WATER TREATMENT IN RAINWATER HARVESTING SYSTEMS FOR POTABLE USE

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Introduction

Rain water harvesting for potable water use is important in many parts of the world from the aspects of both water supply and public health. It can be the sole or an important supplementary source of water in parts of the world where supply of water is limited. Even in parts of the world where there are abundant sources of surface water, rainwater may provide a relatively safe, pure source of water that is important to the public health. In the United States, rainwater harvesting may be an important source of water for populations that are not served by public utilities either by choice or by circumstance. In some areas, rainwater harvesting is commonplace. The states of Texas, California, and Hawaii allow rainwater water catchment. The City of Portland, Oregon allows rainwater catchment and San Juan County, Washington allows it for new construction. Bermuda and the US Virgin Islands require the use of cisterns in all new construction.

Some examples of rainwater harvesting:

- In the town of Volcano on the Island of Hawaii, nearly all of the buildings harvest rainwater as their primary water source. Pockets of groundwater do not exist or are extremely deep because of the porous nature of the volcanic bedrocks. Rainfall averages 60 in. per year so the location is a perfect place for rainwater harvesting.

- A house on the Swinomish Indian Reservation in Skagit County, WA uses rainwater as the sole source of potable water. The system was built in 1999 and serves the need for 2 people. It consists of 1,600 ft^2 of metal roof, a 5,600 gal. storage tank, 20/5 micron cartridge filtration, UV disinfection and 1/0.5 micron carbon filters at taps. Water conservation is improved by use of composting toilets and a small gray water re-use system.

- The owner of the Inscription Rock Trading Company near El Moro National Monument on Highway 53 in New Mexico has had a rainwater system that supplies his household needs fro several years. Additional information about the system designed can be obtained and a potential site visit can be planned in the first quarter of 2008.

Rainwater can be used for both nonpotable (irrigation, toilet flushing laundry) or for potable uses (drinking, showering, cooking). The treatment required for potable uses differs from that required for nonpotable use. Rainwater is considered a surface water and thus shares technical and regulatory issues with other surface water sources such as ponds and rivers. The purpose of this memo is to describe the design of rain harvesting systems for potable water use. We begin with a brief overview of the components and requirements for a rainwater harvesting system designed for potable water use. Next, the potential health concerns associated with rainwater are discussed; a description of chemical and physical processes that can mitigate theses effects then follows.

General Design of Rainwater Harvesting Systems.

Rainwater harvesting systems consist of 7 major components: 1) catchment area, 2) roof wash (first flush/filter) system , 3) prestorage filtration system. 4) rainwater conveyance (e.g. gutter) 5) cistern 6) water delivery , and 7) water treatment (disinfection/filtration) system. Figure 1 shows these major components (items A, B, C, D, E, J), control features (items F, G, H, M), and examples of end use of the harvested water (items I, K, L).

Catchment:

Rainwater catchment systems can include both rooftops and ground surfaces; only roof-based collection systems will be discussed in this memo. The first thing to consider is whether enough rainfall can be collected to provide sufficient water for the intended use. This depends on the rainfall rate, the catchment area, the efficiency of collection, and the water demand. Both the average annual rate of precipitation and the length of dry seasons must be considered in system design. An average annual rainfall of at least 24 in. is generally required if rainwater is to be the sole water source.

Annual water demand: Ranges of demand vary from 25 to 50 gallons/person/day; a convenient rule thumb is to assume 50 gallons of water per day per person. So for a 4 person household, the annual water demand is simply:

50 gal/day-person x 365 days x 4 persons = 73,000 gallons

The actual demand will depend on a number of life style choices such as: use of showers or baths, washing clothes at home or at a Laundromat; installation of water-conserving fixtures, and outside irrigation. Use of other sources of water will also reduce the water demand from rainwater harvesting.

Amount of water that can be harvested: The amount of rain that can be harvested by a roof depends on the roof footprint (horizontal projection of the roof surface) and the amount that is lost by evaporation, diversion by the roof washer, and leakage. The footprint of the roof is smaller than the roof area because the tilt of the roof. A perfectly flat roof would have the largest possible footprint but would be suboptimal because it would not allow for effective draining or roof washing. Estimates of the amount of water that can be harvested vary by geographic region. Fore example, in Montana, it is estimated that each inch of precipitation yields 0.4 gallons of water of harvested water for each square foot of roof footprint. In Texas, the estimate is 0.5 gallons/inch per square foot. The actual amount harvested will depend on how well the system is maintained (leakage of gutters, and other parts of the water conveyance system) and existence of overheard obstacles (tree branches etc.). Finally, the amount of water that can be harvested and stored must be large enough to supply water during period of drought. The sources of information for average rainfall often can be used to estimate the number of continuous drought days in an area. The required storage is simply the product of daily use (gallons/day) times number of continuous drought days. This amount must be considered in designing the storage tank.

Roof wash systems or first flush systems: This is a system for keeping dust and other pollutants (bird droppings, leaves) that have settled on the roof from reaching the cistern. It is not required for systems designed for nonpotable water use, but it is required for potable use systems. It is designed to purge the initial water flowing off the roof during the rainfall.

Prestorage filtration: This part of the system keeps large particulates and debris from entering the cisterns even after the roof wash system has done its job. It may consist of a domed stainless steel screen placed over the inlets leading to the cistern. They may include leaf guards where windblown debris or overhanging trees are significant.

