecal matter of infected animals, which can contaminate drinking water supplies and soil | Most people can be carriers of the disease without becoming sick themselves; less than 2000 people a year get ill from the disease, but 25% of those people who get it die from it | Rodents leave droppings on roof or in catchment system |
| Leptospirosis (Weil's disease) | <i>Leptospira interrogans</i> | The urine of infected mammals | You can vaccinate domestic animals for lepto, but there is no vaccine for humans; most people believe bathing in untreated water is safe, but this is an easy way to come into contact with the leptospira bacteria | Rodents urinate on roof or in catchment system |
| Campylobacteriosis (or gastroenteritis) ⁽¹⁷⁾ | <i>Campylobacter jejuni</i> | Fecal matter of animals, domestic and feral; particularly carried by birds, domestic and wild | The most common cause of diarrheal illness in the USA; a small number of organisms (<500) can cause illness in humans (even one drop of juice from a raw chicken) | Birds or rats leave droppings on roof or in catchment system |
| Diarrhea ⁽¹⁸⁾ (traveller's diarrhea, infantile diarrhea, gastroenteritis, bacillary dysentery, hemorrhagic colitis) | <i>Escherichia coli</i> | The fecal matter of all animals, but types pathogenic to humans are mostly found in human and cattle feces | This is an unlikely candidate for catchment systems but is mentioned because of its similar symptoms, which are often mistaken for other illnesses transferred in the water tanks | Getting this disease via your water system is unlikely |
| Enteritis necroticans (perfringens food poisoning) ⁽¹⁹⁾ | <i>Clostridium perfringens</i> | The fecal matter of animals, domestic and feral | A very common form of food poisoning; you need to ingest a large amount of these bacteria to get ill; the bacteria must contact a food source, then have time to multiply, e.g., salad dressing can be contaminated by washed lettuce if it sits at room temperature for a while | Animals leave droppings on roof or in catchment system |
| Salmonellosis (or salmonella) ⁽²⁰⁾ | <i>Salmonella gastroenteriti</i> | Fecal matter of animals, including birds and reptiles | You need to ingest a large amount of these bacteria to get ill; the bacteria must contact a food source, then have time to multiply; e.g., salad dressing can be contaminated by washed lettuce if it sits at room temperature for a while | Birds or geckos leave droppings on roof or in catchment system |

| Likelihood of getting this illness | How contracted | Illness symptoms | Average duration | Possible severe complications | Who's at risk |
|--|--|--|------------------|--|---|
| It has been found in at least 37 mammalian species, 17 species of birds, and possibly some fish and shellfish | By drinking contaminated water | Fever, chills, upset stomach | 3–7 days | Listeric meningitis; spreading to the nervous system; headache, stiff neck, confusion, loss of balance, convulsions; miscarriage, stillbirth, or serious health problems for fetus | Pregnant women, newborns, older adults, people with weakened immune systems |
| In some areas of Hawaii over half the rat and mongoose populations carry leptospira strains ⁽¹⁶⁾ | Through skin cuts and soft mucus membranes, such as eyes | Fever, chills, headache, muscular pain, sweating, red eyes, vomiting | 2–5 days | Jaundice, kidney failure, death | Most people, particularly young children, older adults, and people with weakened immune systems |
| This illness is commonly caused by contaminated food, but large outbreaks have been associated with water contamination | By drinking contaminated water | Diarrhea | 2–5 days | Arthritis, Guillan-Barré syndrome | Most people, particularly young children, older adults, and people with weakened immune systems |
| You could get this disease if you have an underground water system with cracks allowing cow or human fecal matter to seep in | By drinking water contaminated by human or cow feces | Severe abdominal cramping followed by watery diarrhea becoming bloody stools; maybe nausea, vomiting | 24 hours | Hemolytic uremic syndrome, which causes kidney damage, low red blood cell count; leads to kidney failure, mostly in children | Most people, particularly young children, older adults, and people with weakened immune systems |
| The water probably would not have enough organisms to make you sick. The bacteria could multiply on food the water had touched | By eating food contaminated by infected water | Abdominal cramps and diarrhea | A few days | Necrotic enteritis (pig-bel), a rare infection of the intestinal tissue and multiplication of the bacteria in the blood stream; this requires ingestion of large amounts of the bacteria | Most people, particularly young children, older adults, and people with weakened immune systems |
| The water probably would not have enough organisms to make you sick. The bacteria could multiply on food the water had touched | By eating food contaminated by infected water | Fever, nausea, abdominal pain, cramps, and diarrhea | 5–7 days | Septicemia, death; mostly in infants and the very old | Most people, particularly young children, older adults, and people with weakened immune systems |

Some protozoan diseases associated with water

| Disease | Causal organism | Where harbored | How contracted | Notes or nature of the disease | Example methods of water contamination |
|-------------------|---|---|-----------------------------|---|--|
| Giardiasis | <i>Giardia lamblia</i> ⁽²⁰⁾ | In the fecal matter of infected animals | Drinking contaminated water | Most common cause of epidemic water-borne diarrheal disease | Infected animals leave droppings on roof or in catchment system |
| Toxoplasmosis | <i>Toxoplasma gondii</i> ⁽¹⁷⁾ | In cat, rodent, and other animal feces; also, contaminated soil | Ingesting the parasite eggs | A single-cell parasite; about 60 million people in the USA are infected but few show symptoms | Infected animals leave droppings on roof; wind blows soil with eggs into water |
| Cryptosporidiosis | <i>Cryptosporidium parvum</i> ⁽¹⁹⁾ | In the fecal matter of animals, but mice and birds are not believed to be carrying the human pathogen species | Drinking contaminated water | The majority of people have had this disease; various species, but parvum has been most responsible for large human outbreaks; cysts are tiny and go through most filters (4–6 microns) | Infected animals leave droppings on roof or in catchment system |

Other diseases associated with water

| Disease | Causal organism | Where harbored | How contracted | Notes | How disease can get into your water tank |
|--|---|--|---|---|---|
| Hantavirus pulmonary syndrome <small>(21, 22)</small> | Sin nombre virus | Wild rodents and maybe other small mammals | Drinking water containing feces, urine, or saliva from infected species | Has not been found in dogs and cats in the USA; cannot be passed between people; has been found in 19 states so far | From Mainland building materials that contain rodent feces, urine, or saliva that wash into your tank |
| Alveolar hydatid ⁽¹⁷⁾ | <i>Echinococcus multilocularis</i> (a tapeworm) | In cat, rodent, and other animal feces | Ingesting the tapeworm eggs | A microscopic tapeworm, found mostly in the northern latitudes of the USA | Infected animals leaving droppings on your roof, or wind blowing soil with eggs into the water |

