EVALUATION OF ROOFTOP RAINFALL COLLECTION-CISTERN STORAGE SYSTEMS IN SOUTHWEST VIRGINIA

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Leonard A. Shabman, Director

EVALUATION OF ROOFTOP RAINFALL COLLECTION-CISTERN STORAGE SYSTEMS IN SOUTHWEST VIRGINIA

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This project was in part supported by funds from the Virginia Water Resources Research Center, the Powell River Project, and the Service-Learning Center at Virginia Tech. Mr. Gary Dingus, Virginia Cooperative Extension and Ms. Rhonda Sluss, State Health Department, Dickenson County facilitated the survey and water sampling of cisterns in Dickenson County. Ms. Jennifer Krall assisted with developing the survey.

Special acknowledgments are due to many Dickenson County households who enthusiastically participated in survey and water testing conducted through this project.

ABSTRACT

Many communities in the southwest Virginia coalfields lack safe and adequate drinking water supplies. Extending public water lines to these communities is generally cost-prohibitive because of the rough and elevated terrain and the low number of households in each community. To meet domestic water needs, alternate water sources such as roof top collection of rainfall and cistern storage, and water hauling have been used for many years. The purpose of this project was to gather information about cistern use, properties, and management in the isolated communities of southwest Virginia. Dickenson County, where a large number of cisterns are used, was selected as the model study site for conducting a survey of cistern use and testing cistern water supplies. The survey indicated that more than 30 percent of the households in the surveyed areas depend on cisterns for their drinking water needs, and that 20 percent of the cisterns run dry at least once a month. Cistern waters, in general, are of good quality. However, because of poor maintenance, more than 65 percent of the cisterns tested for coliform bacteria failed to meet the federal drinking water standards established by the U.S. EPA for public water systems. This was the only water quality parameter tested and found to indicate a potential health threat to cistern water users in the study. Based on the survey, water testing results, and cistern use case studies found in the literature, recommendations were made for cistern maintenance and renovation in Dickenson County. It is expected that the results and finding of this study will be applicable to other areas of Virginia.

INTRODUCTION

Many communities in the Southwest Virginia coalfields lack safe and adequate drinking water supplies. In many of these communities, the availability of adequate and safe water from wells and natural springs is limited especially on mountain ridges. Providing water supplies to these communities through a public water distribution system is generally cost-prohibitive because of the rough and elevated terrain and the small number of households in each community. To meet drinking and domestic water needs, alternate water sources, such as roof top collection of rainfall and cistern storage, and water hauling have been used for many years. Drinking water problems in the coalfield communities of Southwest Virginia and probable solutions to these problems were discussed at the Southwest Virginia Water Symposium ’96 held in Abingdon, Virginia on October 30, 1996 (31).

A cistern is a water storage facility, usually a tank, connected to a rooftop rainwater-runoff collection system (Figure 1). It is commonly constructed of poured concrete, concrete blocks, plastic, or plastered blocks. Rainwater runoff from the roof is collected into a cistern that is connected to the roof gutter by a drainpipe called a downspout. The water is stored in the cistern and is usually pumped to the house through a pipe distribution system.

In many isolated communities of Southwest Virginia, where extending public water lines is cost-prohibitive, a rainfall collection-cistern system can be considered a viable option for meeting water demand. However, little information is available about the water quality or the reliability of cisterns as a water source in Southwest Virginia. There is a need to establish guidelines for proper cistern use and maintenance in those areas where other sources of drinking water are not available or affordable.

OBJECTIVES

The overall goal of this project was to gather information on cistern use, properties and management in the isolated communities of Southwest Virginia, and develop guidelines for proper cistern use and maintenance. Specific objectives of this project were:

1. Survey cistern use in a selected county.
2. Determine water quality of selected cisterns.
3. Identify water quality problems associated with cistern use.
4. Make recommendations for improved cistern management.
5. Provide general guidelines for cistern improvement and renovation

To accomplish this goal, Dickenson County (where a large number of cisterns are used) (17), was selected as a model study site. It is expected that the results and findings of this study will be applicable to other areas of Virginia.

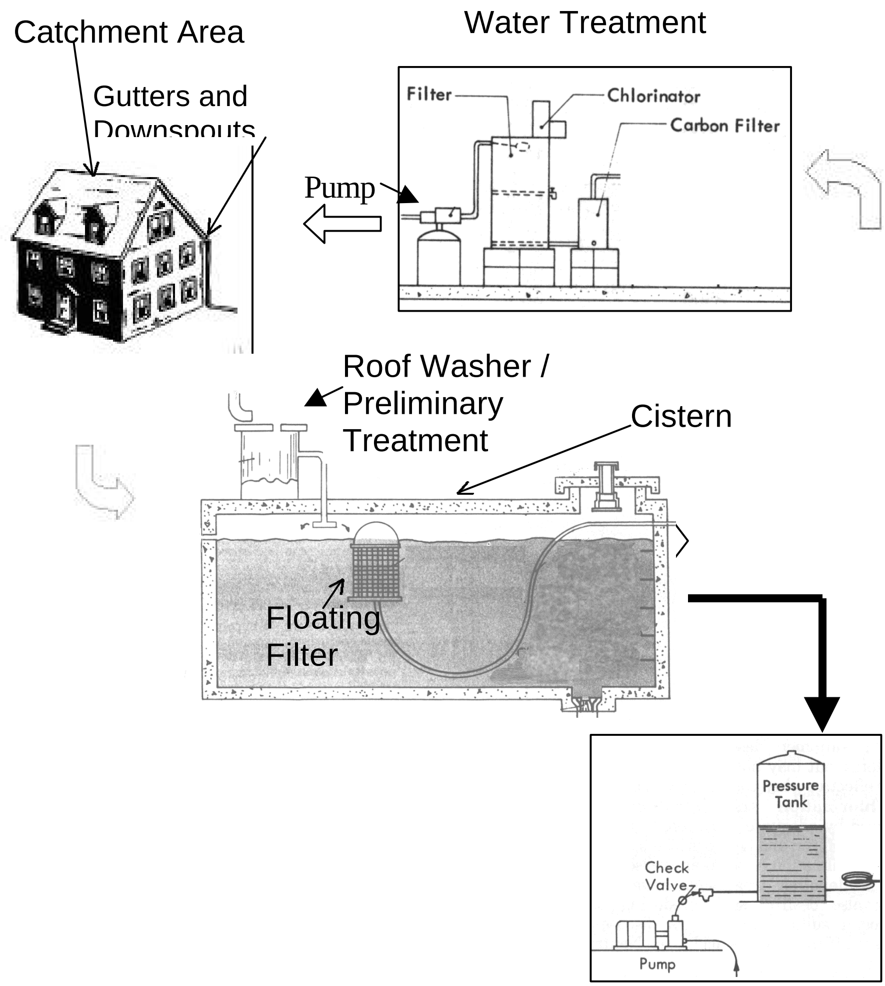

Figure 1. Schematic View of a Rooftop Rainfall Collection-Cistern Storage System

RAINWATER COLLECTION/ CISTERN SURVEY

Method

A survey was developed and reviewed by the Dickenson County Extension and the Department of Health personnel. After reviewer comments were incorporated, the survey (Appendix A) was mailed to 60 households, previously identified as cistern users, in 6 communities (Clinchco, Dante, Coeburn, Nora, Cleveland, and Clintwood) in Dickenson County on January 29, 1997. Thirty-two surveys (53%) were completed and returned. The results of the survey were compiled using the Microsoft Access database system. After reviewing the results of the initial survey, a follow-up questionnaire was distributed in July 1997 to 15 households who had returned the initial survey to clarify some of the responses.

Survey Results

Survey results were summarized under the following general categories: cistern use, cistern properties, cistern water quality, and cistern maintenance.

Cistern Use

There were a few cases in which more than one household shared the same cistern, but generally there was an average of one cistern per household and three users per cistern. For surveyed households, 31 percent of the households depended on their cisterns for drinking water. Bottled water, natural springs, wells, and hauled water were also used as drinking water sources (Figure 2). Other cistern water uses were: toilets (100%), bathing (97%), laundry (91%), dishes (91%), and cooking (47%) (Figure 3).

The survey revealed that 78 percent of the households have cisterns that run dry at least occasionally (Figure 4). When a dry cistern occurred, a majority of the cistern users hauled water to refill them.