Pumping and conveyance systems: This is the system of gutters, downspouts and pipes used to carry water from the roof to the cistern.

Cistern: This may be the most expensive part of the system. Cisterns are used for untreated water storage and are sized to hold enough water to supply water through the drought days. They are made of a variety of materials including galvanized steel, concrete, ferro-cement, fiberglass, polyethylene and durable wood. They can be located above ground, in basement or enclosure or buried below ground depending on site-specific conditions. Typical sizes range from less than 5,000 to 10,000 gallons.

Water delivery system: A pump is used to delivery water from the cistern to the treatment system unless gravity-flow is possible. The pumps, pipes and orifices must be sized to allow delivery to other tanks used for treated water storage and pressurized water storage depending on the system design and intended use of water.

Water treatment/Disinfection: This is likely to be the most complicated part of the system and consist of several components. The design will depend on factors related to intended use (potable or nonpotable), water demand, and relationship of the harvested water system to supplementary sources of water. Processes include: filtration, disinfection and polishing steps as discussed in more detail later. Disinfection may include UV sterilization, ozonation, chlorination and filtration systems such as nanofiltration and reverse osmosis. Water treatment may take place at the point-of-entry into the house, at point-of-use taps or combination of both.

Differences in Requirements between Nonpotable and Potable Rainwater Systems: Table 1 compares the materials, treatment technologies and treatment goals of rainwater systems designed for nonpotable water and potable water production. Although the treatment technologies used in nonpotable water systems are similar to those of potable water systems, components used in the latter application must conform to the listed

ANS/NSF standards in the United States. Finally, the treatment goals and testing requirements for potable systems are much more stringent than those of nonpotable water systems.

Contaminants Potentially Present in Harvested Rain Water

The rooftop is the source for the majority of contaminants entering the rainwater systems. In urban areas, air quality, largely determined by traffic and industry, can be a source of lead, cadmium, zinc and arsenic. In older systems, the rooftop catchment can be a source of heavy metals; acidic rain can leach out metals from lead-coated nails, copper pipes, treated lumber, sealants and paints. Other contaminants of concern include synthetic organic chemicals (SOC) and volatile organic contaminants (VOCs). SOCs are typically found in pesticides, herbicides and similar man-made products. They reach the roof via leaf litter as well as by aerial spraying. VOCs can be introduced when rainwater comes into contact with materials containing refined organic products. These include plastics, glues, solvents, gasoline, greases and oils. Asbestos, a fibrous silica compound is present in older roof shingles and is a carcinogen. The ANSI/NSF standards for materials used in the catchment systems are designed to minimize the leaching of hazardous chemicals from the rooftop.

Microbial contamination comes from fecal contamination from birds and small mammals, leaf litter, mosquitoes, other insects and lizard accumulations. (see Table 2). They pose a greater threat than the chemical contaminants because 1) they can cause disease after a single exposure, 2) pathogen levels can rise very quickly and 3) diseases can be spread from person to person. Pathogenic microbiological contaminants include protozoan parasites, bacteria and viruses. The number of microbes required to cause a disease and the virulence of the disease in an exposed person depend on the type of pathogen and the immune system of the exposed person. Waterborne illnesses can be a serious threat to the elderly, infants, chemotherapy patients and other people with delicate or weakened immune systems.

Water Treatment Processes in Rainwater Systems.

The preceding section gave an overview of the function of various components of a rainwater harvesting system and potential contaminants. In this section, chemical processes that affect water quality that are especially important for potable water are described. Figure 2 illustrates the treatment train of a household rainwater system and shows the sources of contamination and system components that affect water quality. The roof top catchment system is the primary locus of microbial contamination but also is the site of a number of decontamination processes. These reduce the microbial load through heat inactivation, UV irradiation and desiccation. Within the storage tank, biofilms actively remove heavy metals and organics from the water column and surface flocculation and sedimentation remove contaminants. Tank water must pass through a pump and possibly a hot water heater before human contact. Rapid changes in pressure that occur in the former and high temperatures in the later impose sudden stresses on the bacteria, which disrupt cell structure and integrity. In addition to the processes and components shown in Figure 2, disinfection and filtration treatment obviously serve to clean the water before human contact. Details of these processes are given later in this section.

Roof Top Contaminant Removal Processes:

Both physical and chemical processes can remove contaminants from the roof. Wind scour can be effective in removing contaminants. Roof surfaces sloping away from industry often have lower concentrations of industrial pollutants than those that face towards sources of pollution because they are exposed to cleaner winds. In heavily industrial areas, therefore, some roof surfaces may be better for rainwater harvesting than others depending on the direction of prevailing winds.

If present, microbial pathogens must survive solar disinfection, thermal destruction, desiccation and UV radiation to be harmful. In laboratory studies, bacteria exposed to direct sunlight survive only for a relatively short time ranging from 4 hours for *Vibrio sp*. to days for *Shigella sp*; dessication is lethal to *Cryptosporidium*. While these experiments were not done on rooftop microbial communities, these studies suggest that the roof environment provides a *combination* of lethal stresses for bacteria, creating microbicidal conditions that may reduce pathogen populations more effectively than individual stresses.