| Likelihood of getting this illness | Illness symptoms | Average duration of disease | Possible severe complications | Who's at risk |
|---|---|--|--|---|
| There were 19 reported cases of giardiasis on Hawaii island in 1999 | Nausea, weakness, weight loss, abdominal cramps, diarrhea, fatigue | Several weeks or months; could be asymptomatic | Chronic diarrhea with significant weight loss | Most people, particularly young children, older adults, and people with weakened immune systems |
| Most people are asymptomatic | "Flu-like" symptoms, muscle aches | A few days to several weeks | Damage to eye or brain; fetus can be born retarded with serious mental and physical problems | Babies whose mothers were exposed during pregnancy; people with weakened immune systems |
| In Hawaii there were 3 reported cases on Oahu in 1998, none in 1999 | Nausea, vomiting, watery diarrhea, stomach cramps, headaches, and low grade fever | 2 days to 4 weeks | Severe symptoms lasting for months | Most people, particularly young children, older adults, and people with weakened immune systems |

| Likelihood of getting the illness | Illness symptoms | Average duration of disease | Possible severe complications | Who's at risk |
|--|--|---|---|---|
| 19 states have confirmed cases; not in Hawaii yet but infected droppings could easily be imported on goods from infected areas | Fever, muscle aches, headache, cough that progresses rapidly to severe lung disease | Unknown; onset is 2–3 weeks after exposure; 3–4 days until respiratory distress | Severe respiratory failure; mortality rate for the first 227 cases was 42%; could be as high as 50% | All age groups |
| Not a common problem in Hawaii | Tumor-like mass of parasites in liver and other organs; cyst with symptoms like liver cancer | Surgical removal required and continuous medication | Possible severe complications Liver and other organ damage | Mostly people in the northern latitudes; those with weakened immune systems |

Section 4

Water Treatment

The solutions to water contamination

Nothing you do to purify catchment water will be as beneficial as your efforts to keep the catchment system free from contamination in the first place. It is essential to eliminate any overhanging trees, bushes, or wires that allow access to the system by rodents and mongoose. Keep plants and trees far enough away from the system so that leaves and branches do not fall onto the roof. As much as possible, block access of insects, reptiles, birds, and amphibians to the roof and tank. You cannot make a catchment system completely free of contamination, but the more you can do to keep it clean, the better the water quality will be. Make sure the tank is covered and the cover does not hang into the water.



Do not allow trees and bushes to overhang your roof. They provide roof access to rats and other vermin.

Electrical wires and rats

Rodents can get onto the roof not only by climbing up vegetation but also by crawling along electric and telephone service wires. This problem is worse when the wires are attached to the roof rather than the side of the house. During the plantation days, rat-control workers would sometimes place disks or cones on the wires that rodents couldn't climb over. Currently it is difficult to find suitable rodent guards for this purpose, and you would need a licensed electrician to install them. The electric companies warn you not to try to install rat guards on the wires yourself due to the danger of electrocution.⁽²³⁾ If you have a problem with rats getting onto your roof, the first thing you should do is call the Ha-



Rodents can access your roof by climbing utility poles and running along electrical and phone cables. Putting the wires underground is an expensive but good solution to the problem. Attaching the wires to the side of the house may be an option if the house is tall enough to keep the wires out of reach. Contact your utility companies for advice.

waii Department of Health's Vector Control Branch. They will help you find ways to reduce the rat populations near your home.

Disinfection

Regarding drinking water disinfection (or purification), no single answer is available. You need to determine which problems or potential problems your rainwater catchment system has, and then choose ways to prevent them. Following are some things you can use and what they do for you.

Using chlorine in the water storage tank

Laundry bleach is an inexpensive, readily available material that can be used to kill many of the pathogenic microorganisms and algae that may be present in a water storage tank. While chlorination is commonly practiced by municipalities, regulatory policies in the USA tend to discourage private citizens from chlorinating water with chlorine sources not approved for water treatment. Household bleach products are not labeled for use for water treatment because they are not approved for this use by the FDA. Despite this fact, various agencies in the USA and elsewhere do recommend use of household bleach products as part of a water treatment program. In some cases, chlorination with household bleach is recommended only in emergency situations, while in other cases it is recommended as part of a sensible public health approach to disease prevention. People using and drinking catchment water need to evaluate their situation and decide for themselves what action to take to ensure safe water.

A typical recommendation for chlorine treatment from the literature available on the subject⁽¹¹⁾ is to add 2½ ounces (just under ⅓ cup) of unscented laundry bleach (containing 5.25 percent available sodium hypochlorite) for every 1000 gallons of water during rainy periods; during dry periods, the recommendation is to add 5 ounces per 1000 gallons of water.* The objective is to keep 1 part per million (1 ppm) of chlorine in the

tank. In the absence of a method of precisely monitoring and maintaining this level of chlorine in the tank, some sources recommend that chlorine be added once a month. At the recommended level of 1 ppm, the presence of chlorine is slightly discernible in the taste of the water.

The active ingredient of most household bleach products is sodium hypochlorite. Read the label to find out the sodium hypochlorite content. If the percentage is not listed, call the company's customer service department and ask. Do not use scented bleach or products with other types of additives.

Newer household bleach products may contain 6 percent sodium hypochlorite. In this case, you would use 2 ounces (¼ cup) per 1000 gallons during rainy periods and 4 ounces per 1000 gallons during dry periods.

Use the formula or charts on pages 13–14 to determine the amount of water in the tank. In your calculations, measure the total volume of water in the tank, not just the “accessible” water.

If you drink catchment water and are concerned about using laundry bleach, you can buy other, purer forms of chlorine, which usually come in solid rather than liquid form. Solid chlorine is calcium hypochlorite and usually has 75 percent available chlorine. At that strength, 0.85 ounces by weight in 1000 gallons of water would result in a level of 1 ppm chlorine. If you are against ingesting any kind of chlorine, you could filter it out with a faucet filter or some other point-of-use type filter.

One instance where chlorine is not recommended as an effective treatment is when the water pH is above 8.5. Such high levels of pH often occur in concrete tanks because calcium in the concrete raises the water's pH. The higher the pH, the more chlorine is required to disinfect the water, and it is difficult to maintain adequate chlorine levels. If the pH of your water is high, other treatment methods are recommended, such as ultraviolet light treatment systems.

Chlorine may not be a good treatment in combination with reverse-osmosis treatment systems, because

*You may wonder why more chlorine is recommended per 1000 gallons during dry periods, when there is less water to treat. During wet periods there is more throughput and turnover in the system—stored water may be actively consumed due to ample supply, and some water may even be lost in overflow from a full tank. During dry periods, less water is moving through the system, and the volume of water stored becomes smaller. If there are biological pollutants in the system, they tend to become more concentrated in dry periods, and more chlorine is needed to disinfect the water. As a general rule, the more rain, the cleaner the water in your catchment system.

some of the membranes used in these systems break down in the presence of chlorine.

For either liquid or solid chlorine sources, it is best to dilute or dissolve the material in a bucket of water before adding it to the tank. This results in more even distribution. Fill the bucket first, then add the chlorine to the water. Do not add the water to the chlorine source—this can cause a chemical reaction that could splash and burn you. After pouring the solution into the tank, stir the tank with a paddle. Some people mix the water using their garden hose to circulate the water. Do not pour the solution into the tank next to the pipe that takes the water into the house, because the chlorine could be pulled into the pipe before it's mixed. Chlorine added to water will dissipate, reducing its effectiveness. Chlorine dissipates more rapidly in sunlight or if the tank contains organic debris. If the tank is not covered, added chlorine dissipates so rapidly that it is almost impossible to maintain a 1 ppm chlorine level. This is one reason we suggest that water storage tanks should be covered. The amount of rainfall will also influence the dilution of chlorine in your tank. You need more chlorine if your tank is dirty, but the best advice is to clean the tank.

