Rainwater Cisterns: Design, Construction, and Water Treatment

Roof-catchment cisterns are systems used to collect and store rainwater for household and other uses. Such systems basically consist of a house roof, or catchment, and a storage tank, or cistern.

A system of gutters and downspouts directs the rainwater collected by the roof to the storage cistern. The cistern, typically located underground, may be constructed of various materials including cinderblock, reinforced concrete, or precast concrete, fiberglass, or steel. The cistern supplies water to the household through a standard pressurized plumbing system. A typical arrangement for a roof-catchment cistern system is shown in Figure 1.

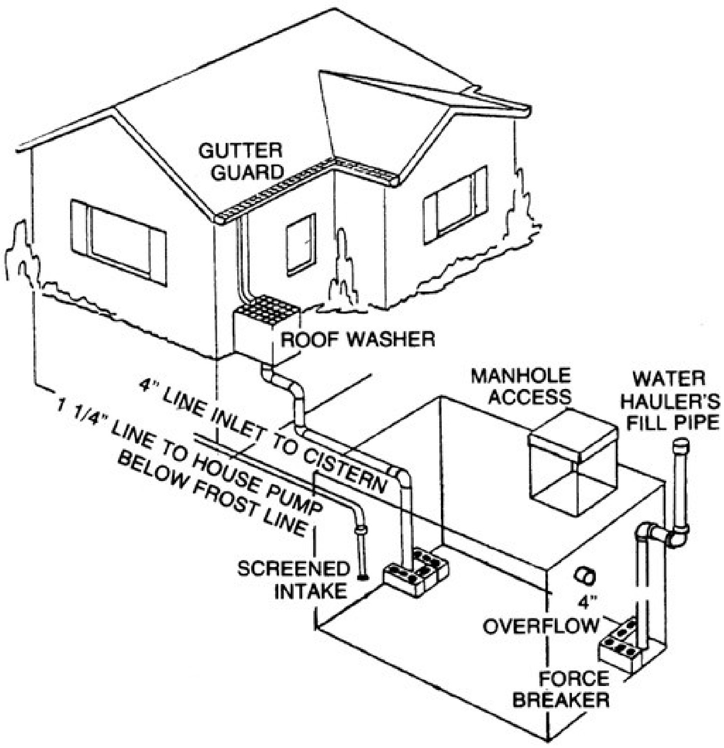


Figure 1. Typical roof-catchment cistern system. (Source: Water Filtration Co. customer information brochure. Water Filtration Co., 1088 Industry Rd., Marietta, Ohio 45750.)

The use of rainwater cisterns is by no means new. They were utilized by both Greek and Roman civilizations, as well as by Pacific island inhabitants prior to any contact with western civilization. Nevertheless, the same basic principles of modern-day systems were used in the roof-catchment cisterns of these earlier times.

Current use of rainwater cisterns may be increasing. Those who live in areas where groundwater and surface water are unobtainable or unsuitable for use have been compelled to resort to other sources of water. Rainwater collection on a household scale is quite practical in areas where there is adequate rainfall, and other acceptable sources of water are lacking. The coal strip-mining region of western Pennsylvania is one such area. Mining has rendered much of the ground and surface water unfit for drinking or other uses in large portions of these areas. Rural residents have been forced to find other sources of water and they have invariably turned to roof-catchment cisterns.

Roof-catchment cisterns may also be used to supply water to farms. Watering troughs and rain barrels can be filled by water collected from barn and other out-building roofs. A storage cistern built alongside a barn or other building could serve as an emergency source of water for firefighting in the event that a pond were not nearby. However, the use of rainwater for supplying domestic water needs is not without its problems.

Water *quality* is of concern especially when the rainwater is to be used for drinking purposes in addition to other domestic uses. Rainwater and atmospheric dust that are collected by roof catchments contain certain contaminants which may pose a health threat to those consuming the water. Lead and other pollutants may accumulate in cistern bottom sediments; and untreated rainwater is quite corrosive to plumbing systems. Measures must be taken to minimize these and other water-quality problems in cistern systems. Recommendations for doing this will be presented, as well as guidelines for designing and building roof-catchment cistern systems.

Rainwater cisterns can provide water of adequate quantity and quality if proper steps are taken in the planning and construction stages, and periodic maintenance is performed throughout the life of the cistern.

Cistern design

The storage capacity of a rainwater cistern depends on several factors:

- the amount of rainfall available for use
- the roof-catchment area available for collecting that rainfall
- the daily water requirements of the household
- and economics

All but the first of these factors can be controlled to some extent by the cistern owner.

Available rainfall

Across most of Pennsylvania, annual rainfall averages around 40 inches (Figure 2). During drought years there may be as little as 30 inches, while excessively wet years may produce 50 or more inches of rainfall. For most planning purposes, the average figure should be used. However, designing a cistern based on the lowest figure would guarantee enough storage to get you through even the driest years.

Due to evaporative, snow and ice, and roof-washer losses (to be discussed later), only about two-thirds of the annual total rainfall is actually available for cistern storage.

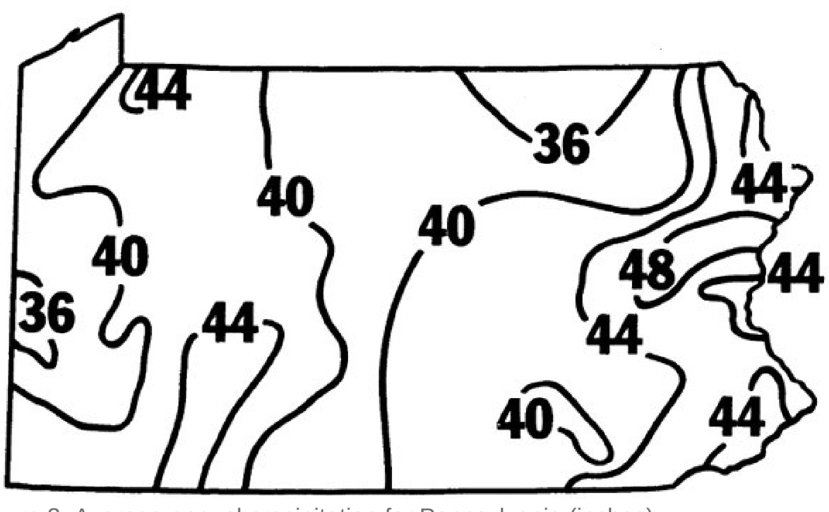


Figure 2. Average annual precipitation for Pennsylvania (inches)

Daily water needs

The amount of water you design your roof-catchment cistern to collect and store depends upon your daily water needs. If you have a small catchment area and low-volume cistern then your water use will be limited accordingly. So it is important when designing a roof-catchment cistern system to have some idea how much water you will require from it every day.

Various estimates of household water use have been published. The average base use determined by water utilities is 7500 gallons per month, which is equivalent to an average yearly minimum need of 90,000 gallons per household. Common household planning provides for 50 to 75 gallons a day per person, or 73,000 to 110,000 gallons a year for a family of four. One-third to one-half of this amount is used for flushing toilets. However, those who must rely solely on rainwater-fed supplies will undoubtedly use less water.

Studies of water use in the U.S. Virgin Islands and Hawaii, where rainwater cisterns are used extensively, indicate that this is generally the case. Water use from rainwater cisterns in the U.S. Virgin Islands averaged only 24 gallons a day per person for owner-residents. However, in Hawaii, where rainfall is much more plentiful (up to 160 inches annually) cisterns tended to be much larger and water use was considerably greater-over 100 gallons a day per person in many cases. Nevertheless, in both situations steps to conserve water were voluntarily implemented when cistern levels fell to low levels. As one cistern owner in the Virgin Islands commented, "We can make the last quarter of our cistern supply last about as long as the first three quarters."

It should be clear from this brief discussion of water use that there is considerable variation, depending on the circumstances. For purposes of general cistern design, the figure of 50 gallons a day per person is probably the best one to use. This figure would be applicable to a family living in a home with hot and cold running water and all the modem conveniences (including automatic washer and dishwasher), and no special water conservation measures. The installation of water-saving devices could considerably reduce household water use with no conscious effort on the part of family members.