Roof wash systems take advantage of the initial period of a rain event in which much of the rooftop contamination is entrained by water flowing on the roof. A properly designed rainwater systems for potable water will include a first-flush diverter (see Fig. 3). The amount of water required to rinse the roof depends on: 1) the slope of the roof (steeper slopes rinse more rapidly), 2) the porosity of the roof (nonporous materials clean more rapidly), 3) the amount and type of rooftop contamination (dust and debris are easier to remove than fecal matter) and 4) the rainfall rate (long slow drizzles are less effective than a brief heavy rainfall). There are 2 types of first-flush diverters. One type diverts a fixed volume of water before the tank begins to fill (fixed volume type; see Fig. 3). The second type begins filling the tank after the rainfall rate reaches a certain level (fixed-rate type). The fixed-volume diverter is better for areas where the rainfall rates are constant; the fixed-rate type is better if rainfall events typically begin with a slow drizzle and then increase in intensity. As a ‘rule of thumb’, fixed volume diverters should be sized so that 1 – 2 gallons per 100 ft^2 of roof area are flushed before the cistern begins to fill. Between storms, the diverted water trickles from the diverter; in some designs, a cleanout allows for removal of debris. One thing to note is that the amount of turbulent mixing and resulting entrainment of debris and contaminants in the diverted volume that can flow into the cistern was not discussed in any of the references that I consulted.

Water Quality Treatment Processes in the Cistern

Microbes that survive rooftop stresses and are not diverted into the first flush device (described in a later section) will end up in the cistern. Studies have shown that the concentrations of microbes within the cistern will vary with depth. At the top of the water column, a micro-layer of bacteria exists at the air-water interface due to the low specific gravity of the microbes and bacterial preference for flocculation. Below this surface, bacterial concentrations are much lower; thus the water that exists from the bottom of the tank is cleaner than that sampled at the top. Heavy metal contaminants may be removed by the passive process of sedimentation (similar to that used in waste water treatment.). During rain events, sediment at the bottom of the tank may be resuspended and act as a coagulating agent, adsorbing metals in the water and then settling to the bottom of the tank below the outlet port. Bacteria may also be adsorbed and removed by this process. Thermal gradients within the tank may also be important for water treatment. Most bacteria have minimum growth temperatures (eg. *Vibrio chlorea* thrives between 15-25°C; pathogenic *Campylobactor* species do not proliferate below 30°C). Because the lower levels of the tank near the outlets are the coldest part tank, the concentration of bacteria in the water drawn from the tank are reduced.

Biofilms may also be an important decontamination feature of cisterns, if they form. These slimy layers of bacterial colonies and extracelluar polymeric substances (EPS) are composed of a collection of chemical compounds that can adsorb many substances from the surrounding water. In water distribution systems, biofilms can clog pipes, provide a haven for antibiotic resistant bacteria, remove chlorine needed for disinfection, and may excrete potentially toxic compounds. However, in cisterns, they may act as a natural filter that removes heavy metals, nitrogen, phosphates and recalcitrant synthetic organic compounds. Because water circulation is gentle in cisterns, thick biofilms can develop. When they slough off, they will sink to the bottom of the tank, adsorbing heavy metals as they settle and remove them from the water.

Purification

The primary barrier to bacterial contamination in potable water systems is the purification system, which will consist of several steps including filtration, disinfection and polishing. Figure 4 illustrates the relations of these components for a system that does not have a treated water storage tank. Filtration can begin at the inlet to the cistern using a sand filter. Within the house, other filters can remove large particles such as parasites, while others can remove the smaller viruses. Table 3 lists some of the filtration technologies commonly used in water treatment systems. The membrane filters can be plugged by large particles so a cartridge or bag filter should be installed upstream. Some, but not all bag and cartridge filters remove *Crytospiridium* and *Giardia*. Some bag filters can be cleaned and reused; the cartridge filters must be replaced. The nanofiltration and reverse osmosis membranes need a much higher operating pressure than the microfiltration and ultrafiltration membranes.

Disinfection: Bag and cartridge filters do not remove bacteria and viruses so disinfectant is required if tighter membrane filters are not used. There are 3 methods of disinfection commonly used: chlorination, ultraviolet light and ozonation. The level of effectiveness or inactivation of the disinfection technology is expressed in log units. For example, a 2-log reduction in the number of organisms means that 10^{-2} or 1% of the pathogens remain and 99% have been removed; a 4-log reduction means 10^{-4} remain. Table 4 shows the microbial inactivation requirement for public water systems (PWS) that can be used as guidance for a private household system. Chlorination is often used in combination with the other two technologies because a free chlorine residual can be maintained in the distribution system, providing on-going treatment for viruses. The membrane materials in filters, such as cellulose acetate, are very susceptible to damage by chlorine and other disinfectants. Therefore, chlorination must be done downstream of the membranes or an activated carbon filter which removes chlorine must be installed upstream of the membranes.

Chlorine is not effective against parasites or *Cryptosporidium* and requires a relatively long contact time to be effective compared to UV and ozonation. Table 4 describes the contact times required for several pathogens at several levels of inactivation, with a 1.0 mg/L free chlorine residual, at pH = 7.0 and 68°F (20°C). The required contact times are longer at higher pH, lower temperature and shorter with a higher residual. For example, at 41°F (20°C), pH 7 and a target 1.0 mg/L free chlorine residual, the required contact time for a 3-log reduction of *Giardia* is 216 minutes, and 121.5 minutes with a 2.0 mg/L residual. These long contact times show that chlorine must be used in combination with filtration (to remove *Cryptosporidium*). An advantage of chlorinated systems is that allow it is best to remove suspended solids before the chlorination step, they will work in relatively cloudy (turbid) waters, unlike the UV systems described below.