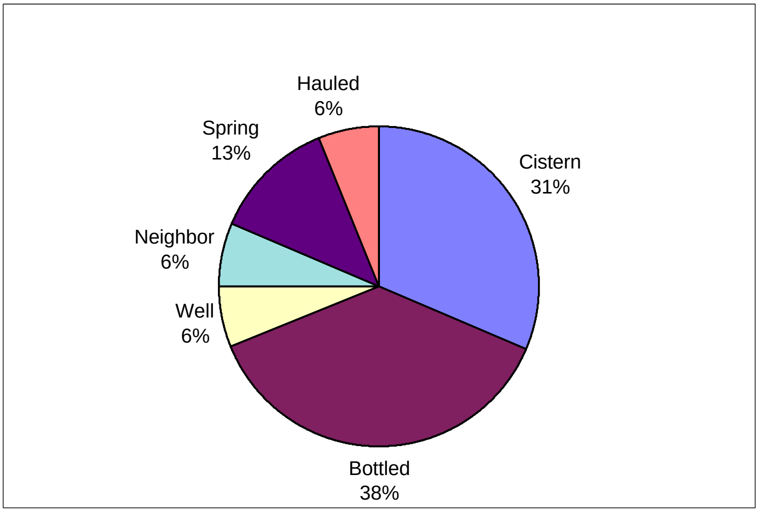

Figure 2. Household drinking water sources.

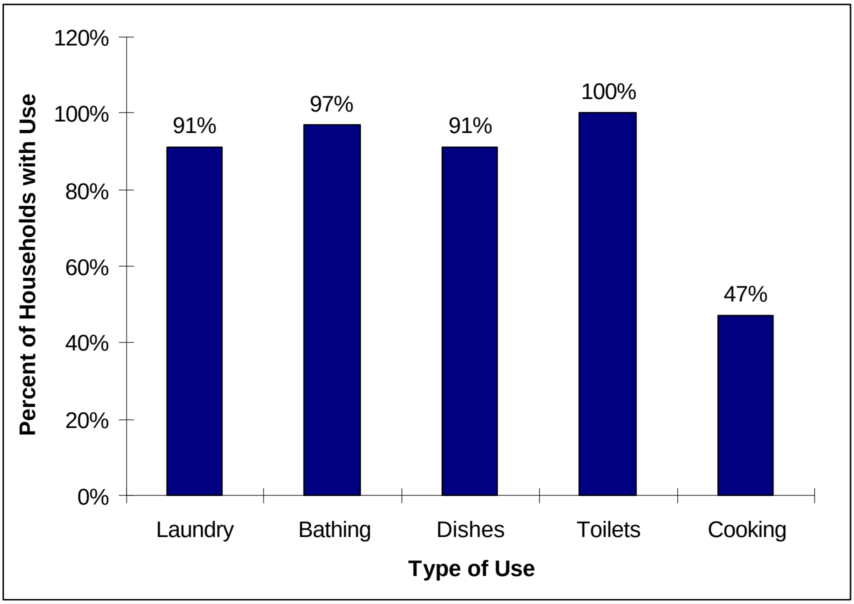

Figure 3. Household use of cistern water.

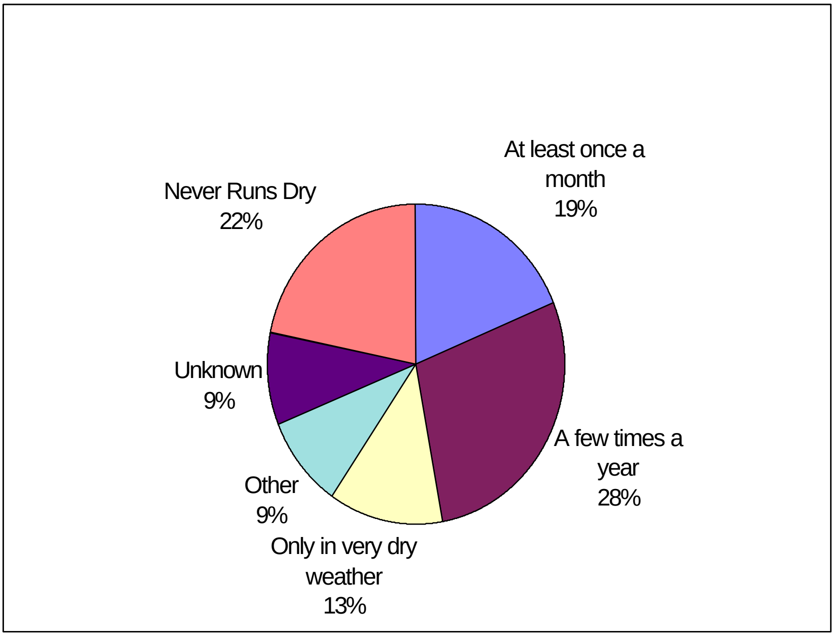

Figure 4. Frequency of the cistern running dry.

Cistern properties

Cistern age in Dickenson County varied from less than ten years to greater than 50 years. Thirty-eight percent of the cisterns were less than 10 years old, 49 percent were 11-49 years old, and 13 percent were 50 years or older (Figure 5). A majority of these cisterns were installed by the owner/previous owner of the house (60%) or by a contractor (31%). Ninety-seven percent of the cisterns were constructed of poured, reinforced concrete or concrete blocks (Figure 6). Most cisterns have an inside liner or, more commonly, a coating of paint on the inner wall (Figure 7). Cistern volume ranged from 750 to 14,500 gallons, with an average volume of 5,300 gallons. Seventy-five percent of the cisterns were installed below ground. However, a few were installed above ground and some were partially buried.

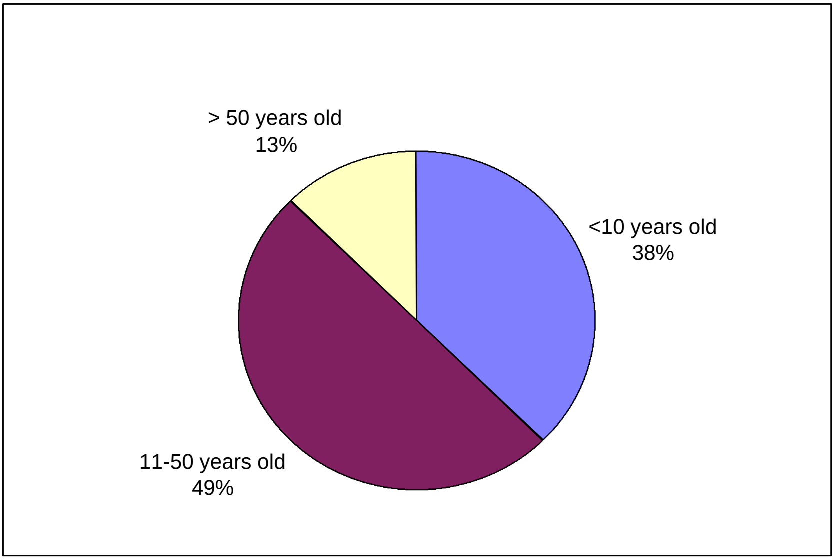

Figure 5. The average age of the cisterns.

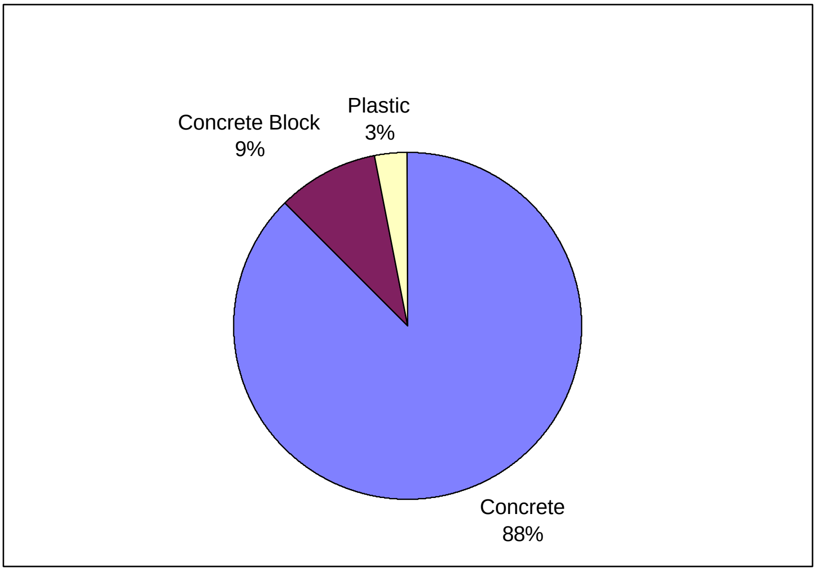

Figure 6. Materials used for building the cisterns.