Catchment area

The roof area to be used as the collection surface is usually predetermined by the size of the existing house or other outbuilding roofs. However, when planning a rainwater collection system from the ground up, where the size of the catchment is to be designed to suit domestic water needs, the following guidelines will be useful.

Figure 3 allows the catchment area required to be determined based on annual water needs and annual precipitation. As an example, suppose the average annual precipitation or your area is 40 inches. You have determined that your family of four requires 200 gallons a day or 73,000 gallons annually. From Figure 3 the needed catchment area is determined to be 4400 square feet. Note: Roof area can be determined by measuring the outside of the building or buildings to be used to collect rainfall. Do not measure the actual roof surface unless it is horizontal.

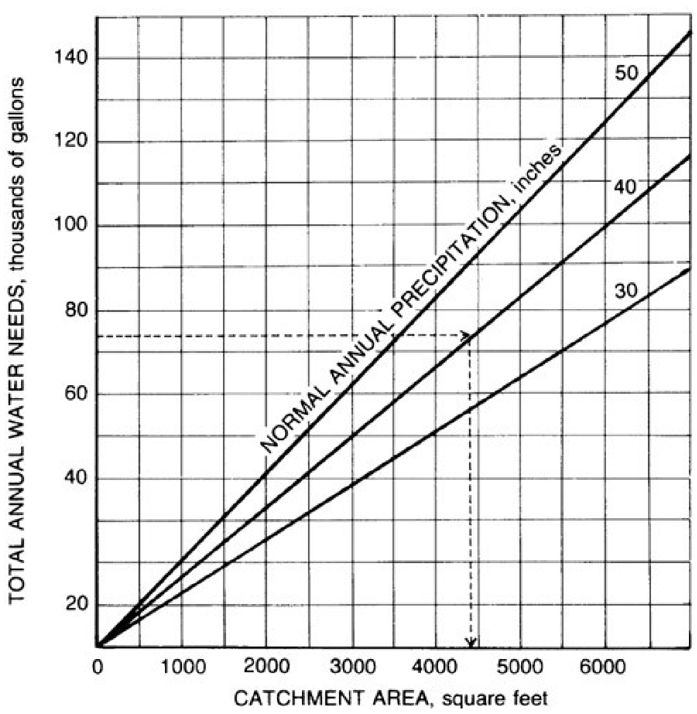


Figure 3. Graph used to determine catchment area needed. (Source: Midwest Plan Service, Iowa State Univ. 1968. Private Water Systems. p. 13.)

Cistern size

A cistern should have sufficient storage capacity to carry the household through extended periods of low rainfall. A three-month supply of water, or one-fourth of the annual yield of the catchment area, is generally adequate in areas such as Pennsylvania where the rainfall is distributed fairly evenly over the course of the year.

Figure 4 illustrates this idea. For example, if you have determined your annual domestic water needs to be 40,000 gallons (and, most importantly, you have enough catchment area and annual precipitation to supply this amount of water), then you should design and build a cistern with a 10,000-gallon storage capacity.

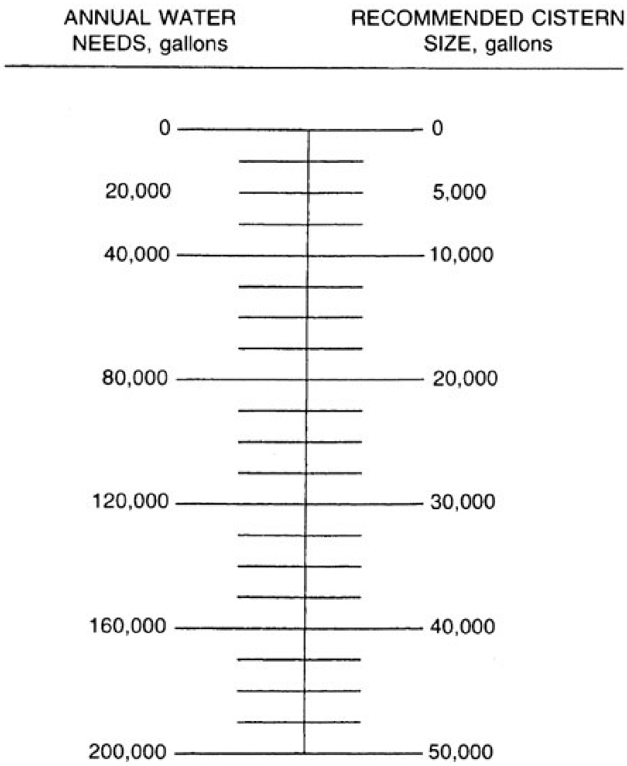


Figure 4. Cistern size based on a storage capacity equal to ¼ of the annual water needs or a three-month supply of stored water. (Source: Midwest Plan Service, Iowa State Univ., 1968. Private Water Systems. p. 15.)

A minimum storage capacity of 5000 gallons is recommended for domestic cisterns. This capacity should eliminate having to buy or haul water, a practice that is not only inconvenient but can become somewhat costly. Remember these words of wisdom when designing your roof-catchment cistern: "You pay for a large cistern once and a small one forever…"

Cistern construction

Location

Cisterns should be located as close as possible to the house or wherever the water is to be used. They may be built above or below ground, but below-ground cisterns are recommended in this part of the country to avoid freezing during the winter months. Underground cisterns also have the advantage of providing relatively cool water even during the warmest months of the year. Cisterns may be incorporated into building structures, such as in basements or under porches. This way you can use foundation walls for structural support as well as for containment of stored rainwater.

A cistern should be located where the surrounding area can be graded to provide good drainage of surface water *away* from the cistern. Avoid placing cisterns in low areas subject to flooding. Both of the above steps will reduce the chance of storm runoff contaminating the stored cistern water.

Cisterns should always be located upslope from any sewage disposal facilities; at least 10 feet away from watertight sewer lines and drains, at least 50 feet away from non-watertight sewer lines and drains, septic tanks, sewage absorption fields, vault privies and animal stables, and at least 100 feet away from sewage cesspools and leaching privies.

It pays to check these things out carefully *before* turning the first shovelful of earth for the cistern excavation. A contaminated cistern is not worth very much.

In certain situations, such as a barn or other outbuilding roof that supplies collected rainwater to a house downslope, cisterns may be located so as to provide gravity flow to the place of use. This setup is definitely preferable if it can be worked into your particular system. However, in most cases the level of water stored in underground cisterns is lower than the points of use within the distribution system so a pump and pressurized system are usually required.

Construction

Cisterns can be constructed from a variety of materials including cast-in-place reinforced concrete, cinderblock and concrete, brick or stone set with mortar and plastered with cement on the inside, ready-made steel tanks, precast concrete tanks, redwood tanks, and fiberglass. Cast-in-place reinforced concrete is considered best, especially for underground cisterns. However, cinderblock-walled cisterns with concrete floors are common and are quite satisfactory for below-ground construction; these will usually be somewhat less expensive than the all-concrete version. Concrete walls and floors should be at least 6 inches thick and reinforced with steel rods.

Two plans for below-ground concrete cisterns are shown in Figures 5 and 6. Figure 5 shows a concrete block-walled version and Figure 6 shows an all-concrete version with a sand and gravel filter on top of the cistern.