One problem with using chlorine is keeping an adequate level of it in the tank. It is because most people cannot or do not want to monitor the chlorine level that various public health sources recommend regular monthly application of chlorine; while this method is imprecise, it is considered better than no treatment at all. If you do monitor the chlorine level, you can add just enough to keep a 1 ppm level in the tank. If you drink the water, you should monitor the chlorine level. Test kits are available to check chlorine levels, but the ones designed for swimming pool water are not likely to be sensitive enough. For more information on chlorine test kits, contact the Hawaii Department of Health, Safe Drinking Water Branch, or the Cooperative Extension Service office in Hilo.

Why almost everyone should purify catchment water with chlorine

The number one reason to use chlorine in catchment water is because it kills leptospira bacteria. Leptospira is found in the urine of mammals. This bacterium is widespread and prevalent in Hawaii, and much of the rodent and mongoose population is infected. Hawaii Department of Health studies on the island of Hawaii have found that

people on catchment systems are at risk for leptospirosis. This disease is usually contracted by skin contact, not through the digestive system. It will enter your blood system through breaks in your skin or through your mucous membranes. Sitting in a bathtub, taking a shower, washing your car or your dog—all of these are risky if your catchment water is untreated. If contaminated animal urine is in your water, you are putting yourself at risk every time you wash your hands.

Chlorination is a proven, inexpensive solution that will not eliminate all potential problems but will take care of most of them, including leptospirosis, if done properly. The need for chlorination can be avoided if you can afford a decontamination device that effectively treats all the water from your rainwater catchment system. If you have objections to drinking chlorinated water, you can buy a faucet filter for your drinking water to eliminate the chlorine after treatment, or you can buy drinking water.

Concerns about using chlorine

People have been drinking and surviving on municipal chlorinated water for generations and have not experienced an obvious health threat. The technology has been proven safe and effective. However, when the technology is transferred to the home catchment system, some people have concerns about it. Even in municipal systems, chlorine can give an odor and taste to treated water that might be found objectionable. Some people are concerned that chlorine will cause gastrointestinal illness, but they likely are at greater risk of gastrointestinal problems when drinking nonchlorinated water from a catchment system. Some people are concerned about carcinogenic trihalomethanes being produced when chlorine reacts with decaying organic material. Production of trihalomethanes can be minimized by keeping your water tank free of debris. Also, it would be difficult to produce enough trihalomethanes in this manner to cause a health threat.

What chlorine doesn't do for you

It is important to remember that while chlorine is very effective on most microorganisms, it doesn't protect you from all of them. While chlorine is a very effective agent for killing many pathogenic organisms, such as leptospira, it will not kill protozoan spores (cysts) of pathogens such as *Giardia* or *Cryptosporidium*. In fact, even full-strength household bleach cannot harm some pro-

tozoan cysts. These single-celled animals can be harmful to humans, especially the young, the elderly, and those with compromised immune systems.

Other disinfection techniques

There is no generally accepted substitute for the use of chlorine as a disinfectant in water purification,⁽²⁴⁾ but there are other methods you could use. Boiling water for 3–5 minutes kills pathogenic viruses, fungi, and bacteria, but this method is impractical on a large scale, and expensive. Solar distillation units are practical for treating small amounts of drinking water, and they are likely less expensive than boiling over the long term.

Chemicals other than chlorine have been tested for effectiveness in disinfecting drinking water, including chlorine dioxide, ozone, bromine, iodine, and colloidal silver, and some of them have been developed into commercial water-treatment products. Claims of companies selling such products should be carefully researched.

Filters

Filters come in various types that do different things. No single filter will take care of all your water treatment needs. A filter is basically a screen that catches particles in water and still lets the water run through. Filters with smaller screen or pore sizes trap more debris, but the small size restricts water flow, and the filter clogs sooner and has to be cleaned or changed more often. The amount of particulate matter caught in your system also determines how often you need to clean or change a filter.

Filters can harbor bacterial growth, so it is important to maintain and change them regularly. Once a month is the standard for coarse filters, but that varies depending on your system's conditions. Most filters do not keep microorganisms out of your water, so you are not safe from pathogens just because you have a filter. Some filters, however, are specifically made to trap protozoan cysts. You should understand exactly what you want your filter to do, then purchase one that does it.

Water pressure can force larger particles through pore sizes that would normally be too small. As pressure builds behind a dirty filter, more particles will get pushed through the filter. Therefore, pore size and filter function are not absolute; as the filter ages, the material in it can stretch, wear down, or tear. This is another reason to change filters on a regular basis.

Coarse filters

Most water pumps come with a coarse filter, sometimes called a sediment filter. These act by catching the larger particles of debris. You can buy filters of various pore sizes. Common ones range from 20 to 30 microns in pore diameter, although they come in smaller pore sizes too. The smaller the holes, the less water pressure is available at the faucet. Coarse filters are not designed to filter out chemicals or pathogens.

Faucet, under-sink, and pitcher-type filters

Many people use small filters to purify their drinking water. These filters are problem-specific and have various limitations. For example, if your concern is to get rid of the chlorine taste in the water, you should choose a specific type that removes chlorine. Other filters remove lead, and others remove protozoan cysts. None of these filters remove bacteria and viruses.

It is difficult to know whom to believe when researching the claims of commercial brands of filters. There are many conflicting opinions. You should not rely solely on the manufacturer's claims about its product. And an important consideration is that most of the near-faucet systems are designed to be used with public water supplies, which are already in compliance with drinking water quality standards, not with catchment water (which is considered "raw water").

One of the better, unbiased sources of information on filters can be found on the Internet at the National Sanitation Foundation's Web site, <<http://www.nsf.org>>. The NSF certifies drinking water treatment units for their ability to reduce the levels of specific contaminants. It is always wise to verify a manufacturer's claim or specifications against their NSF certifications.

Different types of water filters and purification devices are listed on page 37. As the list shows, no single method of treatment can remove all potential contaminants. Generally, a good system will utilize a combination of treatment methods to provide a "multiple barrier."

What is the best system for you?

If you are confused about filtering systems, don't feel alone—even the experts can't agree. Every household needs to determine its own needs and budget restrictions. Remember, the best line of defense is keeping the entire rainwater catchment system clean and free from contamination in the first place.