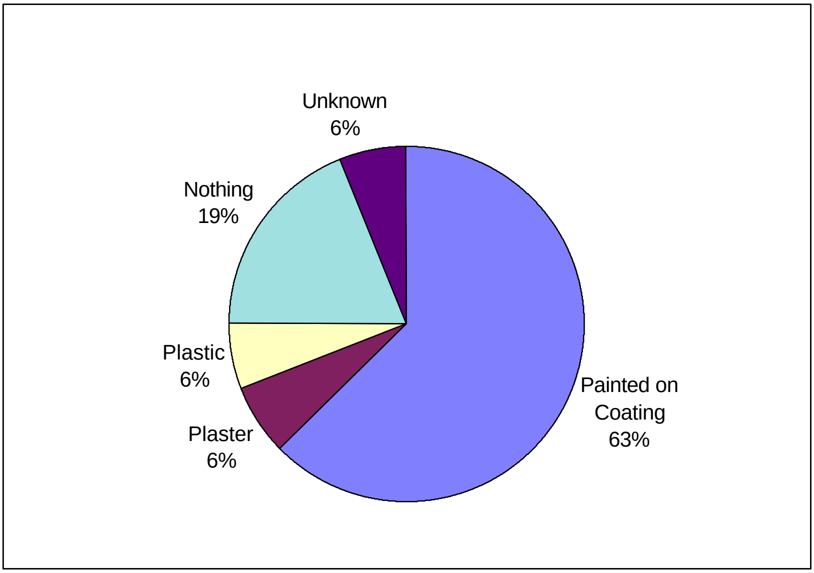

Figure 7. Materials used to line the cisterns

Sixty-seven percent of the house roofs have shingles, 27 percent have metal roofs (usually tin), and 3 percent of the houses have slate roofs (Figure 8). Nineteen percent of the metal roofs were painted. The majority of the houses had unpainted aluminum gutters (62%). Of the remaining gutter types, 19 percent were metal other than aluminum, 3 percent were vinyl, and 16 percent had some other type of gutter or no gutter at all (Figure 9).

Cistern Water Quality and Maintenance

As illustrated in Figure 10, major water quality problems noted by cistern users were odor (50%), unusual taste (28%), unusual color (19%), and cloudiness (13%). These problems were observed seasonally (13%), when cistern water level was low (22%), or after a rainfall (13%). Six percent of the cistern users experienced these water quality problems all of the time (Figure 11). Forty percent of the cistern water users observed solid material in their water on a regular basis. Timing of the presence of solid material appearance varied, with 25 percent of the occurrences reported after rainfall events (Figure 12).

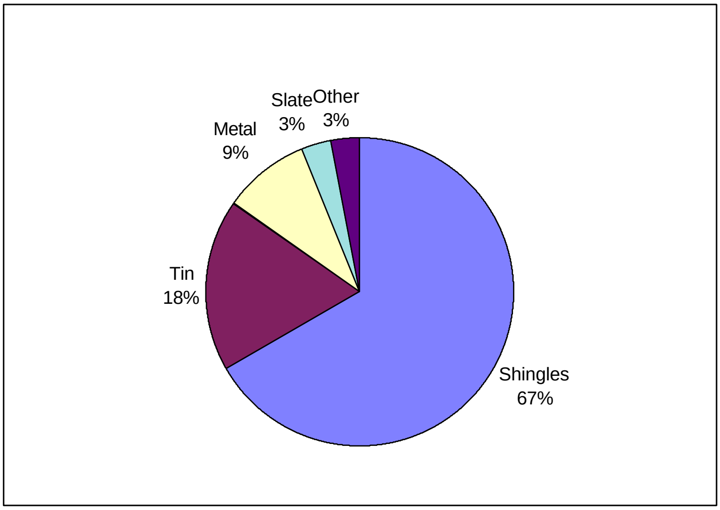

Figure 8. Roof surface material.

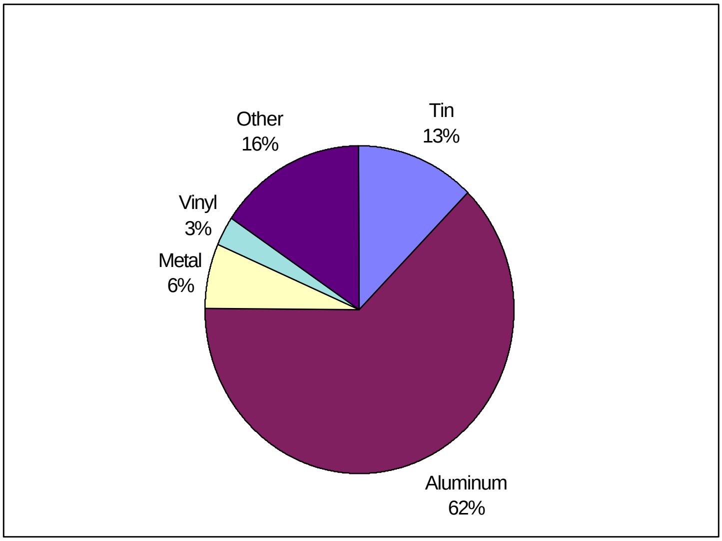

Figure 9. Roof gutter material.

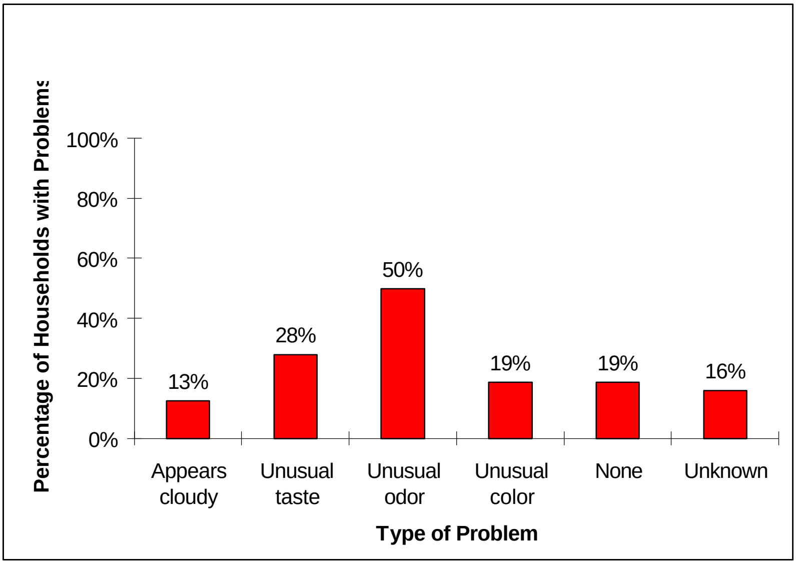

Figure 10. Cistern water quality problems.

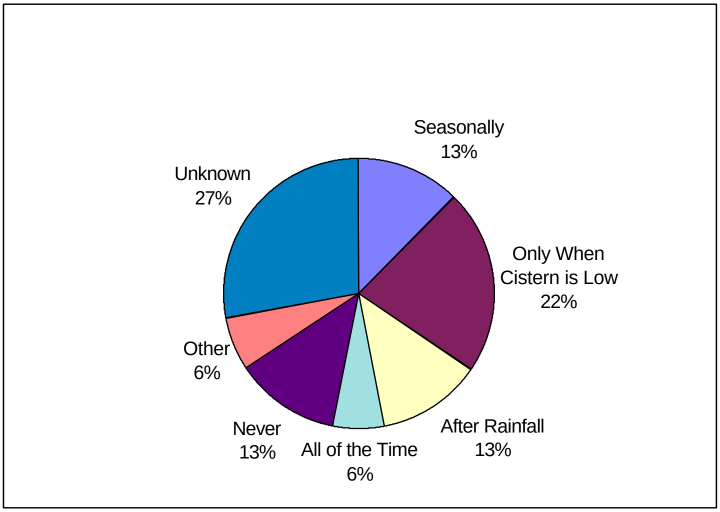

Figure 11. Occurrence of cistern water quality problems.