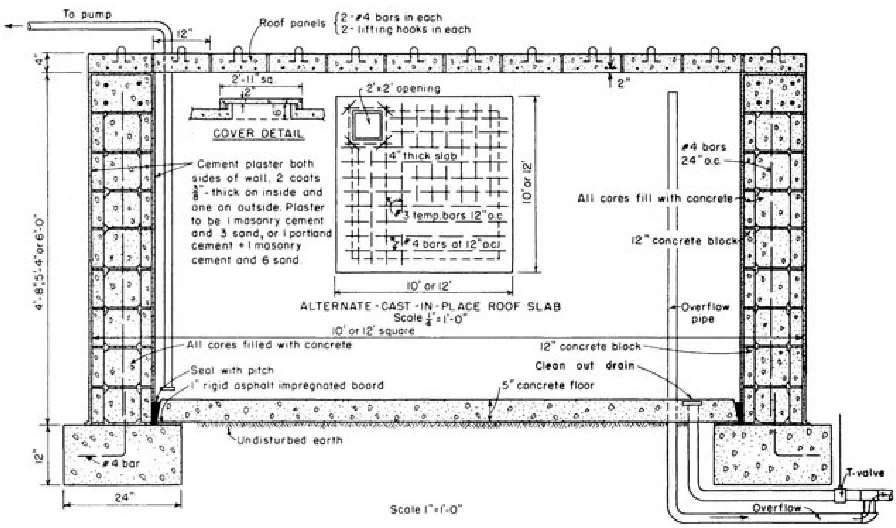


Figure 5. Cross section of a concrete block-walled below ground cistern, showing important features. (Source: Penn State Ag. Ext. Service, Order #800-86 Concrete Masonry Cisterns)

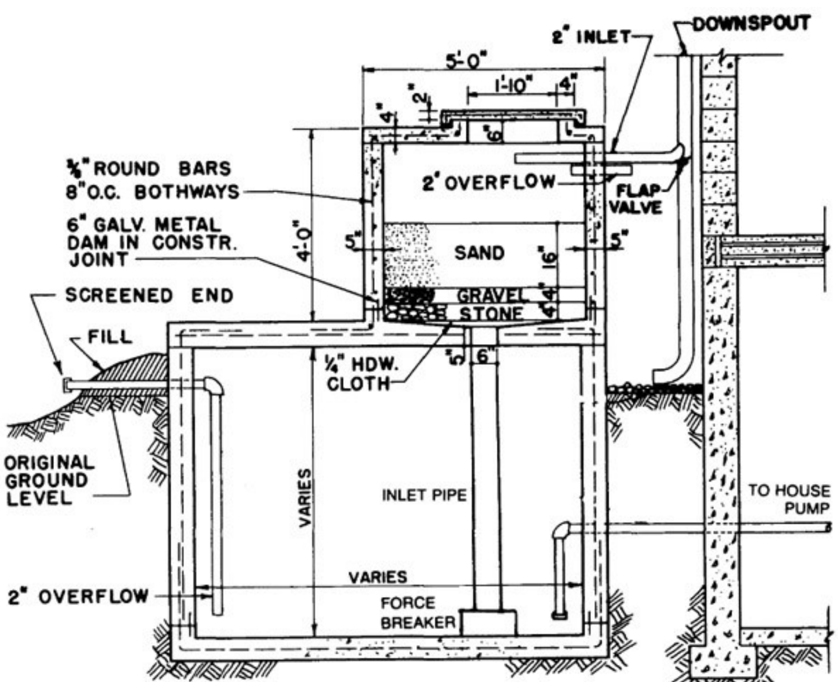


Figure 6. Cross section of concrete cistern with filter (Source: Penn State Ag Ext. Service, Order #800-87 Concrete Cisterns)

If cinderblock or concrete block is used for the walls of the cistern, all hollow cores should be filled with concrete and reinforcing rods should be placed vertically to add strength to the structure. Footers may be necessary for larger cisterns, as shown in Figure 5.

The top of the cistern should be of reinforced concrete and should fit tightly onto the rest of the structure. The top may consist of individual panels as shown in Figure 5, or it may be a one-piece slab, like that shown in Figure 6. In any event, a manhole through the top of the cistern to allow access to the storage tank should be included. Such an opening should be at least 2 feet across. A heavy concrete or iron lid like that shown in Figures 5 and 7 should be fitted tightly over the opening to prevent the entrance of light, dust, surface water, insects and animals.

Manhole openings should have a watertight curb with edges projecting several inches above the level of the surrounding surface. The edges of the manhole cover should overlap the curb and project downward a minimum of 2 inches. Manhole covers should be provided with locks to further reduce the danger of contamination and accidents.

Place the manhole opening near a corner or an edge of the structure so that a ladder can be lowered into the cistern and braced securely against a wall. This access is necessary for the periodic maintenance tasks, to be discussed later. An alternative is to build concrete steps and handholds into the cistern wall beneath the opening.

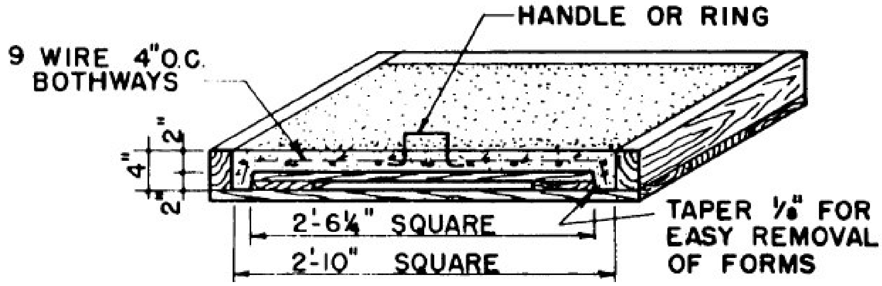


Figure 7. Section thru form for manhole cover.

The interior walls and floor of the cistern should be smooth to make cleaning easier. A cement plaster can be spread over the interior, depending on how rough the basic construction is. Cement-base sealants, such as Thoroseal and Sure-Wall, can be applied to the interior as well, to provide a smoother finish and further protection against leakage. A cistern that leaks is not only useless but it is dangerous as well; if stored water can leak out, contaminated surface or ground water can leak in. It is worth the time when building a cistern to do it right—get a good builder who will guarantee his work against leakage.

Vinyl liners may be used to prevent leakage in some cisterns, but they are usually troublesome. They are expensive, prone to puncture, and they prevent the use of cleanout drains and other accessories inside the cistern. Try a vinyl liner only as a last resort when all other efforts to prevent leakage have failed.

Another important feature of a well-designed cistern is an overflow pipe or pipes. Two different possibilities are shown in Figures 5 and 6. In Figure 5 the overflow is in the form of a standpipe that leads through the floor of the cistern to a drain. Such an overflow pipe, or any other cistern outlet for that matter, should never be connected to a sewer line, either directly or indirectly. The drain line shown in Figure 5 should lead to a free outlet downslope from the cistern. The diameter of the overflow pipe should be at least as large as the diameter of the inflow pipe from the roof catchment. Figure 6 shows an overflow pipe leading through a wall of the cistern directly to the outside.

The outside end of an overflow pipe should be *effectively* screened to prevent the entrance of animals and insects. A fine-mesh rust-proof screening should be used. The screening can be cut to a size large enough to be wrapped over the end of the overflow pipe and should be secured with a hose clamp or similar fastening device. A simple overflow design is pictured in Figure 8.

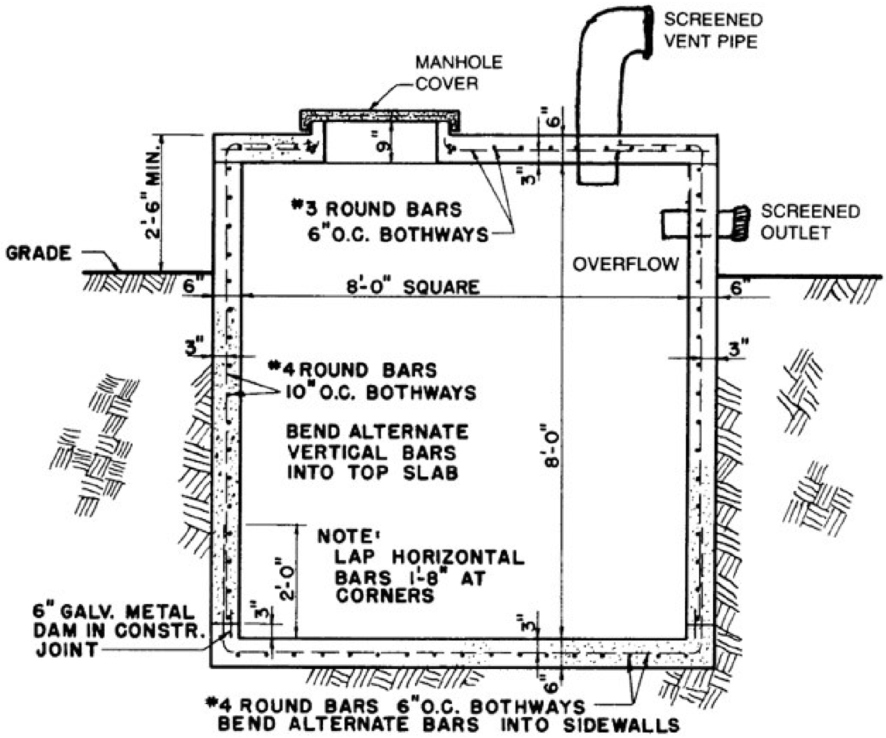


Figure 8. Cross section of 8' x 8' cistern showing overflow pipe, manhole, and vent pipe.