Water treatment systems

| Type | Eliminates | Advantages | Limitations, special requirements |
|---|--|---|---|
| Basic filters | | | |
| Sediment filter ("coarse filter") | Larger particles | Often needed for pre-filtering before other filters or disinfection systems will work; reduces turbidity; inexpensive | Doesn't remove pathogens or small particles, metals, or chemicals; clogs quickly if tank is dirty; filter should be changed approximately once a month |
| Ceramic candle (filters through ceramic) | Particulates and some bacteria | Simple, inexpensive | Probably not effective against viruses; only makes small quantities; needs frequent cleaning |
| Fine filter | Smaller particles | Takes out more sediment than a coarse filter | Specific for a task; may not work on rainwater; clogs quickly; most made to work only on pretreated water, not rainwater; more effective after coarse filter |
| Disinfection treatments | | | |
| Chlorination | Most biological pathogens | Proven, widely used technology; inexpensive | Ineffective on some protozoan cysts; regular application and residual monitoring needed |
| Distillation | Pathogens, most metals and inorganic contaminants | Very effective in killing pathogens including cysts; solar units available; no filters to replace | Done in batches; slow; expensive; may not remove all organic volatile materials; needs holding tank and lots of electricity or energy source |
| Pasteurization (boiling) | Pathogens | Very effective in killing pathogens including cysts | Done in batches; slow; expensive; may not remove all organic volatile materials; doesn't remove metals and inorganic materials; may need holding tank; uses lots of electricity or energy source |
| Ozonation | Pathogens | Short exposure time required; produces no taste or odor | Expensive; only effective at point of contact; could produce toxic by-products such as formaldehyde and ketones; needs electricity (can be solar powered) |
| Ultraviolet light | Pathogens | Doesn't use chemicals | Doesn't work well on turbid water; works best following filtration; may not kill cysts; expensive; water flow rate limited by size of system; light needs to be kept clean; needs electricity |
| Other treatments | | | |
| Activated carbon | Most organic chemicals, chlorine, bacteria, lead, iron, copper, radon | Usually improves taste of water | Doesn't remove minerals, nitrates, viruses, or radioactive particles; if filter has silver nitrate to prevent bacterial growth, then silver could leak and is toxic; large variety of prices, sizes, and types of units; replacement of carbon filter every 6–12 months |
| Reverse osmosis | Toxic metals, radiation (except radon), inorganic salts, most bacterial pathogens (depending on membrane and unit) | Some models and membrane types remove <i>Cryptosporidium</i> cysts; many sizes and types of models to choose from | Susceptible to clogging; flow rate dependent on size of system; interferes with normal water flow (by 25–50%); for every gallon of clean water, 6–8 gallons of water may be wasted; adequate water pressure required; flushing may be required; can be very expensive; membranes vary in quality and durability and may need to be changed frequently; some membranes do not work with chlorinated water or hard water; membranes can harbor bacteria |

If your budget is limited, the least expensive and most effective thing you could do would be to treat your water with chlorine regularly and get all your drinking and cooking water from public spigots. You have to remember not to drink water while in the shower, not to drink water from outside taps, and to brush your teeth in clean water. Your pets can be susceptible to water contamination, so be sure to give them clean water too. Keep your roof and tank clean, and install an inexpensive first-flush diversion device.

If you have a less restrictive budget, in addition to chlorinating and using a first-flush diverter and a coarse filter, you should consider installing another filter or treatment device for your drinking water that will eliminate protozoan cysts. *Cryptosporidium* produce very small cysts, so any system purchased to eliminate cysts should be certified to eliminate *Cryptosporidium*. An “absolute 1-micron” filter is normally used for this purpose.

Absolute 1-micron filters are relatively inexpensive, but they do restrict the water flow rate, which makes them impractical for showers or any faucet where normal pressure and flow volume is required.

If pesticides are applied in the vicinity of your catchment system, you may want to look into specialized filters for removing pesticides, such as a carbon filter. Be sure to read the manufacturer’s specifications, then check out the product’s certification for the target contaminant with the National Sanitation Foundation.

If your budget isn’t limiting, you have many options. For example, if you do not have a heavy metal problem, you can use a pasteurization unit that works on solar power. You can store water in separate tanks, one for collecting “raw water” and a second one for holding purified water, and then you can use the two supplies appropriately. Systems with multiple filters, rapid-flow UV purification units, and other combinations of devices can be developed to meet your particular needs.

Everyone will have different needs and concerns. Each home rainwater catchment system will have its own characteristics, and each will have its individual problems. The important thing is to identify the potential dangers and do your best to prevent them from becoming health hazards to you and your family.

Water treatment highlights

- Keep bushes and trees away from your roof and tank.
- Block off or remove any possible access to your roof or tank by animals.
- Unless water pH is over 8.5 (as in some cement tanks), chlorine is highly recommended as a treatment to kill bacteria, fungi, and viruses, particularly the bacterium causing leptospirosis.
- To treat your water supply with chlorine, add 2 ounces unscented household bleach (6% strength) per 1000 gallons of water in the tank.
- Leptospirosis disease is spread through contact with the urine of infected animals. The leptospira bacteria, which is found in most of our rodent population, enters the human body through tiny skin cuts and soft mucus membranes. This puts you at risk anytime you come into contact with water contaminated with leptospira.
- Chlorine test kits are recommended for monitoring drinking water.
- In addition to chlorine, a treatment system such as an absolute 1-micron filter is recommended to remove protozoan cysts from drinking water.
- Filters are not designed to remove bacteria and viruses.
- Most water treatment and purification options are designed for use with municipal water, not for the raw water of rainwater catchment systems. If you are confused about treatment options, ask for help. Phone numbers are listed in the *Notes and References* section of this document.

Section 5

Water Testing

Water testing—a snapshot in time

When you take a sample of your stored water to be tested, the results only reflect a “snapshot in time.” The analysis tells you only what is in that portion of your water system during the moment when you collected the sample. However, it still is useful to do tests in order to know the general condition of the water and evaluate the effectiveness of your system maintenance and treatment. For example, high total coliform counts suggest a fecal contamination problem and the probability that lizards, birds, and other animals have access to your catchment system.

How often you have your water analyzed depends on your tank and situation. When you move into a house with an existing tank, it is a good idea to test the water. If you suspect contamination, you should test the water. You should particularly do a test if there is a change for the worse in the water’s turbidity (cloudiness), color, or taste. If you don’t regularly treat or purify your water, or if your tank is subject to contamination, you should test it periodically. If you have an older tank and older home, be sure to test for heavy metals.

How to get water tested

The first step is to determine what you want your water tested for. Checking for bacterial contamination is always important, but perhaps you have other concerns. Think about what materials the system components are made of. Could the pipes contain lead? What about your paint? Do the neighbors spray pesticides nearby? What types? Make a list of your concerns, then start searching for a laboratory that can do the analysis.

Only a few laboratories test water in the state of Hawaii. Check the telephone directory under Laborato-

ries-Analytical for local listings. You can also call the Hawaii Department of Health’s Safe Drinking Water Branch in Honolulu toll-free at 974-4000, ext. 64258, or the University of Hawaii Cooperative Extension Service’s Hilo office at (808) 959-9155 for more information.

HDOH has offered subsidized lead and copper testing when funds are available. This test currently costs the consumer \$25 plus shipping. Call the Honolulu branch number given above for details.