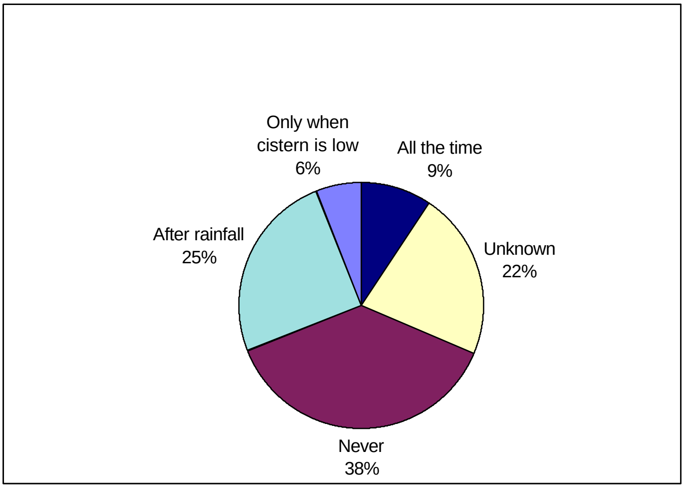

Figure 12. Timing of solid material appearing in cistern water.

About 50 percent of the cistern users who reported water quality problems took appropriate measures to alleviate the problem, such as adding bleach/chlorine (58%) or changing the filters in the cistern and/or water treatment system (24%) (Figure 13). Twelve percent of the users added water to the cistern and 6 percent of the users emptied and cleaned the cistern to correct water quality problems. Fifty-three percent used a filter to improve water quality. Common filter materials included large gravel, small gravel, charcoal, and sand.

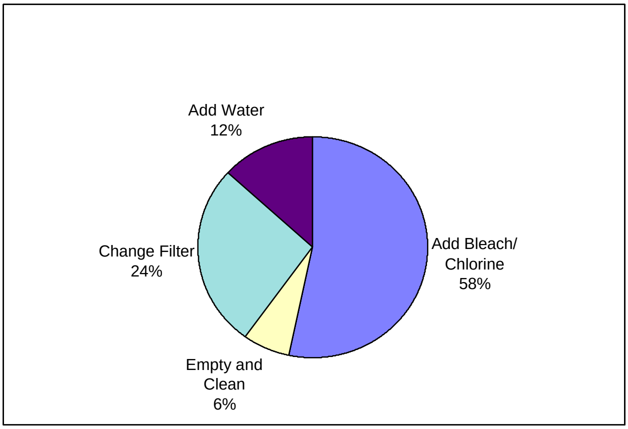

Figure 13. Actions taken to alleviate water quality problems.

The frequency of routine cistern cleaning varied. Fifty-seven percent of the cistern users reported that they cleaned their cisterns once a year, 6 percent cleaned twice a year, 9 percent cleaned once a month, and 6 percent cleaned their cisterns as needed. Nineteen percent of the cistern users never cleaned their cisterns (Figure 14). Eighty-seven percent of those who cleaned their cisterns used a cleaning agent such as bleach and chlorine with water.

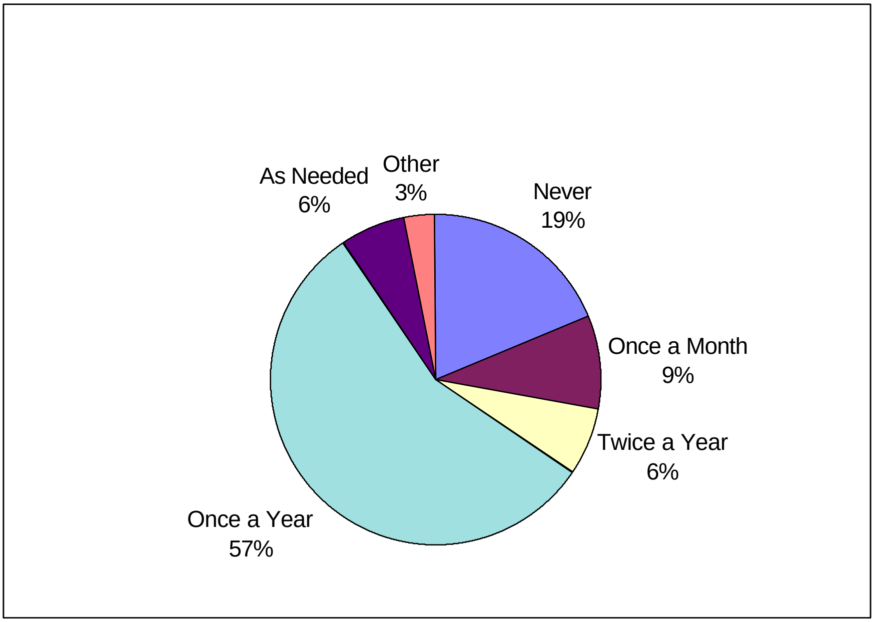

Figure 14. Frequency of Cistern Cleaning.

Cracks and holes in the cisterns were the most common problem and 47 percent of the cisterns needed repairs to prevent leakage. Some cistern users re-coated the inside lining of the cistern yearly to stop leakage. The estimated cost for upkeep of the cisterns surveyed is about $140.00 per year.

It should be noted that 44 percent of the cisterns are situated in close proximity to potential contamination sources (Figure 15) such as septic systems (31%), underground storage tanks (3%), and animal lots (9%).

These sources of contamination may pose a threat to water quality if cracks and holes in the cisterns are not repaired.

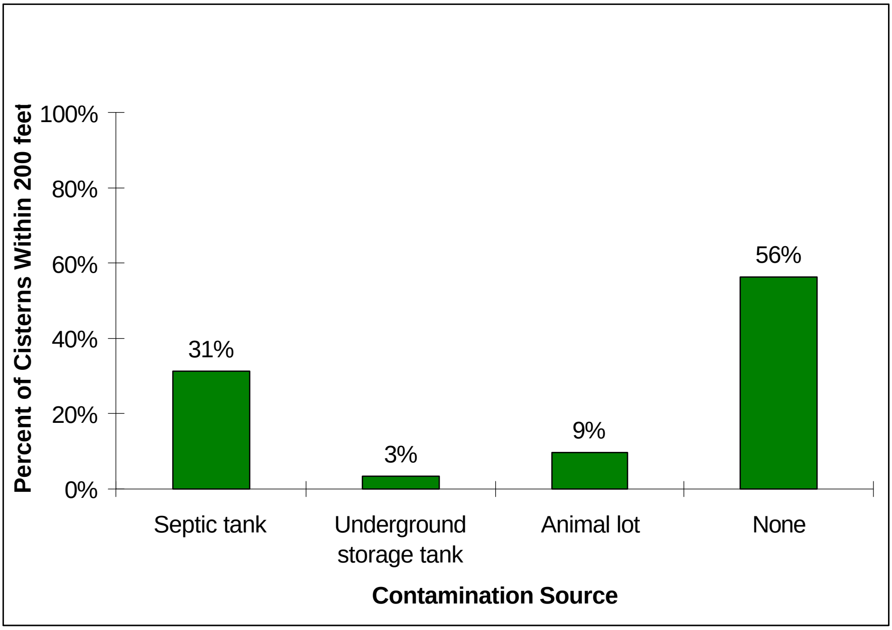

Figure 15. Pollution Sources Within 200 Feet of the Cistern.

TESTING OF THE CISTERN WATER

Method

Water from 33 Dickenson County cisterns was sampled and tested in 1993 as part of the Household Water Quality Testing and Information Program (17). These included cisterns in the communities of Nora, Cleveland, and Clintwood. To expand the 1993 cistern water quality database, a decision was made to target cisterns that were not tested in 1993. As a result, the three communities of Clinchco, Coeburn, and Dante were identified for sampling and testing. A community meeting for cistern users, arranged by the Dickenson County Extension staff, was held on April 14, 1997 in the Dickenson County Extension office. During this meeting, the project goals were explained to the audience, the sampling procedures were described, and bottles for general water chemistry and bacteriological analyses were distributed to 18 cistern users. Water sampling was conducted on April 18, 1997, and all samples were returned to the local Extension office for immediate delivery to the Biological Systems Engineering Department's (BSE) Water Quality Laboratory at Virginia Tech in Blacksburg.

A follow-up water-sampling program for heavy metals was conducted in July 1997 (the Dickenson County cistern water was not tested for heavy metals in 1993) for 15 household cisterns in Clinchco and Dante. Fifteen out of 18 sampling bottles were returned. Each sample was tested for lead, cadmium, copper, and zinc in the Civil Engineering Department's Environmental Engineering Laboratory at Virginia Tech. These metals were selected for analyses based on a literature survey that showed the possible presence of these metals in cistern water because of the type of roof metal, shingles, paint, and pipe distribution systems used in the rainwater collection and cistern storage process.