Large-diameter plastic pipe should be used for the overflow pipe in any case. Good drainage away from the cistern and house should be provided, when designing overflow outlets like those shown in Figures 6 and 8.

A cleanout drain should lead to a free outlet and never a sewer line. The floor of the cistern should be sloped slightly toward the drain to facilitate cleaning. A valve to open and close the drain could be controlled from above ground level as shown in Figure 9, or an underground pit could be built around the valve to provide direct access. See Figure 10. In either case, the valve and drain line should be insulated by a sufficient depth of earth to prevent freezing during even the most severe winter weather.

A cleanout drain line should be at least 3 or 4 inches in diameter to avoid clogging—a large amount of sediment may have to move through the line during cleaning operations. The outlet should be located where draining water will not cause any problems or complaints from neighbors.

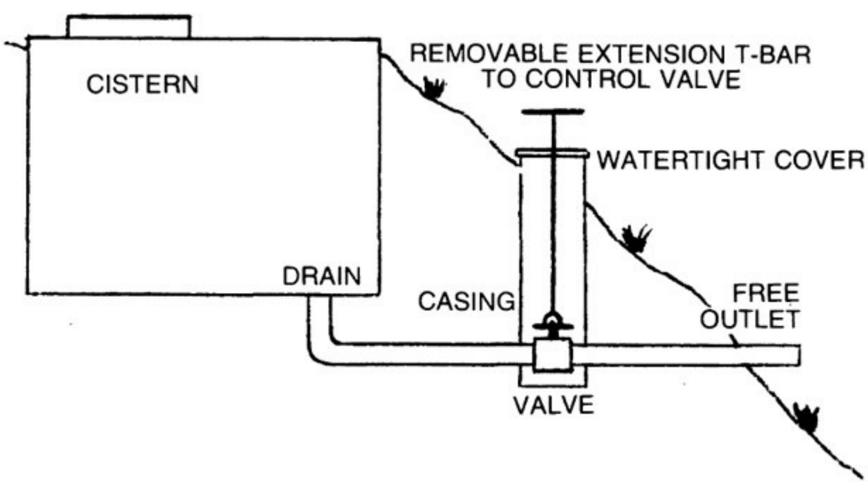


Figure 9. Plan for cleanout drain and control valve.

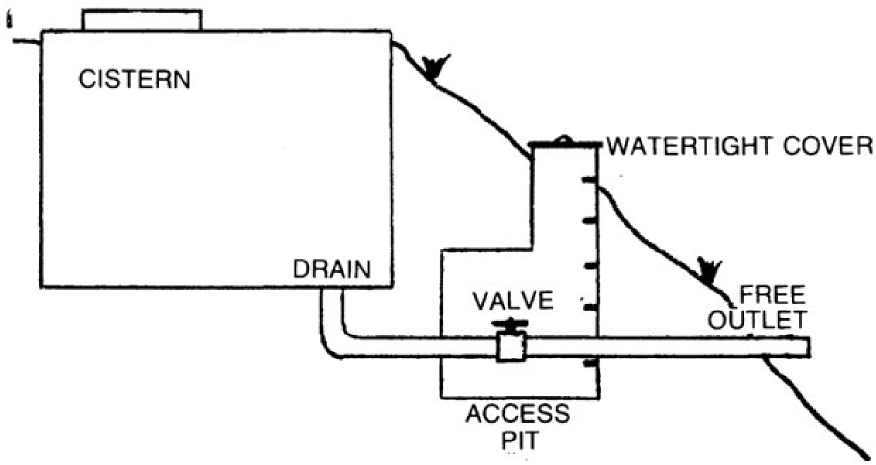


Figure 10. Plan for cleanout drain and control valve.

Cisterns should be *vented* to allow fresh air to circulate into the storage compartment. One or more large-diameter pipes through the top of the cistern will serve this purpose, as shown in Figure 8. The outside opening of each pipe should be screened in the same manner as that described above for overflow pipes. The openings, located several feet above ground level, should face the direction of the prevailing winds, west in most cases, to maximize ventilation. Four- or six-inch diameter plastic pipe is good for vents. Make sure there is a watertight seal where each vent pipe goes through the top of the cistern.

The water line from the cistern to the house or other place of use should be buried below the frost line and should be 1 or 1¼ inches in diameter. The intake head should be effectively screened and elevated a minimum of one foot above the floor of the cistern to prevent sediment from being drawn into the distribution system. The portion of the intake pipe within the cistern should be plastic. The best position for the intake is on the opposite side of the cistern from the roof-water input pipe.

A separate input pipe for adding hauled water is another important feature of the well-designed cistern. The system pictured in Figure 1 shows such a pipe. Where possible, it is best to locate the above-ground portion of the fill pipe near the driveway or other road surface, so that the water truck will not have to drive over your lawn to reach it. Four-inch plastic pipe makes a good fill pipe. A tight-fitting cap should be placed over the above-ground end of the pipe. You may want to padlock the cap to further reduce the possibility of contamination.

Water entering a cistern with any kind of force behind it, as during a summer thundershower, or from a water truck, tends to agitate the stored water and possibly stir up sediment unless steps are taken to lower the force of the incoming water. One way of doing this is through the use of "force breakers," as pictured in Figure 11.

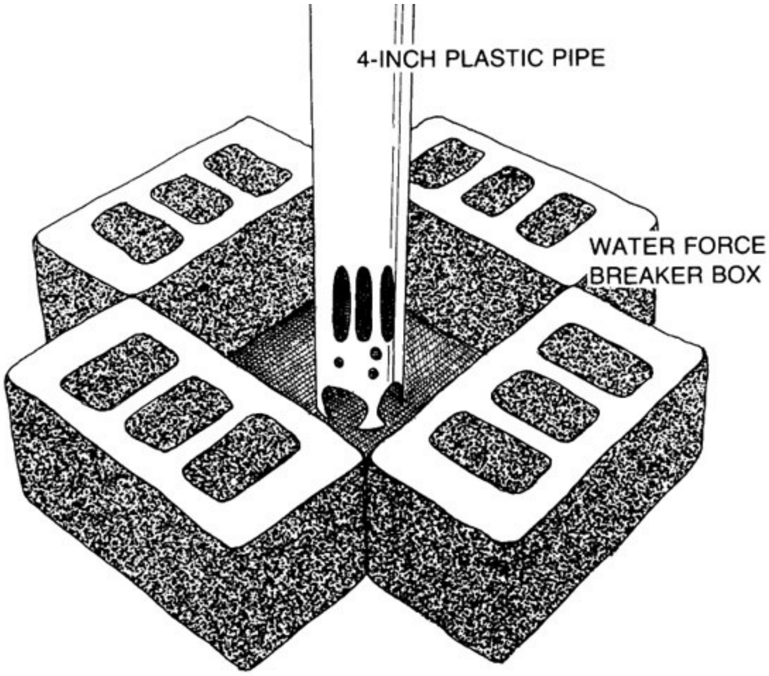


Figure 11. Water force breaker. Should be placed at all inlets to the cistern. (Source: Water Filtration Co. customer information brochure. Water Filtration Co., 1088 Industry Rd., Marietta, Ohio 45750.)