Chlorine can be supplied via chlorine gas, liquid sodium hypochlorite bleach or solid calcium hypochlorite. Chlorine gas is corrosive and dangerous and not recommended for home systems. The solid Ca-hypochlorite is stable and easy to dispense using in-line chlorinators where solid pellets of tablets slowly dissolve. The solid form, however, is very concentrated and must be kept in tightly closed containers away from combustible materials like oils. Liquid bleach is more practical for most homeowners because it is safe and easy to dispense. It is important to use chlorine that is certified by ANSI/NSF as listed on the NSF website. Disinfectants for pools and spas may contain toxic compounds such as cyanide and shouldn't be used in drinking water systems. Chlorine bleach can also be used to initially disinfect a cistern or maintain a free chlorine residual. (see Table 2.1 in [3]). For example for a free chlorine residual of 0.5 mg/L in a 5,000 gallon tank (maintenance dose), one needs 3.75 cups of 10% liquid bleach.

Ultraviolet light is more effective against parasites like *Giardia* and *Cryptosporidium* than it is against viruses. For example, the UV dose needed to obtain a 4-log inactivation of viruses is more than 8x that required for parasites. UV systems that meet the Class A requirements of ANSI/NSF Standard 55 should be used in potable water systems. They can produce a UV dose of 400 mJ/cm^2 and have a sensor that indicates if the system needs to be cleaned or has begun to fail due to lamp age. UV radiation is effective only in relatively clear water; it is important to have a filter installed upstream to remove turbidity. UV systems do not maintain a disinfection residual in the water, avoiding the chlorine taste disliked by many people. However, there is increased risk for bacterial regrowth in the plumbing system.

Ozone is another disinfectant and is effective against both parasites and viruses. It is produced by passing an electrical current through air or oxygen. It has a very short half-life in water (few seconds to minutes) and therefore must be efficiently introduced into the water. The most commonly-used technique is a fine-bubble diffuser, similar to the porous stones used in aquariums. Ozone gas is toxic and corrosive; concentrations in the area must be kept within allowable limits set by OSHA, residual ozone must be destroyed on-site and appropriate materials must be used in construction of an ozone contact vessel. There is no well-accepted ANSI/NSF standard for evaluating the safety of ozone generators.

Polishing Processes

Additional treatment processes may be applied after the disinfection step. These include corrosion control and activated carbon filtration at the tap. Rainwater lacks the buffering capacity that mineral salts provide to ground and surface water. The low pH of pure rainwater (<6) is corrosive, thus care must be taken to prevent pinhole corrosion of thin-walled copper pipes used in many home plumbing systems. The pH in the untreated water cistern should be maintained at about 7.4 – 7.7. Corrosion control can be accomplished by simply adding baking soda (sodium bicarbonate) to the cistern about every 3 months. Arm and Hammer baking soda has been certified in accordance with NSF Standard 61. The dose depends on the pH of the water in the storage tank and the tank volume. For example, if the pH in a 10,000-gallon tank is 7.1, the dose would be 3 pounds of baking soda. Alternatively, the rainwater can be passed through an in–line filter that contains beds of crushed limestone, lime or soda ash. This material dissolves and raises the pH and buffering capacity of the water. Finally, a metering pump that dispenses zinc orthophosphate can be used; this coats the interior of the pipes to prevent corrosion. If the house distribution system is plastic, then the corrosion control is not needed.

Activated carbon filters can be installed at point-of-use taps to provide additional protection and taste control. Such filters are certified for removal of VOCs and SOCs by NSF. Some filters are installed downstream of chlorinators to improve taste; this will reduce the useful life of the activated carbon filter. In older homes, with plumbing containing fittings, pipes and solders with >8% lead, it may be advisable to install GAC filters at drinking water tapes to remove heavy metals. This is unlikely to be a problem in homes constructed after 1988. Any POU filter that is installed should be certified by ANSI/NSF Standard 53 to reduce the target contaminant.

Dual use systems – potable/nonpotable systems and supplementary water sources

In some cases, the rainwater system is supplemented by water from a PWS. In these cases certain precautions must be taken to protect both systems:

- Corrosion control – pH needs to be < 7.7 to avoid potential precipitation of carbonate salts in the pipes.
- PWS water may be chlorinated so need to install GAC filter to protect filtration membranes downstream from the PWS.
- PWS inlet and cistern must be isolated by and air gap to prevent backflow of water from the cistern to the PWS in event of loss of pressure and flow.

In some applications, only a portion of the water is for potable use and an untreated portion is used for toilet, laundry, and irrigation. Pipes for the nonpotable uses should be clearly identified; the standard markings are black letters on bright orange background: “UNTREATED RAINWATER - DO NOT DRINK”.