Water quality analyses were conducted using standard analytical procedures (22,25), and the analytical results are broken down into three sections. Section 1 reports the 1997 water test results (18 households) for general chemistry and bacteriological analyses. In section 2, the 1997 data for general chemistry and bacteriological analyses are integrated with the 1993 data (17) to obtain a broader picture of cistern water quality. Section 3 reports the results of the 1997 metals analyses.

Section 1. 1997 Water Test Results

Results of the 1997 water testing program, along with the U.S. EPA federal drinking water standards established for public water systems, are presented as average values and the percentage of cisterns that meet the federal drinking water standard for each constituent (Table 1). A description of the significance of each of the water quality parameters is included in Appendix B.

Fifty percent of the cisterns met all of the tested federal drinking water standards. Failure to meet the federal drinking water standards that have been established for public water systems was usually due to high total coliform. A “total coliform positive” test indicates that the water has been polluted with animal or human waste, most likely from bird droppings. Other failures were due to high iron levels (6%) and the presence of E. coli bacteria (6%).

Sodium concentrations greater than 20 mg/l were measured in some cisterns and may have resulted from the use of water softeners. For individuals suffering from health problems such as heart disease or high blood pressure the maximum recommended sodium concentration in drinking water is 20 mg/l. Twenty-two percent of the cisterns tested in 1997, and about 14 percent of the cisterns in the combined testing (1993 and 1997 data) had sodium levels higher than 20 mg/l. The maximum sodium concentration was 38 mg/l. Sodium levels of up to 100 mg/l (the World Health Organization (WHO) standard is 200 mg/l) will not pose a threat to healthy individuals.

Table 1. Summary of 1997 Test Results (n=18)

Parameter	Federal Drinking Water Standard	Average Value	Percent that Meet The Federal Drinking Water Standard
Iron (mg/L)	0.3	0.14	94
Manganese (mg/L)	0.05	0.01	100
Hardness (mg/L)	180.0	34.96	100
Sulfate (mg/L)	250.0	2.65	100
Chloride (mg/L)	250.0	43.33	100
Fluoride (mg/L)	2.0	0.11	100
TDS (mg/L)	500.0	79.72	100
pH	6.5-8.5	7.26	100
Copper (mg/L)	1.0	0.01	100
Sodium (mg/L)	100.0	9.50	100
Nitrate (mg/L)	10.0	0.42	100
Total Coliform	0.0	-	50
E. coli	0.0	-	94

Section 2. Water Test Results — 1997 and 1993 data Combined

A combined total of 51 water samples from Dickenson County were analyzed in 1993 and 1997, the results of which are presented in Table 2. When the 1993 and 1997 data are combined, the federal drinking water standards are only met 100 percent of the time for fluoride, copper, and nitrate. However, by comparing Tables 1 and 2, it is obvious that iron, sodium, and bacteria remain the dominant water problems with these cisterns.

Table 2. Summary of Combined 1993 and 1997 Test Results (n=51)

Parameter	Federal Drinking Water Standard	Average Value	Percent that Meet the Federal Drinking Water Standard
Iron (mg/L)	0.3	0.152	88
Manganese (mg/L)	0.05	0.011	96
Hardness (mg/L)	180.0	48.9	96
Sulfate (mg/L)	250.0	15.7	98
Chloride (mg/L)	250.0	60	98
Fluoride (mg/L)	2.0	0.04	100
TDS (mg/L)	500.0	100	98
pH	6.5-8.5	7.0	84
Copper (mg/L)	1.0	0.012	100
Sodium (mg/L)	100.0	10.38	98
Nitrate (mg/L)	10.0	0.45	100
Total Coliform	0.0	-	33
E. coli	0.0	-	90

Section 3. Heavy Metals Analysis — 1997 Samples

Table 3 shows the results for metals analysis. All fifteen samples that were analyzed met the federal drinking water standards for lead, cadmium, copper, and zinc.

Table 3. Summary of 1997 Heavy Metal Analysis (n=15)

Parameter	Federal Drinking Water Standard	Min. Concentration	Max. Concentration	Average Value	Percent that Meet Federal Drinking Water Standard
Lead (micro-g/L)	15	BDL*	13	2.27	100
Cadmium (micro-g/L)	5	BDL	0.210	0.06	100
Copper (micro-g/L)	1000	2	118	21.73	100
Zinc (mg/L)	5	0.03	0.73	0.16	100

* BDL; Below Detection Limit

DICKENSON COUNTY CISTERN EVALUATION

Summary

Surveys and water quality data of cisterns in Dickenson County were analyzed to identify cistern water quantity and quality, and maintenance problems.

More than 30 percent of the households in the surveyed areas depend on cisterns for their drinking water needs. According to Figure 4, 22 percent of the cisterns never run dry, while 19 percent run dry at least once a month. The amount of water that can be harvested through a rainfall collection-cistern storage system depends on the amount of rainfall, and the size of the roof surface area. The amount of rainfall is the common denominator for all households. To collect 1000 gallons of water from a two-inch rainfall, a roof surface area of 1200 square feet is needed (6). When a cistern runs dry, it indicates that there is an inadequate roof surface area for rainfall harvesting, a high level of water consumption by the household, or a loss of water through leakage.

Possible sources of cistern water contamination come from the rainfall

water. It may contain air contaminants originating from vehicle emissions, pesticides, fertilizers, and dust, various materials used in the construction of the roof, gutters, pipes, and cistern, and improper maintenance of the roof, gutters, and cistern. In general, the rainwater in Virginia is of good quality for harvesting purposes. Most water quality problems occur after the rainfall is collected. Water quality analyses indicate that maintenance is the major problem with cisterns that show inadequate water quality.

More than 65 percent (Table 2) of the cisterns failed to meet the federal drinking water standards for public water systems for coliform bacteria, and it appears to be the only water quality parameter that poses a health threat with households using cisterns in these communities. The coliform bacteria in cistern water may originate from improper gutter and pipe maintenance, lack of a filter or improper filter maintenance. The bacteriological problem can be alleviated with proper maintenance.

Sodium concentrations greater than 20 mg/l were measured in some cisterns and may have resulted from the use of water softeners. Twenty-two percent of the cisterns tested in 1997, and about 14 percent of the cisterns in the combined testing (1993 and 1997 data) had sodium levels higher than 20 mg/l. The maximum sodium concentration in one cistern was 38 mg/l. Sodium levels up to 100 mg/l (the WHO standard is 200 mg/l) will not pose a threat to healthy individuals. For individuals suffering from health problems such as heart disease or high blood pressure, the maximum recommended sodium concentration in drinking water is 20 mg/l.

Excess iron concentrations were measured in some cisterns, but this does not pose a health problem in healthy individuals. The survey indicated several nuisance water quality problems such as cloudiness, unusual taste, odor, and color. These problems can be eliminated or controlled by using appropriate filters, periodic cleaning of the cistern, and installing a “first flush” device to divert the first 15-20 minutes of the rainfall away from the cistern. Ten gallons of rainfall per a thousand square feet of roof area is sufficient to rid the rooftop of contaminants (8).

RECOMMENDATIONS FOR PROPER CISTERN MAINTENANCE

Proper construction and maintenance of a roof collection/cistern system will enhance the water quality for domestic use. Taking into account the potential pollutants and sources of pollution in a cistern system, the following recommendations are made to obtain the highest possible water quality in an existing rainwater collection-cistern system (2,3,8,11,20,30).

Clean roof surfaces and gutters of animal droppings and leaves. Monthly sweeping and clearing of the roof surface and gutters can decrease the potential for water contamination. Installing a fine screen mesh over the gutter will alleviate the leaf problem, and greatly reduce the animal-dropping problem. The roof surface gutters, supporting brackets, and downspout (inflow pipe to the cistern) should be checked at least once a year and repaired if necessary.

Divert the first 15-20 minutes of a rainfall event. Water from the beginning of the rainfall event may contain dust and other pollutants and should be diverted from the cistern. To divert the first flush, the downspout should be disconnected from the cistern during dry periods. Then 15-20 minutes after the rain begins, the downspout should be moved back into position so that the water flows into the cistern. Commercial, automatic rainfall first-flush devices are available for about $600 (1997 price list).