In addition to commercial laboratories in Hawaii and on the Mainland, the CTAHR Agricultural Diagnostic Service Center (ADSC), located at UH-Manoa, offers water testing in several categories: (1) pH and salinity; (2) heavy metals including lead, arsenic, selenium, cadmium, chromium, copper, zinc, silver, and nickel; (3) minerals including aluminum, boron, calcium, copper, iron, magnesium, manganese, molybdenum, phosphorus, potassium, sodium, and zinc; and (4) nitrates, nitrites, ammonium nitrogen, and total nitrogen. The sample needed is approximately two cups (16 oz) of water in a clean plastic container. Samples can be brought to ADSC on the Manoa campus or to CTAHR Cooperative Extension Service offices throughout the state.

The type of testing you want done will determine how to take and preserve the sample. It is important to contact the analytical laboratory to find out exactly how to take and transport a water sample for the analyses you want.

Here are some questions to consider, as suggested by the HDOH Safe Drinking Water Branch, before you choose a laboratory for water analysis.

- Do they use U.S. Environmental Protection Agency (EPA) approved drinking water analysis methods to

analyze the contaminants you have chosen?

- If they do not use EPA drinking water methods, what methods do they use, and why do they consider that satisfactory?
- Can they analyze all the chemicals and microbiological agents you have selected?
- What is the cost of the requested analyses?
- Do they provide sampling containers and instructions for sampling?
- Are there requirements for shipping and handling, including time constraints between sampling and analysis?

Microbiological testing

If someone using a water catchment system is ill and the water is suspected to be the cause, a doctor should be seen for diagnosis. Water analysis only tells you what is in your tank at the moment of testing; whatever caused the illness could have already been flushed out of the system.

Total coliform

When you test for total coliform, you are looking for indications of fecal waste. Coliform bacteria are called “indicator bacteria” for waste products including bird and rat droppings. However, the test could also be positive for coliform if you have leaves and other organic materials in your tank. A positive total coliform test tells you—at least—that the system is dirty and could use cleaning and disinfection. It does not necessarily tell you that you have fecal coliform bacteria in the system, but it is likely—if a lot of plant material can enter the tank, it is probable that animals and their wastes can enter it as well.

Fecal coliform

A positive fecal coliform test tells you that there are animal waste products in your water sample. If you have the water tested for total coliform and it comes out positive, then a fecal coliform test would confirm that there were animal waste products in your water. Positive results of either test indicate that you should clean the tank, but if there is any fecal contamination, you definitely should decontaminate the tank and the system. There is no water analysis for leptospira bacteria, which are spread through animal urine, but if the test is positive for fecal coliform, you should assume there also is urine contamination.

Simple test kits are available that can be used by a homeowner to test for fecal contamination. Some kits

indicate the presence of *E. coli* bacteria populations, while others test for bacteria that produce hydrogen sulfide (H_2S). Because Hawaii has indigenous *E. coli* populations in the soil, those test kits are probably not as accurate as the kits measuring H_2S .⁽²⁵⁾ These simple tests will not tell you how much fecal bacteria are present, but they will tell you if there is some or none. Such “presence-absence tests” are useful tools for homeowners who wish to monitor their water systems.

Heterotrophic bacteria

Heterotrophic plate counts are tests that check the general quality of your water by looking for various types of bacteria, not just those associated with fecal contamination. For drinking water, you should not have more than 500 bacteria colonies per milliliter of water.

Because the purpose of the water testing is to see if the water is dirty or not, once you get a positive reading for total coliform or fecal coliform you should decontaminate the system. You really don’t need to pay for an additional heterotrophic plate count.

Inorganic contaminant testing

Inorganic substances from the materials making up rainwater catchment systems often can be leached to contaminate the water supply. Acid rain increases the leaching properties of water; for example, copper pipes will leach copper if your water is acidic, and this will make green stains on porcelain fixtures. Lead is one of the most serious problems caused by metals in Hawaii’s rainwater catchment systems, especially in older homes that used lead paint and other lead materials. Some newer homes also have lead contamination, most often from brass faucets.

The terms you should be familiar with regarding inorganic contamination are the following:

Action level—EPA regulations require that public water systems be treated when the amount of contaminant reaches this level. This amount of contaminant is not an immediate health threat but should be used as an alert that decontamination is advisable.

MCL—maximum contaminant level allowed by federal or state law (standards mentioned below are federal standards).

SMCL—secondary maximum contaminant level; this level is for unregulated compounds, which may not be desirable for aesthetic reasons but are not consid-

ered to pose a health risk.

mg/L—milligrams per liter (= parts per million, ppm)

µg/L—micrograms per liter (= parts per billion, ppb)

The following contaminant levels and definitions of problems are taken from publications of the University of Florida Cooperative Extension Service,⁽²⁶⁾ the South Central Connecticut Regional Water Authority,⁽²⁷⁾ and the U.S. EPA.

Aluminum (Al). No MCL established; SMCL = 0.05–0.2 mg/L. High aluminum levels are associated with premature senile dementia (Alzheimer's disease) and other types of dementia.

Arsenic (As). MCL = 0.01 mg/L. Minor symptoms of chronic arsenic poisoning are similar to those of many common ailments, making actual arsenic poisoning difficult to diagnose. This type of poisoning can make people tired, lethargic, and depressed. Other symptoms are white lines across the toenails and fingernails, weight loss, nausea and diarrhea alternating with constipation, and loss of hair. Arsenic is highly toxic and widespread in the environment due to its natural occurrence and former extensive use in pesticides.

Barium (Ba). MCL = 2.0 mg/L. Due to the scarcity of data on the chronic effects of barium, the MCL includes a large safety factor. High levels of barium can have severe toxic effects on the heart, blood vessels, and nerves. It is capable of causing nerve blocks at high doses; 550–600 mg is a fatal dose for humans.

Cadmium (Cd). MCL = 0.005 mg/L. Acute cadmium poisoning symptoms are similar to those of food poisoning. Cadmium causes damage to kidneys, digestive tract upsets, brittle bones, and is linked to hypertension. There is also some evidence that cadmium can cause genetic mutation.

Calcium (Ca). MCL not established. Low calcium intake can be related to hypertension and cardiovascular disorders. There is a link between low calcium intake and osteoporosis. With a low level of calcium in the diet, drinking water may provide a significant portion of the daily calcium requirement.

Chromium (Cr). MCL = 0.1 mg/L. Freshwater and saltwater aquatic life can be adversely affected by the presence of chromium. The effect of chromium in drinking water has not been thoroughly investigated. However, chromium is known to produce lung tumors when inhaled. It also causes kidney, liver, nerve, and circula-

tory system damage, respiratory disorders, dermatitis, and digestive problems.

Copper (Cu). Action level = 1.3 mg/L. Studies show that diets in the USA are often deficient in copper. Its deficiency causes anemia, loss of hair pigment, growth inhibition, and loss of arterial elasticity. High levels of vitamin C inhibit good copper absorption. However, water containing amounts higher than 1 mg/L is likely to supply too much of this metal and that level is also the taste threshold for most people. Copper is highly toxic and very dangerous to infants and people with certain metabolic disorders. Uptake of copper is also influenced by zinc, silver, cadmium, and sulfate in the diet. Few people have been diagnosed with copper toxicity, but it is possible that acidic water could corrode copper pipes more quickly and they could fail or spring leaks.