Water entering the cistern from either the roof or a water truck should travel down a 4-inch plastic pipe into a force breaker box made from concrete blocks. The blocks should be set in mortar on the floor of the cistern with the cavities facing up. Slots or openings with an area of at least 13 square inches need to be cut into the lower end of the pipe to allow the incoming water to move from the pipe to the cistern. Force breakers should be installed under both roof-water and water-hauler inlets.

Roof washers

There are several other very important construction features that will help insure good quality cistern water. Roof washers and roof-water filters were mentioned earlier, and their importance and construction details will be discussed here.

A lot of dirt and dust collects on the roof-catchment surface between rainstorms. This debris can include particles of lead and other atmospheric pollutants as well as bird droppings. These contaminants will enter the cistern along with the roof water unless steps are taken to prevent contamination. The use of roof washers and roof-water filters can reduce the amount of these contaminants entering the system.

The first water to come off the roof at the beginning of a rainstorm is the most contaminated. The degree of contamination will depend on several things including the length of time since the last rainfall, proximity of the catchment to a highway or other local source of airborne pollution, and the local bird population. Also, certain types of materials are preferable for the catchment surface, as will be detailed later.

A roof washer is a mechanism that diverts this initial, highly contaminated roof water away from the cistern. Once the catchment surface has been washed off by an adequate amount of rainfall, the roof water is once again routed to the cistern for storage. Usually the first 0.01 inch of rainfall is considered to be adequate to remove most of the dust and dirt from the surface of the catchment. In this way, only the cleanest roof water is collected in the cistern, whereas the contaminated roof wash is discharged to waste.

There are several ways of accomplishing this. The roof water can be diverted manually through a series of valves within the spouting system, or automatic roof washers may be fabricated by the cistern owner or purchased from commercial distributors.

A simple roof-wash diverter is shown in Figure 12. This particular design requires manual operation of a flap valve to control the flow path of the roof water within the spouting system. Such a valve would be necessary on each downspout unless they all converged into a single pipe just before emptying into the cistern. This single-valve arrangement is definitely preferred since the operation of this type of diverter requires someone to go out and close the valve shortly after the rain begins, allowing the roof water to flow into the cistern. The valve should be located so that it can be reached or controlled from a covered porch or other roofed area adjacent to the house or cistern.

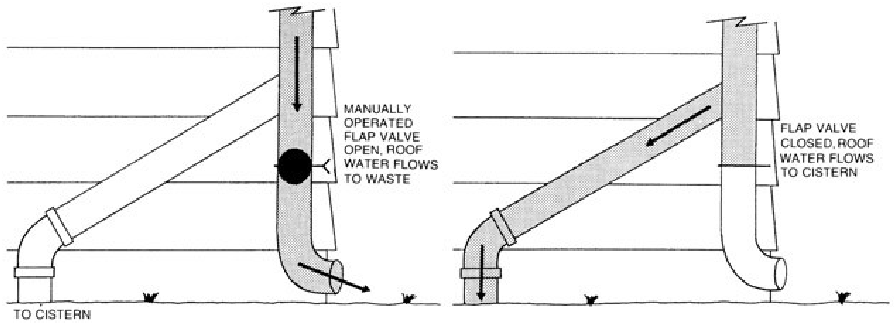


Figure 12. A simple roof-wash diverter.

During periods when rains are separated by only brief periods of time (less than a day), it would not be necessary to divert the initial roof wash every time it began to rain. However, it is important to divert the initial roof water produced by the first rainfall following an extended dry period.

As far as determining how much roof water to allow to run to waste before routing it to the cistern, this will vary for each storm. You can use the visual appearance of the roof water as an indicator—if it runs clear to your eye when collected in a clear glass jar, then you can direct the water to the cistern for storage and subsequent use. Or, you can place a large 10- to 20-gallon container under the down-spout draining to waste. The container should be sized to suit your particular roof area—10 gallons per 1000 square feet of roof area. So, at the beginning of a rainstorm the dirty roof water is directed into the container; when it is full, you know that the catchment has been sufficiently rinsed and the roof water can thereafter be routed to the cistern. For this type of arrangement, a single roof-water collection vessel for the entire catchment would be best. Adequate drainage, such as into a gravel-filled hole, should be provided for the roof water that is to be wasted, whether or not it passes through a collection vessel first.

Figure 13 is an illustration of an automatic roof-wash diverter that does not require someone's presence to operate at the start of a rainstorm, as was the case for the previous design. The basic principle is the same. A certain quantity of contaminated roof water at the beginning of a rainstorm is collected in a vessel so that it cannot enter the cistern. Once the catchment has been rinsed off by a sufficient quantity of water, the roof water is again routed to the cistern. For the design pictured in Figure 13, the volume of the collection vessel should be 10 gallons per 1000 square feet of roof area. If more than one collection vessel is necessary, as in the case of a very large catchment, then the size of the vessels should be adjusted accordingly to provide for the entire catchment area.

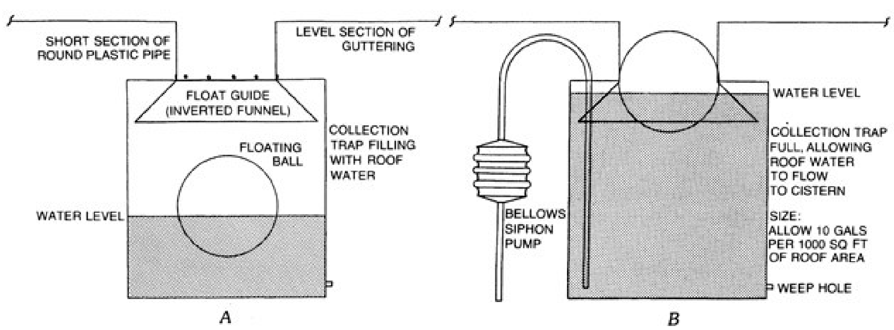


Figure 13. Automatic roof-wash diverter. (Adapted from Jenkins, D. and F. Pearson. 1978. Feasibility of Rainwater Collection Systems in California. Calif. Water Resources Center, Univ. of Calif., Contrib. No. 173, p. 51.)

The design shown in Figure 13 is a fairly generalized one, in that few specifics are given for the components of the homemade roof washer. The collection vessel could be a large plastic or glass bottle, or a rain barrel or other similar container. Regardless of the type of container that is used, several important features should be included in such an automatic roof washer. These include a float to seal off the vessel or collection trap when full, tapered guides to insure that the float will not become lodged off to one side of the opening as the vessel fills, and provision for draining the collection vessel between storms.

A buoyant plastic ball several inches in diameter will serve as the float in an automatic roof-wash diverter fashioned after that shown in Figure 13. Of course the ball must be slightly larger in diameter than the section of pipe leading into the top of the collection trap. This will keep the dirty roof water collected in the trap from escaping and flowing to the cistern once the trap is full. A soft rubber strip may be fastened around the lip of the pipe at the top of the collection trap where the ball will come to rest, to improve the seal.

As the collection trap fills and the float rises to the top, the float should be guided to the input pipe opening by means of an inverted funnel or similar device. Otherwise, the float may become lodged off to the side and thus will not block off the inflow pipe. The funnel or float guide should extend far enough toward the sides of the collection trap so that the float cannot possibly be caught up between the edge of the guide and the side of the collection trap. The float guide can be flared and attached to the input pipe by means of rustproof bolts, as pictured in Figure 13A. A plastic float guide is preferable; however, other materials such as galvanized steel, sheet aluminum, or tin are also acceptable for use in this portion of the roof-catchment system.