Check the cistern at least once a year for possible leaks. This task must be performed during a dry period, i.e., when water is not added to the cistern through rainfall. During the leak detection test, the cistern water should not be used over a 24-hour period. To perform the test, a clean graduated stick should be used to measure the water level in the cistern at the beginning and at the end of the 24-hour period. If there is a measurable drop in the water level over this period, the cistern is leaking and should be repaired. Also, a leak can be observed as wet spots on the cistern walls, base, and surrounding soils. Where wet spots have appeared on the walls, apply a cement/water mixture on the inside and finish it off with a layer of waterproof plaster. If there has been evidence of leakage but no wet spots have been discovered on the walls, the cistern floor should be treated with a cement/water mixture and finished off with a layer of waterproof plaster. Repair all leaks when the cistern is empty.

Equip all cisterns with some type of filter if the water is used for drinking purposes. However, improper maintenance of the filter is a major source for bacteriological contamination of cistern water. A filter failure may be detected by a change in water taste or appearance. However, the only sure method to detect bacteriological pollution is by having the water tested. A semi-annual water-testing schedule is recommended.

Commercial filters such an activated carbon filter should be maintained and replaced according to directions provided by the manufactures. If a sand filter is used, the sand should be washed with clean water twice a year or renewed if necessary. Other types of strainers, filters, or screens must be checked and repaired as necessary.

Remove deposits from the bottom of the tank as periodically necessary. Bottom deposits may not only affect water quality but can reduce the storage volume as well. Depending on the situation, bottom deposits may be removed as often as annually or as seldom as every 3-5 years.

Disinfect the cistern after repair work or the installation of a new tank. The tank interior should be scrubbed down with a solution of one-fourth cup (75 ml) of 5% chlorine bleach to 12 gallons of water. Alternatively, a solution of 2 pounds of baking powder to 2.5 gallons of water may be used. After scrubbing, the tank should be left empty for 36 hours and finally washed down with clean water.

CISTERN RENOVATION OR CONSTRUCTING NEW SYSTEMS

Detailed information for the design of a rainfall collection-cistern storage system is given in the Virginia Water Resources Research Center's publication (31). Based on a literature review, some elements of the renovation and design are described below (1,4,6,7,9,10,12,13,14, 15,19,21,23,24,26,27,28,29).

Roofing Materials

Various types of roofing materials can contribute to contamination of runoff water. Roofs with tar and shingles are known to add copper to runoff. Asphalt and shingle roofs are not as efficient at collecting rainwater, and can more easily pick up dust, soot and other material. Shingles also add gravel grit that can build up in the gutters and the pipes leading to the cistern. Galvanized steel is not resistant to weathering, and a roof made of this material can greatly increase the amounts of lead and cadmium present in the runoff. For this reason, galvanized steel roofing should be avoided, as well as any paint, coatings, flashing, or roofing materials that may contain lead, cadmium, or copper. Nontoxic, smooth, dense roofing materials that do not accumulate organic matter or form small pools of water should be used. Aluminum roofing is generally recommended for rooftop rainwater catchment systems because it holds up well and corrodes very little in comparison to other materials. Aluminum roofing may add a trace amount of aluminum to the water but will not pose a major health risk nor affect the taste. The FDA as a safe product for human consumption should certify any paint, sealant or coating to be used on the roof. Read the label for an explanation of the approved uses of the material before applying it to the rooftop.

Regardless of the roofing material used, the roof can become contaminated from the buildup of organic material. This material may include leaves, tree branches, animal and bird droppings, and other solids. Most of the organic material buildup comes from trees too close to the house. The buildup of organic material on a rooftop can be reduced if tree branches hanging over the rooftop are removed and trees are kept away from the house. Anything that attracts birds should be removed to cut down on the amount of droppings.

Conveyance system

The conveyance system includes gutters, downspouts, return pipes (described later), and the flushing device (roof washer). Its purpose is to transport rainwater from the roof to the cistern. The gutters and downspouts for a rooftop rainfall collection system are constructed similarly to those for controlling stormwater. Instead of directing water onto the lawn, the downspout connects to a pipe (usually PVC) that takes water to the cistern. Because several pipes are usually used, there is the opportunity for water to leak or the pipe to clog. Organic material caught in pipes can adversely affect the water's taste, smell and color. Designing a system that can be easily maintained will minimize these problems.

Gutters

For maximum effectiveness, gutters should be six inches wide, and made of a seamless .0025 inch aluminum. The gutter should be covered with a one-fourth to one-half inch steel mesh screening. The gutter coating should be certified by the FDA to be non-toxic and contains no heavy metals and should be FDA approved. Check the packaging label for FDA approval. The slope along the gutter should be from 1/16 inch per foot to 1/8 inch per foot in the direction of the nearest downspout. The gutters should have hangers every three feet to prevent damage during storms. A gutter should not run longer than 60 feet without a downspout so that the gutters will not overflow or be damaged in a storm.

Downspouts

The downspouts should be covered with a one-fourth inch steel basket-strainer. The number of downspouts to be installed depends on the size of the roof area to be drained. One four-inch diameter downspout can drain about 600 square feet of roof area. Unless the water is going to be piped through the basement, downspouts should be put on the corners of the house to simplify running the pipes to the cistern.

To help with maintenance, there should be a cleanout opening at the bottom of every downspout, where it connects to the PVC return pipe. A one-fourth inch screen should be placed at each cleanout to catch solid material that may have passed through the gutter screen.

Return pipes

The return pipes transport rainwater from the downspouts to the cistern (or to the roof washer). The return pipe should be Schedule 40 PVC or a comparable material. To trap sediment, the return pipe should be set about one-half inch above the outlet from the downspout. A four-inch diameter pipe will easily carry all runoff from the downspouts. Pipe bends should not exceed 45° so there will be less stress on the pipes and fittings. To maintain an adequate flow within the return pipe, there should be a constant slope of at least one-fourth inch per foot of pipe length. There should be cleanout openings on both ends of all horizontal pipes.

Flushing Device (Roof Washer)

A roof washer is a simple device that diverts the first portion of rainfall (which carries air borne pollutants and roof contaminants) to a container other than the cistern. The container stores the first part of the rain and after the container fills, the water flows directly into the cistern. Generally, the roof washer is placed directly over the cistern allowing the overflow to empty directly into it. Its entrance must be effectively screened (1/16-inch steel mesh) to keep all wildlife and insects out of the water. The roof washer should hold 10 or more gallons for every 1000 square feet of roof area. Automatic roof washers are available commercially. A roof washer designed for a catchment area of 3000 square feet can be purchased for approximately $600 (1997 price listing).

The Cistern (Storage Tank)

Cistern material and construction

Concrete-made cisterns are highly recommended for several reasons. Concrete buffers the water with calcium carbonate so the water becomes less corrosive to plumbing and fixtures. Cast-in-place reinforced concrete cisterns last many years, and although more expensive, the long-term benefits outweigh the cost.

The inside surface of the cistern should be smooth and clean. Vinyl liners are not recommended because they maintain the high corrosiveness of the rainwater. The cistern walls should be at least 6 inches thick. Manhole or other covers should have openings of at least 24 inches, and rise eight or more inches above the ground. The cover should be watertight, overlap the framed opening, and extend vertically down around the frame at least two inches. Locks should be installed to prevent accidents and contamination. To prevent the entrance of animals, insects and pollutants, all openings into the cistern should be screened.

Outlets or drains from the cistern should not be connected to any sewage lines. All drain water should flow into the ground. To facilitate the disinfection process (discussed later), the cistern wall should be marked to indicate the volume in gallons at various water levels.

A cistern is a heavy structure (500 gallons of water weighs two tons). Therefore, the foundation for the cistern needs to be solid. If the selected site does not have appropriate soil, installation of a gravel foundation should be considered. The gravel will provide a strong foundation as well as adequate drainage. Soils around the cistern should be well drained to allow surface runoff to move quickly past the cistern. The cistern should be located at least 100 feet away from possible sources of contamination such as septic tanks and drain fields, animal lots and outhouses, and at least 10 feet away from any watertight sewer lines.

Cistern placement

The cistern should be placed on the highest ground near the house to cut down on pumping costs. It should never be located in a position that is subject to flooding such as a basement. The cistern should be easily accessible for cleaning, the annual removal of sediment, and to a water truck, in case it needs to be periodically refilled. Keeping trees away from the concrete cistern will prevent roots from penetrating the tank and possibly damaging it. An underground cistern placed outside the house has several advantages. The ground will protect the cistern water from freezing during the winter, and allow it to remain cool in the summer. An underground cistern is not unsightly, nor takes up a large amount of space next to the house.

Water Distribution System

The pump, pressure tank, and pipes that transport water from the cistern to the point of use are collectively called the distribution system.