Benefits and Risks from Use of Harvested Rainwater

There is some evidence suggesting that it may be safer to drink properly harvested rainwater than water from public water systems (PWS). An epidemiological study of 1000 participants showed that those drinking chlorinated filtered water from a PWS reported higher rates of gastrointestinal sickness than those drinking rain harvested water. [3]. The use of chlorine as a disinfectant has come under public health scrutiny in recent years because of the carcinogenic disinfection byproducts (DBPs) that are produced by the reaction between natural organic matter (NOM) in water and the chlorine oxidants. The NOM or Total Organic Content (TOC) of rainwater is very low (absent contamination by animal and microbial sources mentioned above); therefore, the risk of DBP formation is lower in rainwater than in ground or surface waters. The purity of properly harvested rainwater, however, carries its own health risks. The absence of essential nutrients in rainwater has health implications: lack of calcium and magnesium increases the risk of cardiovascular diseases; the lack of fluoride increases the risk for dental caries. Care must be taken to include vitamin supplements in the diet if harvested rainwater is the sole source of drinking water.

References Cited:

[1] Yocklic, M.R. 2004. Cold Climate Rainwater Harvesting Systems, RIP-3333-001; Environmental Research Laboratory, University of Arizona, Tucson, AZ..

[2] Spinks, A.T., et al. 2003. Water Quality Treatment Processes in Domestic Rainwater Harvesting Systems. Proceeding of 28th International Hydrology and Water Resources Symposium. 10-14 November 2003, Wollongong, Australia; The institution of Engineers, Australia

[3] TCEQ, 2007. Harvesting Storing, and Treating Rainwater for Domestic Indoor Use, Texas Commission on Environmental Quality, Austin, TX.

[4] Rupp, G. 1998. Rainwater Harvesting Systems for Montana, MT907, MSU Extension Service, Montana State University.
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FIGURES

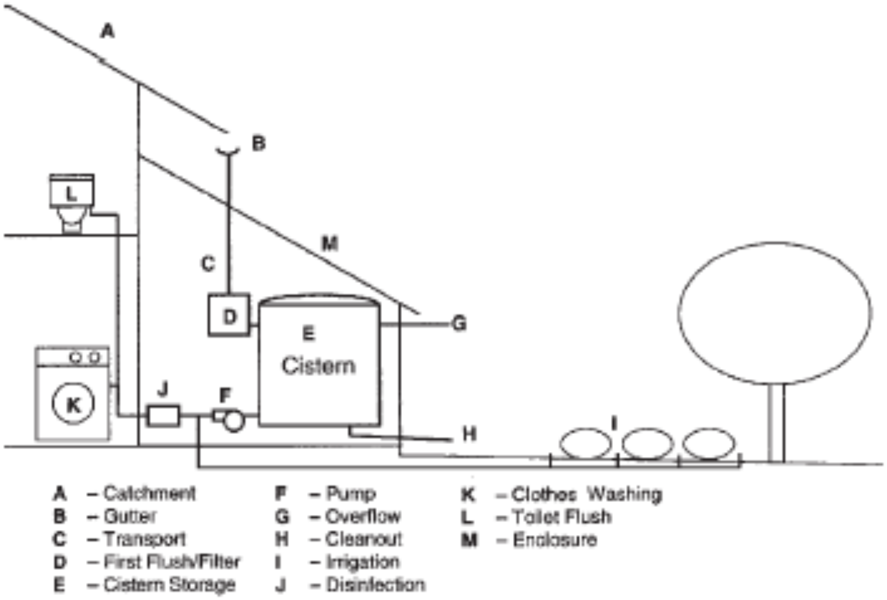


Figure 1. Typical Components of Rainwater Harvesting System [1]

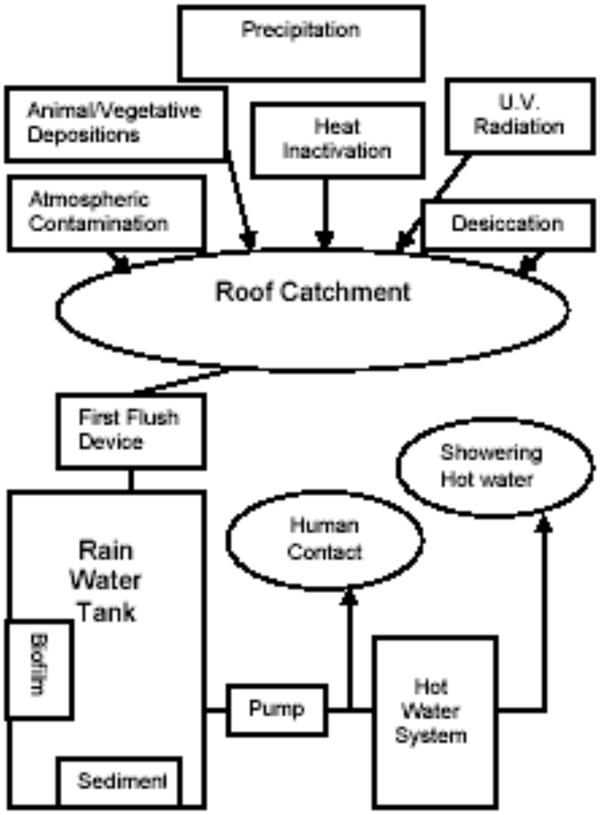


Figure 2. Treatment Train of a Rainwater Harvesting System Independent of Disinfection/filtration. From [2]