Iron (Fe). SMCL = 0.3 mg/L. The presence of iron in drinking water may increase the hazard of pathogenic organisms, because most of those organisms need iron to grow, but this availability of iron in drinking water has not been well researched. It is known that iron influences the uptake of copper and lead. Iron can stain laundry and porcelain and produce an "off" taste.

Lead (Pb). Action level = 0.015 mg/L. Lead can occur naturally, or result from industrial contamination, or be leached from lead pipes in some water systems. If the plumbing contains lead, higher levels will be detectable in the morning after water has been standing in pipes throughout the night. Lead is a cumulative poison. Lead poisoning is difficult to distinguish in its early stages from minor illness. Early reversible symptoms include abdominal pain, decreased appetite, constipation, fatigue, sleep disturbance, and decreased physical fitness. Long-term exposure to lead may cause kidney damage, anemia, nerve damage including brain damage, and death. Lead poisoning affects almost every organ and system in the body. The most sensitive is the central nervous system.

Magnesium (Mg). MCL not established. An average adult ingests as much as 480 mg of magnesium daily. Any excess amounts are quickly expelled by the body. No upper limit has been set for this metal in drinking water. It can, however, create a problem for people with kidney disease. They may develop toxic reactions to high levels of magnesium, with symptoms including muscle weakness, coma, hypertension, and confusion.

Manganese (Mn). SMCL = 0.05 mg/L. Excess manganese in a diet prevents the use of iron in the regenera-

tion of blood hemoglobin. Large doses of manganese cause apathy, irritability, headaches, insomnia, and weakness of the legs. Psychological symptoms may also develop including impulsive acts, absent-mindedness, hallucinations, aggressiveness, and unaccountable laughter. Finally, a condition similar to Parkinson's disease may develop. Manganese causes a bitter taste in water, and at high concentrations (above 0.1 mg/L) it causes laundry stains and can stain fixtures.

Mercury (Hg). MCL = 0.002 mg/L. Mercury poisoning symptoms include weakness, loss of appetite, insomnia, indigestion, diarrhea, inflammation of the gums, black lines on the gums, loosening of teeth, irritability, loss of memory, and tremors of fingers, eyelids, lips, and tongue. At higher levels, mercury produces hallucinations, manic-depressive psychosis, gingivitis, diarrhea, increased irritability, muscular tremors, and irreversible brain damage.

Selenium (Se). MCL = 0.05 mg/L. One recognized effect of selenium poisoning is growth inhibition. There is some evidence that selenium is related to skin discoloration, bad teeth, hair and fingernail loss, and some psychological and gastrointestinal problems. On the other hand, a small amount of selenium has been found to be protective against other heavy metals including mercury, cadmium, silver, and thallium.

Silver (Ag). SMCL = 0.01 mg/L. The first evidence of excess silver intake is a permanent blue-gray discoloration of the skin, mucous membranes, and eyes. Large doses of silver can be fatal.

Zinc (Zn). SMCL = 5 mg/L. Zinc, which can leach from unpainted galvanized metal roofs, is essential in our diet. However, very high concentrations can irritate the digestive system. More than 5 mg/L of zinc can cause a bitter taste and opalescence in the water, but it is unlikely that you would ingest enough zinc from your water supply to cause harm. Zinc does not accumulate in the body with continued exposure.⁽²⁴⁾

Other water testing

Dissolved silica can cause scale formation on pipes, particularly in hot water systems.

Ammonia is a decomposition product of plant and animal protein. It can be very toxic to fish.

Nitrate (MCL = 10 mg/L) is more of a concern in well water, and excessive amounts can cause illness and

infant death. The presence of nitrate contamination could indicate bacterial contamination.

Nitrites (MCL = 1 mg/L) are formed during the decomposition of organic materials that contain nitrogen. Even low levels can be harmful to humans.

Sulfate in the form of magnesium sulfate or sodium sulfate can act as a purgative.

Tannin (found in redwood tanks) is an astringent material found in many plants. Tannin is also present in tea, coffee, and walnuts.⁽²⁸⁾ It is water soluble and can stain laundry, although it is usually diluted enough in water tanks to not be considered a problem.

Trihalomethanes (MCL = 0.08 mg/L) are volatile organic compounds that contain chlorine and/or bromine, such as chloroform and bromodichloromethane. They can be formed when chlorine is added to water containing decaying organic material, such as algae, leaves, and dead bugs. The more organics you have in your tank, the more trihalomethanes will be formed if chlorine is added to the water. In very large amounts, trihalomethanes have been linked to cancer and reproductive problems. The threat of cancer and other health risks from trihalomethanes is much less than the threat of water borne diseases that occur when water is not chlorinated. Scientists have asserted that the risk of getting cancer from eating one peanut-butter sandwich (containing 2 ppb aflatoxin) is higher than the risk of drinking water with one part per billion of chloroform (a component of trihalomethane).⁽²⁹⁾ It is estimated that the risk of getting cancer from the consumption of 1 part per million of chloroform in water is 1 in 10 million.⁽³⁰⁾ Even though the risk of health problems from trihalomethanes is small, keeping water storage tanks clean of organic materials is recommended as the best way to minimize the chance that trihalomethanes will be produced by chlorine treatment.

Other organic chemicals

MCLs have been established for a variety of organic chemicals. For more information, call the Hawaii Department of Health's Safe Drinking Water Branch toll-free at 974-4000, extension 64258.

pH

pH is a unit used to describe the acidity or alkalinity of water. Most drinking water is in the range of pH 6.5 to 8.5. pH 7 is neutral. Water above pH 7 is considered alkaline (basic), and below pH 7 it is considered acidic.

Rainwater is more acidic than groundwater. Due to acid rain in parts of Hawaii (see p. 27), many water catchment systems, particularly those in the Volcano area, have pH readings that are lower than 5.5. The more acidic the water, the more prone to corrosion the system is. You can lessen the acidity of your catchment tank water by using a concrete water tank or by adding bicarbonate of soda to the tank.

Turbidity

Turbidity (cloudiness) is usually caused by undissolved inorganic or organic materials washed into the system from the catchment area. Turbidity tests measure the suspended particulate matter in water using nephelometric turbidity units (NTU). The MCL is 1.0 NTU for surface water. Even if the undissolved materials aren't carrying pathogens, the appearance of cloudy water is often displeasing to someone who has to consume it. If your catchment system water is turbid, it is time to clean your tank and eliminate the source of the problem. If you use filtering or purification devices, be aware that many of them will not work if your water is too turbid.

Color, odor, taste

Whenever water has a distinctive color, odor, or taste, you should be concerned with contamination. If you are chlorinating the water, it should have a slight chlorine taste or odor (some people may be quite sensitive to this, while others may not notice it). Other than chlorine, water should not have any taste or odor.