Some provision must be made for draining the automatic roof-wash diverter between rainstorms. This can be accomplished in a number of ways. Two are shown in Figure 138. Either a simple bellows siphon pump or a small-diameter weep hole can be used to drain the water out of the collection trap. Although both of these mechanisms are shown in Figure 138, only one of the two would be required in an actual system. If a siphon-pump were used, someone would be required to operate it following each rainstorm. The end of the siphon tubing inside the collection trap should be positioned at least ¼ to ½ inch above the bottom of the collection trap, to avoid the layer of sediment that will accumulate there. If you decide to use a weep hole to drain your roof-water collection trap, it should be drilled through the side of the collection trap about ½ inch above the bottom and 1/16 inch in diameter. This will allow the water to slowly drain out of the collection trap during non-rain periods, yet the water will drain out slowly enough that very little will be lost during a rainstorm. A third method of draining the collection trap would simply be to install a faucet with valve on the side or bottom of the collection trap. The valve would be closed during rainfall events and opened during non-rain periods. This arrangement would also require someone to be there to operate the valve, although it could be done at one's leisure during non-rain periods.

Regardless of the type of waste outlet used on the collection trap, it should lead into a gravel-filled hole or to air, never into a sewer line. Also, a layer of sediment will accumulate on the bottom of any roof-water collection trap, necessitating periodic cleaning. These factors should be considered when planning the location and fitting of these units in your particular system.

If you do not want to construct your own roof-wash diverter, commercial units are available from a variety of suppliers. The one pictured in Figure 14 is made by Water Filtration Co., 1088 Industry Rd., Marietta, Ohio 45750.

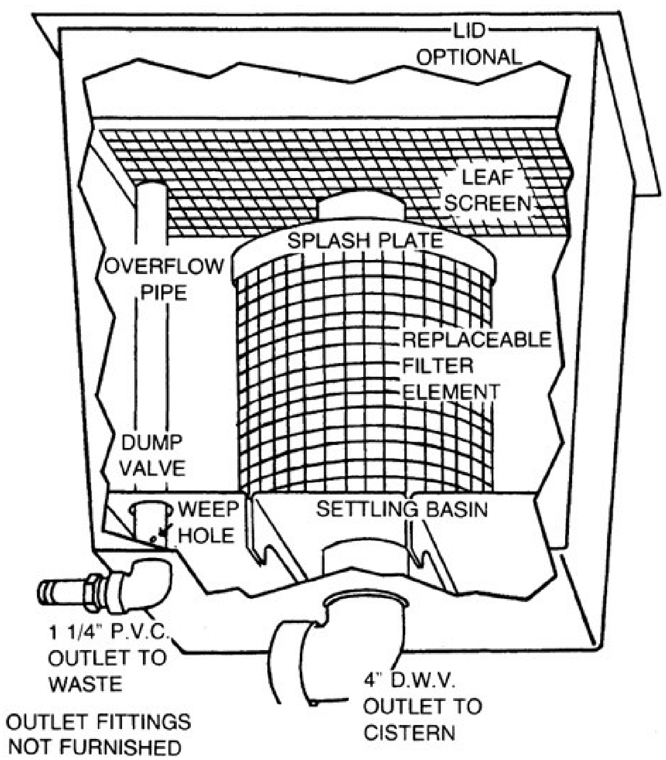


Figure 14. Commercially available filter-type roof washer. (Source: Water Filtration Co. customer information brochure. Water Filtration Co., 1088 Industry Rd., Marietta, Ohio 45750.)

Roof-water filters

In addition to roof washers, your roof-catchment system should also include a roof-water filter located between the catchment and cistern. Such a filter will primarily serve to remove gross particulates and associated contaminants from the water before it enters the cistern. It can also serve to neutralize the acidic rainwater to some extent if limestone is used for the gravel and stone portions of the filter.

One possible design for a roof-water filter was pictured in Figure 6. The filter box could be totally or partially buried underground to lessen the chances of freezing during the winter months. The filter box shown in Figure 6 is of reinforced concrete with walls and top a minimum of 4 inches thick. A short section of precast concrete culvert pipe could also function as a filter box; a lid or top would be required, however. A manhole and cover similar to that described previously for the cistern itself should also be built into the top of the filter box to provide access for periodic inspection and maintenance. If the filter box is positioned directly on top of the cistern, as shown in Figure 6, be certain that there is a watertight seal where the two join.

Several layers of gravel and sand will make up the filtering medium. The total thickness of the filtering material should be a minimum of 12 inches and a practical maximum of around 3 feet, depending upon the area of the catchment and size of the filter box. A filter the size of that shown in Figure 6 would be adequate for a roof area of up to 2000 square feet for all but perhaps the most intense rainfalls. For this reason, an overflow should also be built into the filter box, as shown in Figure 6. Mesh hardware cloth (¼- to ½-inch) or aluminum screening is placed on the bottom of the filter box (on the inside) before the gravel and sand are placed. This will keep the filtering material in place.

A cross-section of a typical roof-water filter is shown in Figure 15. Sizes and depths of the sand and gravel layers are shown in detail. Limestone should be used for the gravel and stone portions of the filter. Clean filter sand and gravel must be used, and the entire filter box should be cleaned and disinfected before the sand and gravel are placed. The completed system should also be disinfected with chlorine. Before placing the filter sand and gravel, wash down the interior of the filter box with a disinfecting solution of ¼ cup of 5 percent chlorine bleach mixed with 10 gallons of water. Use a brush to thoroughly wash all interior surfaces. After the sand and gravel are in place, a gallon of 5 percent chlorine bleach should be added to the filter, the filter filled with clean water and allowed to stand for 24 hours. After this period of time, the chlorine solution should be drained from the filter and clean water should be run through the filter until the chlorine smell dissipates and the water is clear.

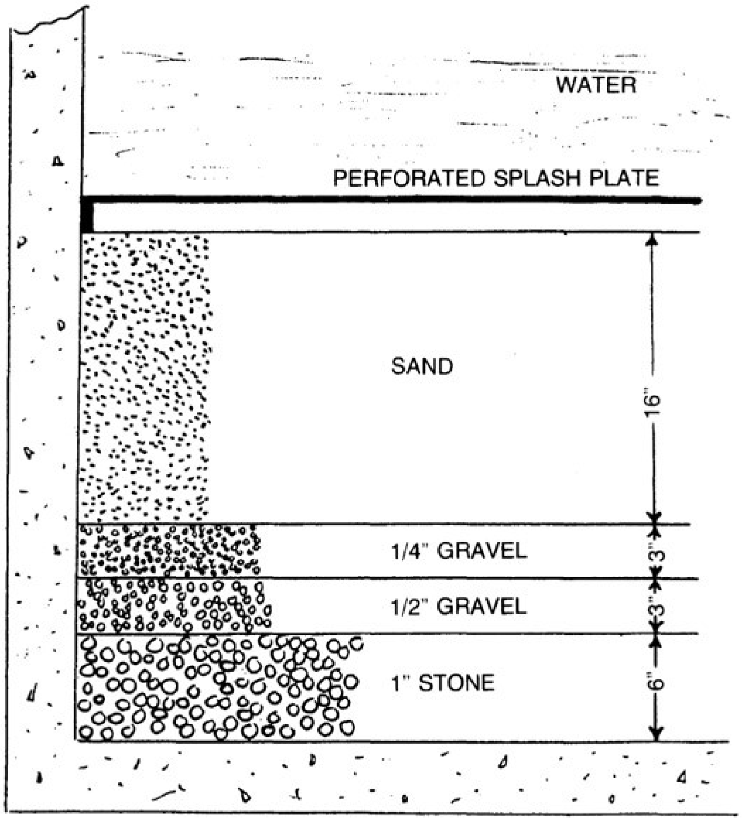


Figure 15. Sand and gravel sizes and depths for a roofwater filter. (Adapted from Midwest Plan Service, Iowa State Univ. 1968. Private Water Systems., p. 53.)

A perforated splash plate is also pictured in Figure 15. It is located approximately 2 inches above the top of the sand and serves to break the force of the incoming water, spreading it evenly over the top of the filter sand. In this way the sand will be disturbed as little as possible. A non-metallic material such as wood or plastic should be used as a splash plate. Half-inch holes should be drilled through the splash plate on 2-inch centers. Supports for the splash plate should be built into the walls of the filter box, thus allowing for easy removal and refitting of the plate for inspection and maintenance of the filter.