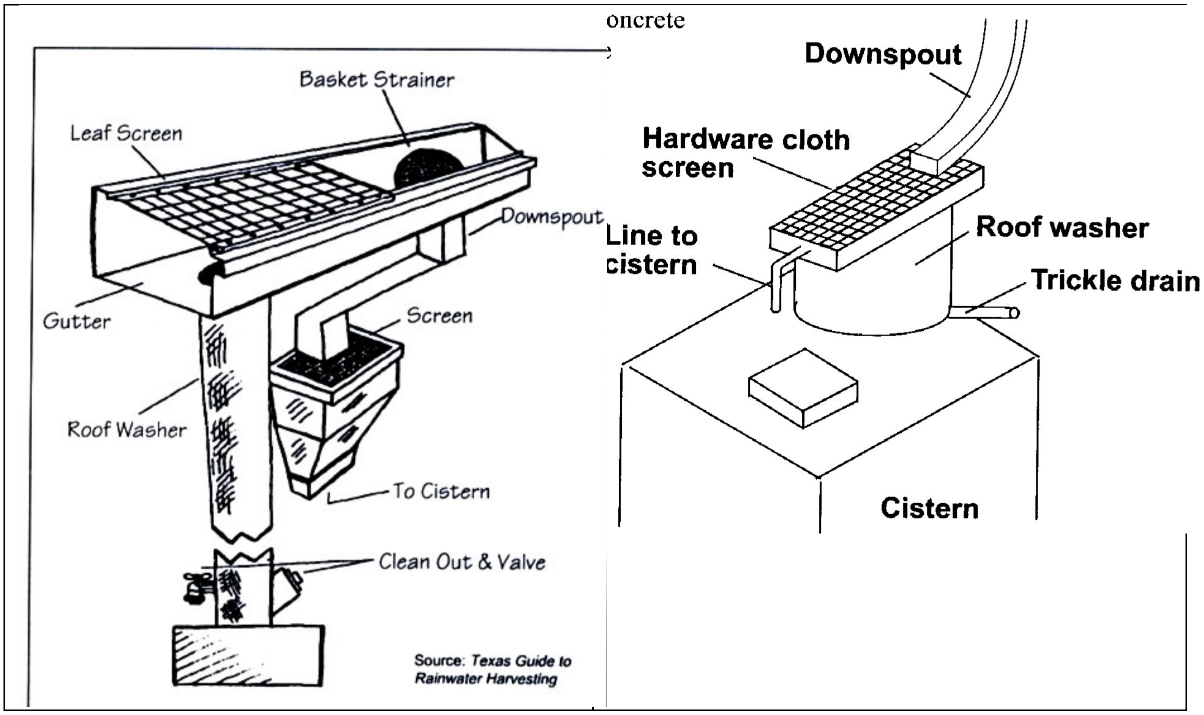


Figure 3. Roof Wash Systems (first-flush diverters) (from [3] and [4]).