Discoloration can come from certain metals and organic materials, described previously, some of which cause stains. These contaminants can also change the taste of the water. While the presence of minerals often gives water a certain subtle flavor that is desirable, metallic and "off" flavors should be regarded with suspicion. Discoloration by itself is not considered a health threat, but it can be a nuisance, and its source should be investigated. Water's color is measured in color units (CU); the SMCL is 15 CU.

Odor is a subjective observation. Water quality specialists have established a numeric code to denote the type of odor and its intensity. For example, using an odor code of 31, the "3" denotes that the odor is chlorine and the "1" describes the intensity.⁽²⁷⁾

Trucked-in water

If you are buying water in bulk, delivered by a tank truck, be sure to know its source. Water tankers that look clean and shiny on the outside could be harboring rust, decay, pathogens, or contaminants on the inside. To legally be a commercial water hauler, truck owners must have a Public Utilities Certificate (PUC). A PUC still does not guarantee that the water comes from a clean source or is carried in a clean container. Haulers may, at their own expense, certify their tanks for safe water hauling.

According to the HDOH Safe Drinking Water Branch,⁽³¹⁾ state regulations require HDOH to ensure that truckers hauling water to a *public water system* meet procedures or standards specified by the department. Water haulers transporting water to private homes are not subject to such health procedures or standards. When shopping for a water hauler, ask whether the hauler is currently approved by the HDOH, because some truckers hauling water to private businesses such as restaurants are also approved by the department.

HDOH approval provides the following: (1) assurance that the tank is used only to transport water or food products and not petroleum products or chemicals, (2) assurance that the tank has been tested for coliform and bacteria contamination, and (3) that a visual inspection has been conducted to provide assurance that the water tank is sealed and that the water will not be contaminated during transportation. This approval is valid for one year.

Some water haulers are in business to carry water for toilet and other non-potable uses. They have no reason to get HDOH approval. Their prices could be much cheaper than other haulers who do comply with HDOH standards, so be wary of "cheap" rates. Be sure you are not getting water from a container that normally carries non-potable water.

Don't be afraid to ask questions of your water hauler. Avoid giving up quality for a discounted price. Does the hauler have a Public Utilities Certificate? Where does the water come from? What is the tank made of? Does the cover have a gasket seal to prevent contamination from entering? Do the output hoses have covers on both ends and are they sealed between use? Has the tank ever carried anything other than water? How often is the tank cleaned, and how is the cleaning done?

Often during droughts, there are not enough haulers to meet the demand. Just about anyone who can carry

water can find desperate people to sell water to. Plan ahead before a drought hits and find a hauler you trust. Call before your water gets too low, so if you need to wait for the delivery, you can do so. Every time the rains let up, keep an eye on the levels in your tank.

Water testing highlights

- Testing water from storage systems only tells you what is in the sample at that moment. If someone is ill and you need to identify the cause, test the person, not the water.
- If you have had your water tested and do not know how to interpret the results, call one of the sources of assistance listed under Notes and References.
- A positive result of a total coliform test should be enough to induce you to clean and decontaminate your system.
- Everyone should be concerned about microbiological and lead contamination.
- If your water changes in taste, odor, or color, have it tested.
- Use a reliable water carrier if you need to buy water.

Section 6

Firefighting Concerns

In a 1999 survey, 106 residents living on water catchment were asked if their water should be available to firefighters in case of an emergency;⁽³²⁾ 44 respondents said yes, 35 said no, and 22 were unsure. When asked if all rainwater catchment system users should be required to keep a certain percentage of water in their tanks at all times for firefighters, 12 said yes, 75 said no, and 18 were unsure. This is an interesting question to ponder, and everyone depending on rainwater catchment should think about it, because the time may come when these considerations are put before the legislature and could be put into law. Even more important, the time may come when your house is on fire, and the only way to save your house is quick access to additional water from a neighbor's tank.

If your house were on fire, how much water would the fire department need to put the fire out? According to the National Fire Protection Association, the average fire in a 1200 sq ft dwelling requires about 2570 gallons of water to extinguish. A 2000 sq ft home takes 3429 gallons.⁽³³⁾ The water capacity on hand depends on the community. If the supply runs out, how long would it take a back-up tanker from a nearby department to get to your location? Here are examples from some parts of the island of Hawaii regarding water resources at firefighters' disposal: Pahoa's fire station has an 1100-gallon tanker and an engine that carries 1000 gallons; Keaau has a 1000-gallon tanker and a 1000-gallon engine; Hawaiian Paradise Park has a 1000-gallon engine, and volunteers have a 750-gallon tanker; Ocean View volunteers have a 1000-gallon tanker; and Volcano volunteers have a 500-gallon tanker with KMC and National Park Service back-up.⁽³⁴⁾

Think of the distances other support tankers would have to travel to get to your home, especially if you are located in a remote rural area. The amount of easily accessible water during a brush fire is even more critical because of the volume needed. Currently, if an owner allows the fire department to use his or her private water supply, the fire department refills the tanks once the fire is over.

Being able to use water from a catchment system storage tank is not just a matter of throwing a hose over the top. If local fire departments got to dictate how they would set up a private water tank for ease of access for firefighting, this is what they would like:⁽³⁴⁾

- Situate the tank(s) in front of the home for easy access.
- Have the tank and outlet at least 50 feet away from the home or structure that needs protection.
- Provide an outlet pipe with a National Standard 2½-inch fitting to match the fire department's hoses. National Standard fittings can be purchased at local hardware stores. Call the fire department numbers listed below to get more information on piping specifications.
- Keep the tank no more than 5–6 feet tall for easy drafting of the water if piping is not provided.
- Cut back trees and bushes from the driveway and access way to the tank so the large fire department vehicles can get to the tank.
- Provide an access to the tank for big trucks.
- If you have a fence, make the gate large enough for a big rig to go through, and account for their turn radius.

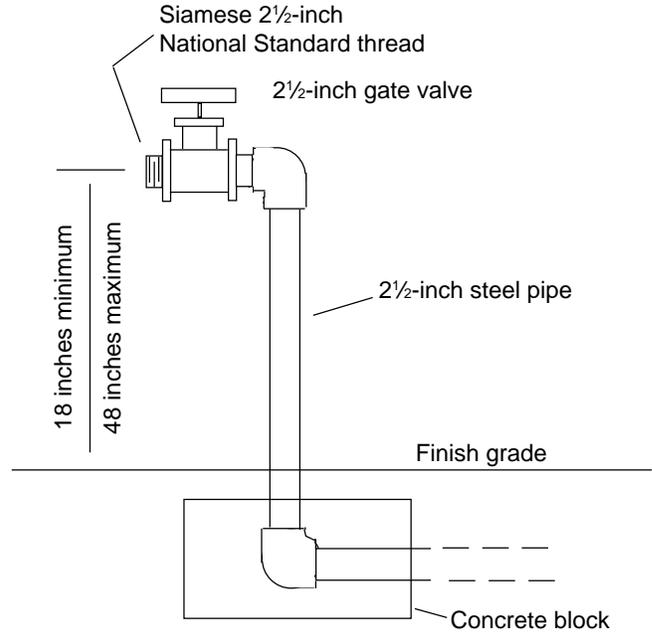
- Keep the end of the outlet pipe inside the tank at least 2 feet from the bottom so the fire engine pumps do not get clogged with sediment.