Any filter will tend to clog over time and will require periodic maintenance. This may entail the removal of portions of the filter medium and replacement with new sand or gravel. Whenever such replacement is necessary, the entire filter box should be cleaned and disinfected following the procedure described earlier. Periodic inspection of the roof-water filter in your system should provide visual evidence of a malfunction or clogged condition requiring remedial action.

Roof catchments

As mentioned previously, certain types of roofing materials are more suitable than others for use as collection surfaces for rainwater cisterns. Those most suitable for catchments are asphalt shingle, slate, and sheet metal (tin or aluminum). The following factors should be considered when planning a roof-catchment cistern system:

- Rough-surfaced roofing materials will collect dirt and debris which will affect the quality of the runoff.
- Some painted surfaces, some wood shingles, and some asphalt shingles may impart objectionable taste or color.
- All gutters and downspouts should be easy to clean and inspect.
- The roof area should be large enough to supply the amount of water needed.
- The atmosphere in your area may contain undesirable or harmful pollutants that might affect the quality of the collected rainwater.
- Before using a roof coating, consult local health authorities concerning possible toxicity of the material.

Gutter guards should also be installed along any roof catchment. Aluminum screening or ¼-inch or ½-inch mesh hardware cloth can be cut into strips and secured over the top of open gutters, as shown in Figure 16. Gutter guards will keep leaves, twigs, and animals out but let water in. Also remove any tree limbs overhanging the catchment. You may also want to remove nearby trees that contribute leaves and twigs to the catchment; or, if you're planning a new home and cistern system, don't plant trees right next to the house.

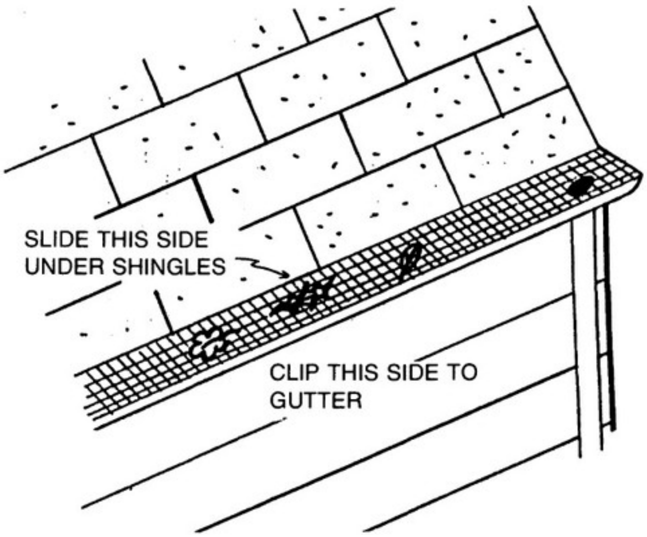


Figure 16. Gutter guard. (Source: Midwest Plan Service, Iowa State Univ. 1968. Private Water Systems p. 14)

Cistern water treatment

Several of the design features described previously will help insure good-quality cistern water. These would include roof washers, roof-water filters, gutter guards, water force breakers; and effectively screened cistern inlets and outlets. In addition to these measures, however, specific water treatment will be necessary to insure safe, potable cistern water. Recommendations for disinfection of cistern water and minimization of corrosion and sediment transport within distribution systems will be covered in the following pages.

Disinfection of cistern water

The interior of a new cistern should be scrubbed down with a disinfecting solution of chlorine and water, as described for roof-water filter boxes. **Caution:** make sure there is adequate ventilation while working inside the cistern because of the dangers of chlorine gas and lack of oxygen. Following the disinfecting operation, and before filling with water, the interior of the cistern should be rinsed down with clean water until the strong odor of chlorine is no longer present. A cistern should also be disinfected following cleaning or other maintenance that requires emptying the cistern.

To disinfect stored cistern water the simplest procedure is to add standard, unscented bleach once each week, at the rate of one ounce per 200 gallons of stored water during dry periods, or one ounce for each 400 gallons of stored water during wet spells. If a chlorine taste develops in the water it may be reasonably safe to dose weekly with one ounce for each 400 gallons of stored water. If, due to the absence of occupants, water is not chlorinated for a week or longer, one ounce of chlorine bleach for each 200 gallons of stored water should be added to the cistern upon returning.

You can devise a simple way of measuring the volume of water stored in your cistern. A wooden pole, long enough to reach the bottom of the cistern through the manhole opening, should be obtained. The pole can then be calibrated such that when it rests on the bottom it will indicate the approximate volume of stored water from the depth of the water. This can be done in the following way. First, find the capacity of your cistern from one of the two tables at the back of this booklet. If your cistern is rectangular in shape, rather than square or circular, you can determine its capacity by the following procedure. Multiply the length by the width by the depth (all in feet) to get the number of cubic feet of storage. Then multiply this figure by 7.5 to get the number of gallons of storage capacity. For example, a cistern measuring 10 feet by 8 feet, with a depth of 6 feet, would have a storage capacity equal to (10 X 8 X 6) X 7.5, or 3600 gallons.

Once you have determined the capacity of your cistern, the pole can be calibrated according to the following example. To calibrate a measuring pole for a cistern that measures 10 feet by 8 feet, with a depth of 6 feet, first divide the capacity by the depth in inches to obtain the number of gallons per each l-inch-thick layer of stored water (3600/72 or 50 gallons in this example). Then simply mark the pole at l-inch intervals, starting at one end and going toward the other until the total depth of the stored water is reached (6ft. or 72 inches in this example). At each l-inch interval mark the corresponding volume, starting (at the bottom) with 50, 100, 150, 200,… etc., adding 50 (for this example) to each successive interval.

Once calibrated, such a measuring stick would give you a quick way of estimating the volume of water remaining in the cistern at any given time. Depths and corresponding volumes also could be listed side by side in a simple table, and the stick would then only be used to measure the depth of water in the cistern. Chlorine dosages required could also be listed alongside the various volumes for quick reference.

If the water has disagreeable taste and odor, the following procedure may be used. Add 2 ounces of crystallized sodium thiosulfate to 1 gallon of clean water. Then add 1 quart of this solution to each 1000 gallons of water in the cistern, mixing it with the cistern water but being careful not to stir up bottom sediment. After a few hours the water should be free of the disagreeable taste and odor.

Any water supply should be tested for bacterial contamination at least once a year. If a water analysis shows that the water is contaminated, a careful examination of the entire water supply system and of the area surrounding the cistern has to be made in order to find and eliminate the source of contamination.

As an alternative to adding disinfectant directly to the cistern, commercially distributed in-line automatic chlorinators are available from most distributors of water conditioning equipment.

Minimizing corrosion within cistern water systems

As pointed out previously, rainwater is acidic and therefore corrosive. Unless steps are taken to neutralize this water, it will corrode household distribution systems adding toxic metals such as lead and cadmium to the tapwater. Corrosion processes are very complex chemical reactions that involve many different factors. Employing the recommendations presented here will not completely eliminate corrosion within your cistern system, but should reduce it to tolerable levels. Minimizing the amount of corroded metals in the finished tapwater is the goal.

Perhaps the surest way of minimizing tapwater metals is to use plastic pipe to service at least one cold-water tap within the system. This would effectively replace the source of metallic lead and copper with a nontoxic, noncorrodible conduit of PVC or PEX plastic. Be sure to use plastic pipe that meets specifications for conveying drinking water, if that is what you intend to use it for. If just one cold-water tap within your household were to be serviced by an all-plastic water line, then you should draw all of your drinking water from that tap and from no other. It would probably be best to plumb the kitchen cold-water tap and perhaps a bathroom lavatory with plastic. If you are planning a new system from scratch, then you may want to consider using plastic plumbing throughout the entire distribution system.

If your existing distribution system is older (pre-1990), it is likely composed of lead-soldered copper plumbing throughout. If you do not want to replace a portion of it with plastic, an alternative would be to install an in-line acid neutralizer to reduce the corrosivity of the water. Such units are available commercially from water treatment equipment distributors located throughout Pennsylvania. The acid-neutralizing units are approximately $1,500 and are available in either manual or automatic models.

In lieu of an in-line acid neutralizer, a neutralizing agent could be added directly to the cistern. Following is a table of common alkali reagents along with approximate treatment rates. They are listed in order from lowest to highest cost per pound.