Pump

The pump and pressure tank work together to get water to the highest point in the house. The pump propels the water and sends it to the pressure tank. From there, the water has to make it to the highest point in the house with a sufficient amount of pressure for household operations. A centrifugal jet pump is most commonly used in homes. It is economical, reliable, and requires little maintenance. Also, it is ideal for a cistern storage-distribution system because of its ability to provide high capacity with less pressure. The pump size is determined according to the pressure requirement at the highest point in the house. Generally a three-quarter horsepower (hp) pump is effective for most home applications. Because there will be filters and disinfection devices within the system, anything smaller might not provide the required power to adequately supply the household with water. The pump that is used must be able to provide a flow of at least 6 gallons per minute. However, there are cases when a larger pump may be needed, i.e., if there are a number of bathrooms. Pumps that will meet these requirements are available for as low as $250 (1997 price list). Less expensive pumps are available for about $140, but the life of these pumps is only about 3-5 years.

A floating filter intake should be installed to collect water one foot below the surface water in the cistern. This is generally considered to be the best water in the cistern, i.e., the water below any floating scum but above the bottom sediment level. The floating filter can be connected to the pump via a flexible plastic hose that allows it to rise and fall with the water level. A 50-micron floating filter will cost about $200 (1997 price list).

Pressure Tank

A pressure tank is used in the water distribution system to provide a constant water pressure at the faucet and to extend the life of the pump by keeping it from turning on and off every time a faucet is used. The pressure tank is a container filled with air and water under pressure. This pressure is created by the pump forcing water into the tank until the air is compressed enough to provide a pressure of about 40 pounds per square inch (psi). The pump can be turned off automatically by a pressure control switch. Water flows out of the tank and the pressure drops when a faucet is opened, When the pressure gets low (around 20 psi), the pressure control switch is activated to turn the pump back on. Most pressure tanks are designed to automatically do this and there is no need for any special controls.

The pressure tank volume should be determined from the peak flow capacity of the pump. The most common size tank for household use is 42 gallons. Several sources suggest that the pressure tank be ten times the pump capacity in gallons per minute. However, this usually turns out to be much too large. About 10-15 gallons per person in the household is a reliable sizing guide.

A pressure tank made of galvanized metal should have some sort of expandable diaphragm within its interior. The diaphragm prevents water from absorbing air in the tank that causes a decrease in its efficiency and an increase in operating costs. The diaphragm also keeps the water from coming into contact with the galvanized metal tank, thus preventing heavy metals from entering the water. A 42 gallon pressure tank costs $150-$250 (1997 price list).

Water Quality Control

The ultimate goal of water quality control in a cistern is to produce water that is safe for drinking purposes and does not cause undesirable effects such as staining of laundry and fixtures. This goal can be achieved by incorporating several treatment components within the system.

Preliminary Treatment

A preliminary treatment mechanism should be incorporated between the catchment area (roof) and the cistern to remove any solids and other impure material from the water before they can enter the cistern. Some cisterns are equipped with a sediment-settling chamber. The roof runoff enters this chamber first and then the chamber overflow enters the cistern. Incorporating permanent cinderblock, gravel, fiberglass, charcoal, or sand filters into the system can serve as a preliminary treatment mechanism.

In-Cistern Treatment

To obtain safe and bacteria free water, the cistern water should be routinely disinfected. While an automatic disinfecting device could be installed, the cistern can be easily disinfected manually by adding one ounce of laundry bleach for every 200 gallons of water in the cistern. If a noticeable chlorine taste develops, then the dosage should be reduced to one ounce for every 400 gallons of water. Clorox and Purex are recommended because they do not contain heavy metals that may be found in some generic and low-cost brands. However, any brand of bleach will act as a disinfectant agent as long as it is free of heavy metals. Also, avoid using laundry bleaches that contain additives.

Rainwater can be very corrosive and cause deterioration of the in-house water distribution pipes and fixtures. Pipe corrosion may result in leaching of heavy metals into the water. The best way to prevent corrosion is to add a neutralizing agent to the cistern water. Common neutralizing compounds and their appropriate dosages per 1000 gallons of water are: limestone (2 oz), quick lime (1 oz), hydrated lime (1 oz), soda ash (1 oz), and caustic soda (1.5 oz). The addition of these agents should only be done after a rainfall and fresh water has been added to the cistern since it was last neutralized. In some cases, a large piece of limestone can be added to the cistern to neutralize the water. While this may be effective for corrosion protection, it may cause an increase in water hardness.

Post-Cistern Filtration and Treatment

There are several alternatives for water treatment after the water leaves the cistern and before it reaches the faucet. A treatment unit called Point of Entry (POE) system can be installed immediately after the pressure tank. This allows all the water that comes into the house to be treated before it reaches any faucet or appliance. However, because of the relatively high cost, this option may not be feasible. Another treatment option is called the Point of Use (POU) unit. The POU unit treats the water when it reaches a particular faucet where a small treatment unit (the type used depends on the nature of the contamination) is attached. The advantage of the POU system is that only the water at a few taps would be treated, i.e., the water that is used for drinking and cooking. This can be accomplished for a relatively low price. The disadvantage is that the remaining taps have untreated water, which could be inconvenient at times. The POE and POU units usually consist of various types of filters. Since organic matter, bacteria, odor, and taste are the major water quality problems in the rooftop rainfall collection systems, the use of a Granular Activated Carbon (GAC) filter is highly recommended. When compared to other filters, the GAC filter is relatively expensive, however, it has many advantages. The GAC filter can remove algae, protozoa, some bacteria and viruses, many pesticides, and other organic chemicals. It is also effective in removing many of the taste and odor problems. In addition, it is effective in removing excess chlorine and chlorine by-products that may be present in treated cistern water. The GAC filter is easy to maintain by replacing the filter according to an established schedule. The disadvantage of using this type of system is that it is not very effective in removing coliform from the water.

According to the federal standards for public water systems, the acceptable amount of a total coliform count is zero. Coliform bacteria occur naturally in the intestines of warm-blooded animals (fecal coliform) and non-fecal coliform bacteria. Escherichia coli (E. Coli) is a species of fecal coliform bacteria and its presence in a water sample indicates that more harmful disease causing organisms may be present. As part of a “multiple barrier” approach to water treatment, some sort of disinfecting treatment should be used in conjunction with the GAC filter. This could be accomplished by using the disinfection treatment method using laundry bleach to disinfect the cistern water before the water enters the carbon filter.

Another treatment system that could be used is ultraviolet radiation. This method of disinfection is recommended after carbon filtration. Ultraviolet radiation is a method that employs a light chamber to effectively kill any organism in the water. Low-pressure mercury lamps, similar to the common florescent bulbs, are often used for this purpose. To accomplish the treatment, water flows through a chamber that is subjected to the light from these special bulbs. This process leaves no unpleasant tastes, no disinfection by-products, is inexpensive to install and operate, and requires almost no maintenance. An ultraviolet radiation unit appropriate for household use costs about $800 (1997 price list).

APPENDIX A — Cistern Survey Sheet

Name____Telephone _____________
Address____

I. Cistern Properties

What is the age of the cistern? <5 yr. 6-10yr. 11-20yr. 21-50yr. >50yr. Unknown Other _______________________________

Who installed the cistern? You Contractor Previous Homeowner Unknown Other _______________________________

What is the cistern made of? Concrete Plastic Wood Other_______________________________

What is the inside of the cistern lined with? Plastic liner Painted-on-coating Nothing Unknown Other __________________

What is the size of the cistern?________________________Unknown

Is the cistern above or below ground? Above Below Unknown

What is the gutter on your roof made of? ________________________________

What type of roofing material do you have on your house? ________________

Is your roof painted? Yes No Unknown

Do you have any of following within 200ft of the cistern? (Circle all that apply): Septic tank Underground storage tank Animal lot None Other ____

II. Water Quantity

How many persons and households use the cistern?

No. of persons _________ No.of households _______________________

For what purposes do you use the cistern water? (Circle all that apply)

Laundry Bathing Dishes Toilets
Drinking/cooking Other____________________________________

If you did not circle drinking/cooking for the previous question, from what sources do you get your drinking water?

Bottled Trucked in from public water supply Neighbor Unknown
Other _______________

Does the cistern ever run dry? Yes No

If Yes, how often does this occur on an average over the course of a year?

Once a week Once a month Every couple of months Once a year
Unknown Other ____

Do you attempt to refill the cistern when it is dry or when it freezes during the winter? Yes No

If No, what do you use as a water source if water for each of the following tasks are usually supplied by the cistern?