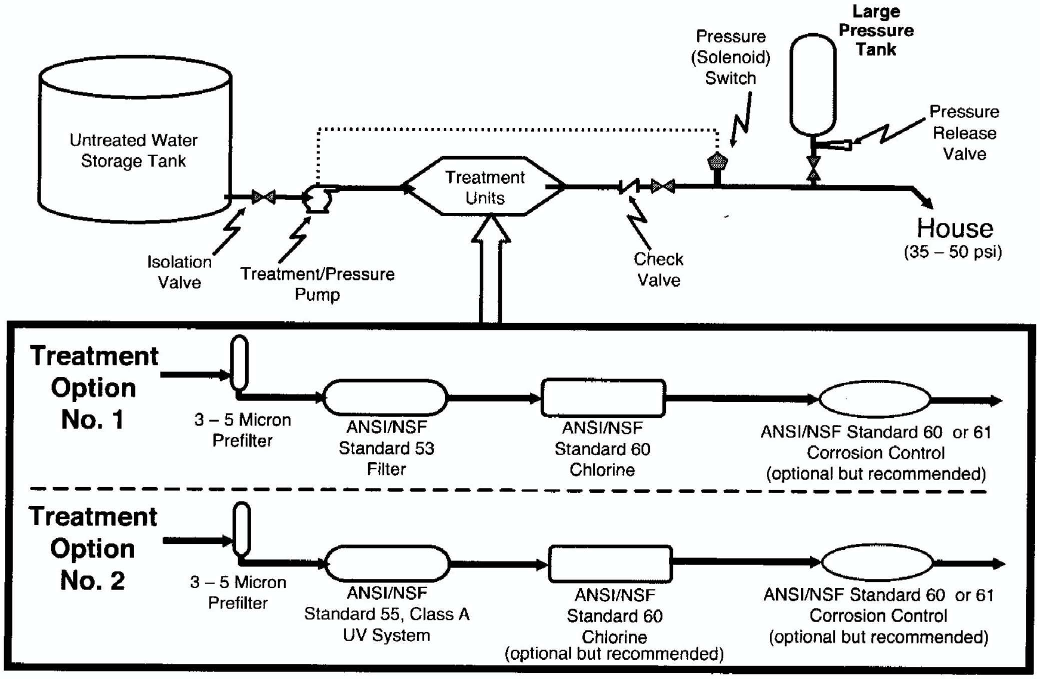


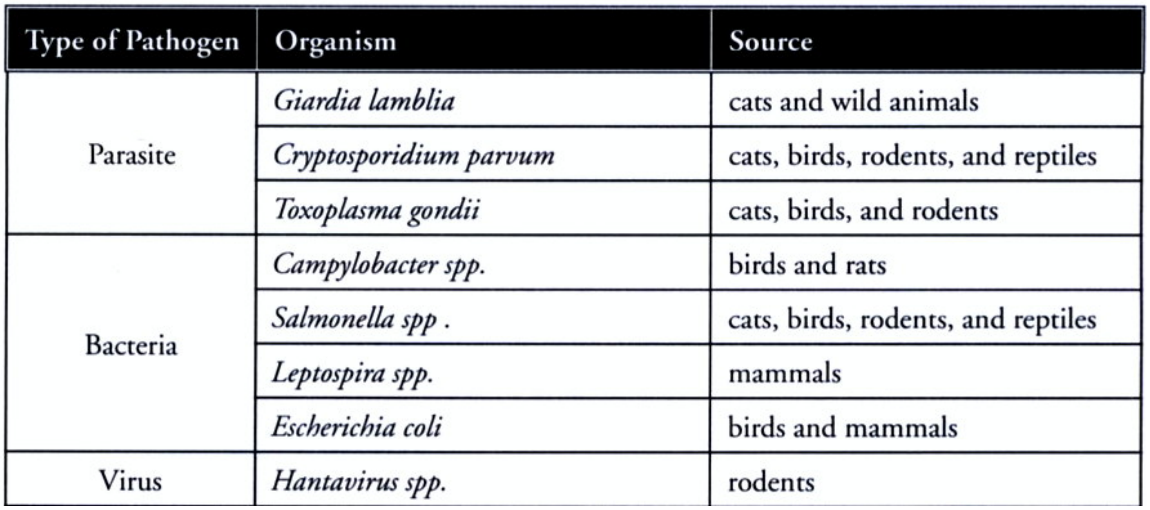
Figure 4. Treatment System Without Treated Water Storage. (from [3]).

TABLES

Table 1. Comparison of Nontpotable and Potable Water Systems (from [3])

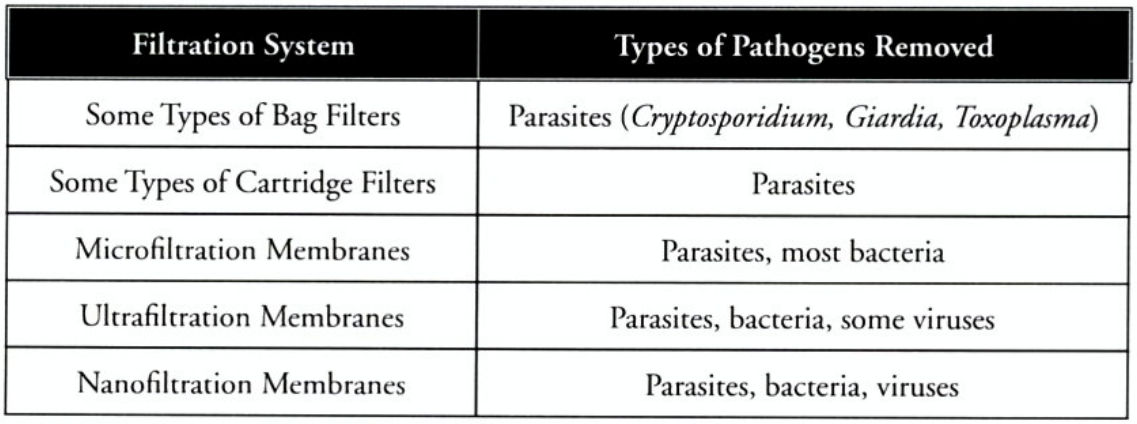
Issue	Nonpotable System	Potable System
Materials of Construction	Potable water certification not needed. Thin-wall copper tubing should not be used.	Materials used should be (when available) certified for potable water applications under ANSI/NSF Std 61. Thin-wall copper tubing and materials containing lead or biocides should not be used.
Treatment Technology	*Pre-treatment* First-flush, roof washer, or other appropriate pre-filtration method. *Treatment* Bag or cartridge filtration with a 5-micron sediment filter and periodic chlorination with household bleach.	*Pre-treatment* First-flush, roof washer, or other appropriate pre-filtration method. *Treatment* Filtration with an ANSI/NSF Std 53 filter followed by disinfection with ANSI/NSF Std 60 chlorine or an ANSI/NSF Std 55, Class A UV unit. ***OR*** Filtration with a 3- to 5-micron ANSI/NSF Std 61 sediment filter and disinfection with an ANSI/NSF Std 55, Class A UV unit.
Treatment Goals	Total Coliform: < 500 CFU/100 mL Fecal Coliform: < 100 CFU/100 mL Turbidity: < 10 NTU Water should be tested annually.	Total Coliform: 0 Fecal Coliform: 0 Protozoan Cysts: 0 Viruses: 0 Turbidity: < 0.3 NTU Water should be tested every 3 months.

Table 2. Types and Sources of Pathogens That Can be Found in Harvested Rainwater (from [3]).