Reagent	Chemical formula	Amount required to neutralize 1000 gallons of rainwater
Limestone	$CaCO_3$	2 oz.
Quick lime	CaO	1 oz.
Hydrated lime	$Ca(OH)_3$	1 oz.

Soda ash	$NaCO_3$	1 oz.
Caustic soda	NaOH	1.5 oz.

It would be necessary to add the appropriate amount of neutralizing agent at periodic intervals, depending on the amount and frequency of rainwater input to the cistern. Perhaps the most convenient treatment procedure would be to add the neutralizing agent when you add disinfectant to the cistern (once a week), at least during weeks when additional rainfall is collected. During weeks when little or no fresh rainwater is collected it would not be necessary to add more neutralizer to the cistern.

Some cistern owners have placed blocks of natural limestone in their cisterns to serve as continuous neutralizing agents. We have no guidelines to offer you as to the size or other characteristics of such blocks.

Regardless of whether or not you install an acid neutralizer or plastic pipe, or add a neutralizing agent directly to the cistern, there is one simple thing that you should do before using the tapwater for drinking or cooking purposes. You should always allow the cold water to run for about a minute before using it for drinking or cooking. This will flush the "stale" water (laden with toxic metals if from lead-soldered copper or other metallic pipe) from the supply line, leaving you with tapwater of acceptable quality. This practice is especially important after a tap has gone unused for several hours, or overnight. Rather than just letting the water run down the drain during this procedure, you may use it for purposes other than drinking or cooking.

Minimizing sediment transport through cistern systems

Use of roof washers and roof-water filters, described in detail earlier, will minimize the input of particulate matter to the cistern. However, these devices will not completely eliminate input of fine particulates or the formation of a sediment layer on the bottom of a cistern. Therefore, certain steps need to be taken to prevent this sediment from being transported through the distribution system and possibly reaching the tap.

Periodic cleaning of the cistern to remove the sediment accumulation is recommended. This would involve draining the cistern, scooping out the sediment, and washing down the interior with a brush and disinfectant. Thorough rinsing with clean water should precede refilling of the cistern. Such cleaning should be done at regular intervals every three to five years. Applying a new coat of interior sealant may also be necessary at the time of cleaning.

An in-line sediment filtering unit, like those distributed commercially by either of the two companies listed previously for acid neutralizers, should be installed between the cistern and tap to remove any sediment that might otherwise be transported to the tap. Such units are in the same price range as acid neutralizers, and some units are available as a combination acid neutralizer/sediment filter.

Summary statement

This publication is intended to serve as a guide to homeowners who are planning to build a roof-catchment cistern system. It will also provide useful information to those who already own a rainwater cistern and want to improve the quality of the water used. The material presented here has been consolidated from scientific research, public agencies, and private firms specializing in domestic water systems. The cistern study that formed the basis for this publication was conducted in rural Clarion and Indiana counties, Pennsylvania during 1979 and 1980, under the direction of the School of Forest Resources, the Environmental Resources Research Institute, and Penn State Extension. Funding was provided through Title V of The Rural Development Act.

References

Information in this circular has been adapted from the following publications:

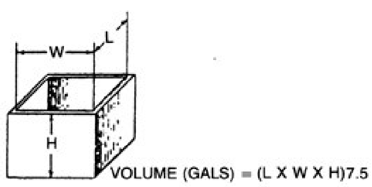
- Contribution No. 173, "Feasibility of Rainwater Collection Systems in California," by David Jenkins and Frank Pearson. Available from California Water Resources Center, University of California, 475 Kerr Hall, Davis, California 95616.
- Customer information brochure. Water Filtration Co., 1088 Industry Rd., Marietta, Ohio 45750.
- *Private Water Systems*. Midwest Plan Service, Iowa State University, Ames, Iowa 50010, attn. Extension Agricultural Engineer.
- *Cisterns for Rural Water Supply in Ohio* by Norman G. Bailey. Water Resources Center, The Ohio State University, 1791 Neil Avenue, Columbia, Ohio 43210

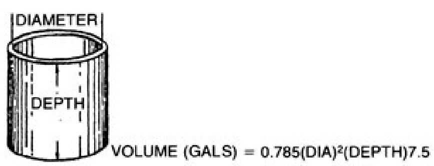
Area in Feet	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft	11 ft	12 ft	13 ft	14 ft	15 ft	Span of One Side
16	480	600	720	840	960	1080	1200	1320	1440	1560	1680	1800	4
25	750	937	1125	1312	1500	1687	1875	2062	2250	2437	2625	2812	5
36	1080	1350	1620	1890	2150	2430	2700	2970	3240	3510	3780	4050	6
49	1470	1837	2205	2572	2940	3307	3675	4042	4410	4777	5145	5512	7
64	1920	2400	2880	3360	3840	4320	4800	5280	5760	6240	6720	7200	8
81	2430	3037	3645	4252	4860	5467	6075	6682	7290	7897	8505	9112	9
100	3000	3750	4500	5250	6000	6750	7500	8250	9000	9750	10500	11250	10
121	3630	4537	5445	6352	7260	8167	9075	9982	10890	11797	12705	13612	11
144	4320	5400	6480	7560	8640	9720	10800	11880	12960	14040	15120	16200	12
169	5070	6337	7605	8872	10140	11407	12675	13942	15210	16477	17745	19012	13
196	5880	7350	8820	10290	11760	13230	14700	16170	17640	19110	20580	22050	14
225	6750	8437	10125	11812	13500	15187	16875	18562	20250	21937	23625	25312	15
256	7680	9600	11520	13440	15350	17280	19200	21120	23040	24960	26880	28800	16
289	8670	10837	13005	15172	17340	19507	21675	23842	26010	28177	30345	35512	17
324	9720	12150	14580	17010	19440	21870	24300	26730	29160	31590	34020	36450	18
361	10830	13537	16245	18952	21660	24367	27075	29782	32490	35197	37905	40612	19
400	12000	15000	18000	21000	24000	27000	30000	33000	36000	39000	42000	45000	20

Capacity (gallons) of Square Cisterns

Diameter in Feet	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft	11 ft	12 ft	13 ft	14 ft	15 ft
4	378	472	566	661	755	850	944	1038	1133	1227	1322	1416
5	590	737	885	1032	1180	1327	1475	1622	1770	1917	2065	2212
6	850	1062	1274	1487	1699	1912	2124	2336	2549	2761	2974	3186
7	1156	1445	1735	2024	2313	2602	2891	3180	3469	3758	4047	4336
8	1510	1888	2266	2643	3021	3398	3776	4154	4531	4909	5286	5664
9	1908	2385	2863	3340	3817	4294	4771	5248	5725	6202	6679	7156
10	2360	2950	3540	4130	4720	5310	5900	6490	7080	7670	8260	8850
11	2856	3569	4283	4997	5711	6425	7139	7853	8567	9281	9995	10708
12	3398	4248	5098	5947	6797	7646	8496	9346	10195	11045	11894	12744
13	3988	4985	5983	6980	7977	8974	9971	10968	11965	12962	13959	14956
14	4626	5782	6983	8095	9251	10408	11564	12720	13877	13033	16190	17346
15	5310	6637	7965	9292	10620	11947	13275	14602	15930	17258	18585	19913
16	6006	7516	9026	10537	12047	13558	15068	16578	18089	19599	21110	22620
17	6820	8526	10230	11936	13641	15346	17051	18756	20461	22166	23871	25577
18	7646	9558	11470	13381	15293	17204	19116	21028	22939	24851	26762	28674
19	8520	10650	12779	14909	17039	19169	21299	23429	25559	27689	29819	31949
20	9440	11800	14160	16520	18880	21240	23600	25960	28320	30680	33040	35400

Capacity (gallons) of Circular Cisterns





Prepared by Edward S. Young, Jr., and William E. Sharpe, former research assistant in the Environmental Resources Research Institute and former associate professor of forest hydrology

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Penn State College of Agricultural Sciences research and extension programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

Code: SC277