Fire hoses cannot be put over weak-framed tanks, such as plastic swimming pool tanks, because the weight of the hose could collapse the framework of the tank. If you have such a tank, you could install a support that will allow hose access, or install a supported outlet pipe with the standard 2½-inch National Standard fitting.

If you run pipes from the tank to an area accessible to the fire department, use thick PVC pipe, because thin pipe tends to crack and become brittle with age, particularly if it runs on top of the ground.

While it is not realistic to expect homeowners to meet all the fire department’s ideal conditions, it would be wise to give consideration to their needs, particularly considering that the house or life they save may be your own. For further information about assisting your local fire department, you may call the Fire Prevention Bureau of the Hilo Fire Department at 961-8350, the Training Division at 961-8520, or the Kona inspection office at 327-3546. On Oahu and Kauai, private water tanks are not often used for firefighting supply, but information is available for those islands by calling 831-7778 (Oahu) or 241-6517 (Kauai). At the time of publication, Maui County did not have policies regarding use of catchment water for firefighting.

Standardized piping preferred by fire departments; these fittings are needed to connect firefighters’ hoses to your tank.



Firefighting highlights

- Take firefighting into consideration when planning your catchment system.
- Some fire insurance companies require a specific size of catchment tank, usually 10,000 gallons.

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Cooperative Extension Service, Hilo office, (808) 959-9155. Trisha Macomber, Natural Resources and Environmental Management educational specialist; rainwater catchment resource and information center. Web site: <<http://www2.ctahr.hawaii.edu/>>.

Appendix. Pump Systems for Rainwater Catchment

[This information on pump systems was contributed by Verne Wood, owner of Puna Water Services, Keaau, Hawaii.]

Understanding how water gets from the catchment tank to the faucet can help people on rainwater catchment systems feel more comfortable with their system and be more self-reliant.

A normal pump system is composed of a pump, a pressure tank, a pressure switch, and a check valve. These main components all work together automatically to supply pressurized water to your point of use.

Catchment pump systems draw water from the tank, pressurize it, and store it in a pressure tank until you need it. There is a one-way valve called a check valve (also called a foot valve) between the water tank and the pump; this valve prevents the pressurized water from returning to the water tank, and it simultaneously creates a closed system between it and your faucets.

When you open a faucet, water is delivered under pressure. The subsequent pressure drop activates the pump switch and the pump turns on, drawing more water from the tank and delivering it, under pressure, to the pressure tank and thence to the faucet. When you close the faucet, the same switch senses the pressure build-up and, at a prescribed pressure, shuts the pump off.

Shallow-well pumps, which are commonly used for catchment systems, are designed to push water rather than to pull it. For that reason, the most appropriate place for the pump is at the same level (elevation) as the water storage tank. The pump can be placed elsewhere, but the efficiency and the life of the pump will be compro-

mised as the demand to “pull” increases. The diameter of the supply line from the tank to the pump also affects the pump’s performance. This pipe should be a minimum of 1 inch diameter—larger if possible—to reduce strain on the pump.

Changing filters on a regular basis will give you better water flow and reduce work for the pump. It is possible for a dirty filter to impede water flow completely.

Your pump will also give you better service if you have a large pressure tank in the system. The larger the pressure tank, the less the pump will turn on and off, which in turn will extend the life of the pump and consume less electricity. It is possible to add a multiple number of pressure tanks in your system.

You can improve the pump’s performance and reduce electrical consumption by using a 220-volt pump. Higher quality water pumps are configured to run on 220 volts, and these pumps will lower electrical consumption and improve the performance of your system. Some pumps have a “dual-voltage” feature whereby you can select either 110 volts or 220 volts as your power source. From the point of view of pump operation performance, the 220-volt option is preferable.*

*Editor’s note: All electrical installations and electrical trouble-shooting should be done by a qualified electrician. A 220-volt system can be much more hazardous than a 110-volt system. Pump housings should be locked to prevent unauthorized access.

The correct pressure setting between the switch and the pressure tank will ensure that the pump does not run any longer than it needs to. It should shut off promptly once it has delivered water to your point of use and re-filled the pressure tank.

The pressure switch on the side of the pump should cycle freely without sticking. A switch that is dirty can stick and cause the pump to run longer than it needs to. Sometimes ants nest in the switch and cause it to stick. Also, the check valve must work properly and prevent water from returning to the tank. If debris gets stuck in the check valve, the valve will not close tightly, and pressurized water will leak back into the tank. You may notice this problem if your pump turns on when you are not using water.

Many times when people think a water pump is broken and needs repair, the problem is actually in the switch, the check valve, or the pressure tank. Understanding how the system works could save you from the inconvenience of no water or an unnecessary service call.

Some simple checks that can be done prior to having a service call are (1) make sure that the pump is getting water from your tank, and (2) make sure that the pump is getting electricity.

After this, a more technical investigation begins, and you may want to call a service person. If you feel capable of continuing the process, the next step is to check to see if the air pressure in the pressure tank is correct. Open the valve stem and let some air out. If water comes out or there is no air in the pressure tank, place a tire gauge on the pressure tank valve stem. The pump needs to be turned off (or isolated) so that the water pressure

can be drained down. The tire gauge should read between 18 and 38 pounds of pressure. When the system is turned on again, the pump switch should activate the pump when the pressure gauge reads 2 pounds above what the tire gauge reading was (it should be between 20 and 40 pounds). If these numbers do not correlate, then it is necessary to add air or adjust the switch. If your pump turns on when you are not using water, the first thing to look at is the check valve. It could be releasing pressurized water back into your water tank.

Most problems with pump systems are actually a failure of one of the components and not the pump itself, although a sustained malfunction of one of the components can damage the pump.

If the pressure setting is not matched between the air tank and the switch, the pump can cycle repetitively and damage the pump motor. The motor also can be damaged if the check valve leaks or if there is an air lock in the system.

The pump can also be damaged from overheating. This is the single biggest cause of water pump damage. Water moving through the pump housing cools the pump. If the water supply is severed or the water does not get pumped out of the housing, the pump will overheat. This circumstance will lead to a burnt motor, a damaged impeller, or a warped shaft and seal.

If you ever run out of water or lose water flow for any reason, the pump should be shut off immediately. To further protect your pump, there are two types of sensors that can be installed at the switch that will automatically shut off the pump before any damage occurs. One unit senses heat in the electrical wire, and the other one reacts to a drop in water pressure.



An estimated 30,000 to 60,000 people in Hawaii are dependent on rainwater catchment systems for their water needs. Despite the fact that so many people own and use these systems, very little information has been available about their design and maintenance until now. This publication addresses water quality issues from the raindrop to the faucet. It includes chapters on water collection, water storage, water treatment, water testing, and firefighting concerns, and it gives an overview of the typical kinds of catchment equipment used in Hawaii. These guidelines are intended as a practical reference on the major concerns and best management practices for proper maintenance of rainwater catchment and storage systems.



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