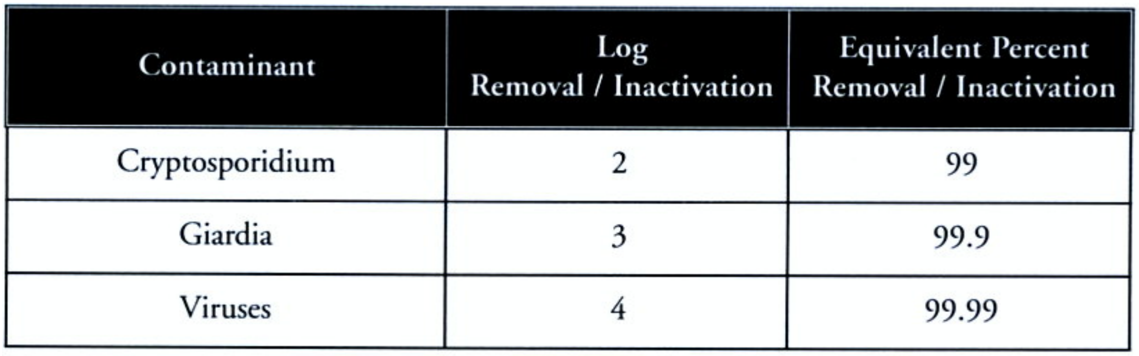
Type of Pathogen	Organism	Source
Parasite	*Giardia lamblia*	cats and wild animals
	Cryptosporidium parvum	cats, birds, rodents, and reptiles
	Toxoplasma gondii	cats, birds, and rodents
Bacteria	*Campylobacter spp.*	birds and rats
	Salmonella spp .	cats, birds, rodents, and reptiles
	Leptospira spp.	mammals
	Escherichia coli	birds and mammals
Virus	*Hantavirus spp.*	rodents

Table 3. Filter Technologies and Microbe Removal (from [3].



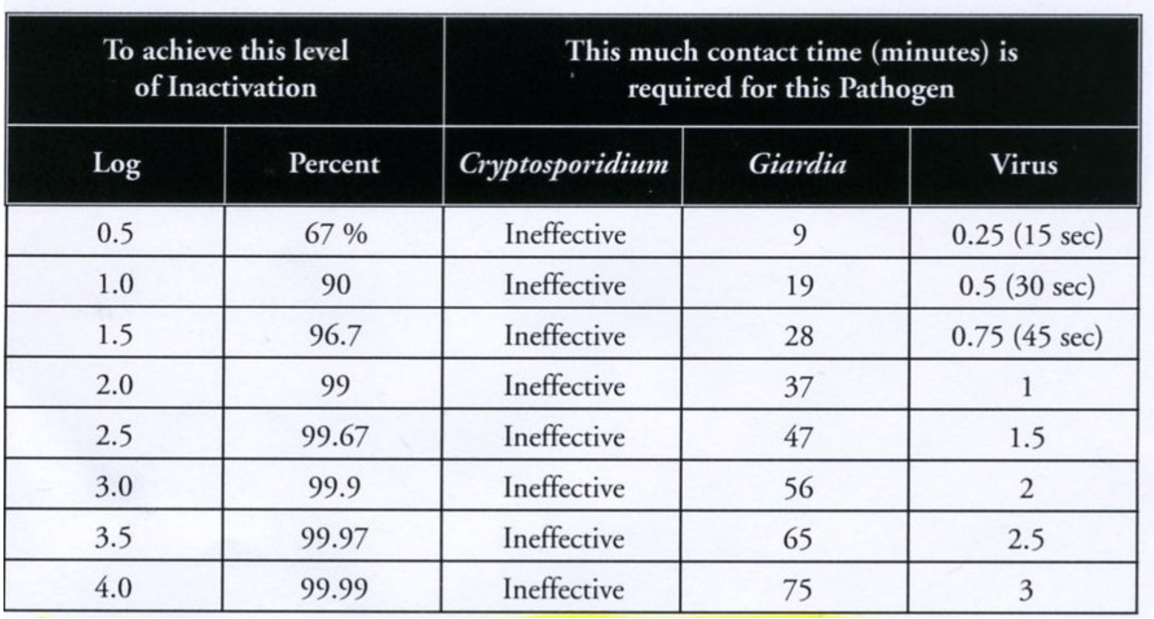
Filtration System	Types of Pathogens Removed
Some Types of Bag Filters	Parasites (*Cryptosporidium, Giardia, Toxoplasma*)
Some Types of Cartridge Filters	Parasites
Microfiltration Membranes	Parasites, most bacteria
Ultrafiltration Membranes	Parasites, bacteria, some viruses
Nanofiltration Membranes	Parasites, bacteria, viruses

Table 4. Microbial Removal/inactivation Requirements for Public Water Systems Using Rainwater (from [3])



Contaminant	Log Removal / Inactivation	Equivalent Percent Removal / Inactivation
Cryptosporidium	2	99
Giardia	3	99.9
Viruses	4	99.99

Table 5. Examples of Chlorine Contact Time Requirements for Inactivation of *Cryptosporidium, Giardia* and Viruses (from [3]).



To achieve this level of Inactivation		This much contact time (minutes) is required for this Pathogen		
Log	**Percent**	***Cryptosporidium***	***Giardia***	**Virus**
0.5	67 %	Ineffective	9	0.25 (15 sec)
1.0	90	Ineffective	19	0.5 (30 sec)
1.5	96.7	Ineffective	28	0.75 (45 sec)
2.0	99	Ineffective	37	1
2.5	99.67	Ineffective	47	1.5
3.0	99.9	Ineffective	56	2
3.5	99.97	Ineffective	65	2.5
4.0	99.99	Ineffective	75	3