Laundry____
Bathing ____
Dishes ____
Toilets____
Cooking\Drinking ____
Other ____

III. Water Quality

Is there solid material (dirt) in the cistern water? Yes No Unknown

How often does this occur? All the time After rainfall
Only when cistern is low Seasonally Never Unknown
Other ____________________________________

Does the water from the cistern ever have the following problems: (circle all that apply)

Appear cloudy   Unusual taste   Unusual odor   Unusual color
None   Unknown   Other ______________________

How often does this occur? (Circle all that apply)

All the time   Seasonally   After rainfall   Only when cistern is low
Never   Unknown   Other______________________________

When the cistern water has any of the problems circled above, do you do anything about the problem?

Yes   No   Unknown

If Yes, please explain____

IV. Maintenance of the Cistern

What do you use to clean the cistern?

Bleach and water   Nothing   Other________________

How often do you clean the cistern?

Once a week   Once a month   Once a year   Never
Other ____________________________

Did the cistern ever need repairs?   Yes   No

If Yes, what was repaired? (Explain)_______________________

Do you use a filter to treat the water in the cistern?   Yes   No

If Yes, what type of filter?_______________________________________

What is the estimated cost for upkeep of the cistern on a yearly basis? $__________________________________

APPENDIX B — DESCRIPTION OF WATEER QUALITY PARAMETERS

Iron. Iron in water does not usually present a health risk. It can be objectionable if present in concentrations greater than 0.3 mg/L. Excessive iron can leave brownish orange stains on plumbing fixtures and laundry. It may give water and/or beverages made with tap water a bitter, metallic taste and discolor them.

Manganese. Manganese does not present a health risk. However, if present in concentrations greater than 0.05 mg/L, it may give water a bitter taste and produce black stains on laundry, cooking utensils, and plumbing.

Hardness. Hardness is a measure of calcium and magnesium in water. Hard water does not present a health risk. However, it prevents soap from lathering, decreases the cleaning action of soaps and detergents, and leaves "soap scum" on plumbing fixtures, and scale deposits on water pipes and hot water heaters. A softening treatment is highly recommended for water with a hardness rating above 180 mg/L. Water with a hardness of 60 mg/L or less does not need softening.

Sulfate. High sulfate concentrations may result in adverse taste or cause a laxative effect. Sulfates are often naturally present in groundwater and may be associated with other sulfur-related problems, such as hydrogen sulfide gas. This gas may be caused by the action of sulfate-reducing bacteria, as well as by other types of bacteria (possibly pathogenic bacteria) on decaying organic matter. While it is difficult to test for the presence of this gas in water, it can be easily detected by its characteristic "rotten egg" odor, which may be more noticeable in hot water. Water containing this gas may also corrode iron and other metals in the water system, and may stain plumbing fixtures and cooking utensils. Sulfate is of concern when present in concentrations greater than 250 mg/L.

Chloride. The drinking water standard for chloride is 250 mg/L. Chloride in drinking water is not a health risk. Natural levels of chloride are generally low. High levels present in drinking water usually indicate contamination from a septic system, road salts, fertilizers, industry, or animal wastes. Increased levels of chloride may speed the corrosion of metal pipes and cause pitting and darkening of stainless steel.

Fluoride. The federal drinking water standard for public water systems for fluoride is 2 mg/L. Fluoride is primarily of concern from the standpoint of its effect on teeth and gums. Small concentrations of fluoride are considered to be beneficial in preventing tooth decay. However, moderate amounts can cause brownish discoloration of teeth, and high fluoride concentrations can lead to tooth and bone damage.

Total Dissolved Solids (TDS). The federal drinking water standard for TDS is 500 mg/L. TDS is a combination of several chemicals including chloride, sodium, sulfate, hardness, and alkalinity. High concentrations of TDS may cause a salty or bitter taste and deteriorate household plumbing and appliances.

pH The pH indicates whether water is acidic or alkaline. The EPA has set a suggested range between 6.5 and 8.5 on the pH scale for drinking water. In addition, acidic water can cause corrosion in pipes and may cause toxic metals from the plumbing system to be dissolved in drinking water. The life of plumbing systems may be shortened due to corrosion, requiring expensive repair and replacement of water pipes and plumbing fixtures

Sodium. Sodium levels up to 100 mg/l (the World Health Organization's standard is 200 mg/L) will not pose a threat to healthy individuals. Sodium can be a health hazard to people suffering from high blood pressure or cardiovascular problems, or kidney diseases. For those on low-sodium diets, 20 mg/L is suggested as a maximum level for sodium in drinking water, although a physician should be consulted in individual cases.

Nitrate-Nitrogen. High levels of nitrate may cause methemoglobinemia, or "blue-baby" disease, in infants. Though the federal drinking water standard for nitrate is 10 mg/L, it is suggested that water with greater than 1 mg/L nitrate concentration not be used for feeding infants. Levels of 3 mg/L or higher may indicate excessive contamination of the water supply by commercial fertilizers and/or organic wastes from septic systems or agricultural operations.

Coliform. Coliform bacterial detection is simply an indication of the possible presence of pathogenic, or disease-causing, organisms. However, coliforms are always present in the digestive systems of all warm-blooded animals and can be found in their wastes. Coliforms are also present in the soil and in plant material. Other possibilities (in the case of cisterns) include contamination of the household plumbing, or filters. Coliform bacteria is of concern if a detection of coliform bacteria is confirmed by a total coliform analysis resulting in a detection rate above zero.

E. *coli*. (*Esherichia coli*) is a member of the fecal coliform group of bacteria. The occurrence of E. *coli* is an indicator of recent fecal contamination of the drinking water and the possible presence of pathogenic organisms, which is the major source of many enteropathogenic diseases transmitted through water. E. *coli* is found in the feces of warm-blooded animals. E. *Coli* contamination is of concern if a detection of above zero is confirmed.

Cadmium. The federal drinking water standard for cadmium in public water supplies is 5 μg/L (micro-g/l). Cadmium is highly toxic and minute quantities of cadmium are suspected of being responsible for adverse changes in the arteries of human kidneys. Cadmium also causes generalized cancers in laboratory animals and has been linked epidemiologically with certain human cancers. Cadmium may enter water as a result of the deterioration of galvanized pipe.

Copper. The EPA drinking water standard for copper in public drinking water supplies is 1.4 mg/L, the maximum level recommended to protect people from acute gastrointestinal illness. Lower levels of dissolved copper may also give water a bitter or metallic taste and produce blue-green stains on plumbing fixtures. Consequently, federal standards have established a SMCL (Secondary Maximum Contaminant Level) for copper of 1.0 mg/L in household water.

Lead. The federal drinking water standard for lead in public drinking water supplies is 15 μg/L (micro-g/l). Lead is a serious cumulative body poison. Natural water seldom contains more than 5 μg/L. Lead in the water supply may originate from the dissolution of old lead plumbing or solder from the pipe joints.

Zinc. The federal drinking water standard for zinc is 5 mg/L. Zinc is an essential and beneficial element in human growth. Concentrations above 5 mg/L can cause a bitter astringent taste. Zinc most commonly enters the domestic water supply from deterioration of galvanized iron and dezincification of brass. In such cases, lead and cadmium also may be present in water because they are impurities of the zinc used in galvanizing.

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Food and Drug Administration
Office of Consumer Affairs
(HFE-88)
5600 Fishers Lane
(room 16-85)
Rockville, Maryland 20857
http://www.fda.gov/
oca/guide.htm

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville NC 28801-5001
for data:
http://www.ncdc.noaa.gov/pub/
data/coop-precip/virginia.txt
home page:
http://www.ncdc.noaa.gov

Water Ace Pump Co.
Ashland, Ohio 44805
1-800-942-3343

National Drinking Water
Clearinghouse
West Virginia University
P. O. Box 6064
Morgantown, WV 26506-6064
1-800-624-8301

Farm & Ranch Service
Supply Company
P. O. Box 10165
San Antonio, TX 78210
(800) 292-0007
concrete tanks, roof washers,
floating filters

Rainwater Collection Over
Texas
201 Thurman Rd.
San Marcos, TX 78666
(800) 222-3614 (512) 353-4949
rainwater systems,water
conservation products

Rain Man Waterworks
P. O. Box 972
Dripping Springs, TX 78620
(512) 858-7020

U.S. HCN Data for Virginia
http://cdiac.ESD.ORNL.GOV/
r3d/ushcn/statepcp.html#VA_