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RAINWATER HARVESTING FOR ARMY INSTALLATIONS

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RAINWATER HARVESTING FOR ARMY INSTALLATIONS

1. Purpose.

a. This Public Works Technical Bulletin (PWTB) provides an overview of rainwater harvesting for Army installations. Rainwater "harvesting," or the capture of rainfall runoff from roofs or similar hard surfaces that would normally escape to storm sewers or overland flow, provides a high quality source of water that can be used to extend an installation's water supply. This alternative allows beneficial use of water and helps meet a number of recent policy requirements. This bulletin presents a brief history of rainwater harvesting; a review of policies and regulations; guidelines that may play a role; and a summary of institutional barriers. Guidelines are also presented on how to develop an active rainwater harvesting system including design factors, user considerations, materials, implementation, and operation and maintenance (O&M). Additionally presented are representative economics, examples of local requirements, and military experience with lessons learned. This document does not attempt to provide an exhaustive treatment of every aspect of rainwater harvesting; rather, it means to present sufficient information to encourage greater consideration of the necessity and benefits of incorporating this option on installations. Application of the guidelines presented in this bulletin will provide installation personnel with the information to properly determine the applicability of rainwater harvesting for their installations. Further description is found in paragraph 4.c.

b. All PWTBs are available electronically (in Adobe® Acrobat® portable document format [PDF]) through the World Wide Web (WWW) at the U.S. Army Engineering and Support Center's Technical Information – Facility Design ("TechInfo") web page, which is accessible through URL:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability. This PWTB applies to all U.S. Army facilities engineering activities within the United States.

3. References.

a. Army Regulation (AR) 200-1, "Environmental Protection and Enhancement," Headquarters, Department of the Army, Washington, DC, 13 December 2007.

b. AR 420-1, "Army Facilities Management," 19 February 2008

c. Executive Order (EO) 13423, Strengthening Federal Environmental, Energy, and Transportation Management, 26 January 2007.

d. Federal Energy Management Program, Best Management Practices.

e. U.S. Green Building Council (USGBC), Leadership in Energy and Environmental Design (LEED).

f. Boozer, James C. Memorandum. Subject: Army Water Conservation Program – 2009 Update. 18 June 2009.

4. Discussion.

a. Use of rainwater is an important factor contributing to resource efficiency. LEED, the International Code Council (ICC) National Green Building Standard, and ASHRAE's Standard for High Performance Green Buildings all recognize the use of rainwater to meet the prescriptive option to reduce building water use. Rainwater harvesting (RWH) is one water conservation practice that can be used to expand the existing water supply available to installations.

b. Laws and regulations governing RWH vary from state to state. (RWH is encouraged in many states, but is discouraged in others.) Those planning to institute an RWH program should first consider the variety of regulations that may affect the practice.

c. The information in this PWTB will enable installation personnel and Corps District planners to:

i. evaluate the potential for rainwater harvesting (RWH) to expand the available water supply at their installations as a supplemental water supply source for potable or non-potable use (with appropriate treatment alternatives and implementation scenarios)

ii. cost-effectively implement rainwater harvesting opportunities while pursuing their missions and maintaining quality of life.

d. The PWTB appendices will cover:

i. history and definitions

ii. regulatory and policy review

iii. pros and cons of rainwater harvesting

iv. appropriate scenarios and applications for rainwater use, including larger scale applications such as RWH from parking lot runoff

v. various types of RWH systems and their components

vi. Federal examples and potential military installation applications.

e. Appendix A presents information to aid in implementing rainwater harvesting or to determine feasibility for use at a military installation or U.S. Army Corps of Engineers (USACE) facility.

f. Appendix B contains source citations.

g. Appendix C lists acronyms used throughout this PWTB.

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Appendix A

Rainwater Harvesting for Army Installations

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Introduction

History of Rainwater Harvesting

Collecting and storing rainwater is not a new idea. While the origin of rainwater catchment systems are not known precisely, historical evidence suggests structures for holding runoff water date back to the third millennium B.C. Structures have been found in numerous locations including the Negev desert in Israel, the Mediterranean, India, Greece, Italy, Egypt, Turkey, and Mexico. Historical structures range from saucer like ground catchments and below ground cisterns to above ground rooftop runoff storage tanks. Many of the Asian and Middle Eastern countries and island communities still use some type of water catchment devices due to current low water supply and low water quality.

In the United States, evidence of historical rainwater harvesting systems can be seen in Texas and Arizona. Rock cisterns known as the Hueco Tanks in Texas and Tinajas in Arizona trapped rainwater for native residents, from the archaic hunters to the Mescalero Apaches and they later became a stopping point for stagecoach travelers and missionaries. In early central Texas communities, central plazas went beyond social and market locations to be collection surfaces for vast underground cisterns that stored the collected water for use by adjacent shops and homes. In more recent times, Germany has been a leader in development of rainwater harvesting system design and sustainable technology.

The Need for Water Conservation

Climate change has become one of the most important environmental issues world-wide. A related topic that also requires urgent attention is that of expected water shortages around the globe and the options available to cope with them. Water scarcity is no longer a problem isolated to arid areas; it happens in every climate. Even in the United States, where water was widely regarded as a limitless resource, water supply is under increasing demand. Groundwater levels are declining, and water treatment plants struggle to meet current demands while dealing with declining infrastructure.

Predictions vary as to whether the Southwest will become wetter or drier. However, the amount of precipitation is changing; climate research shows a greater variability in precipitation is expected, resulting in a higher frequency of extreme events such as droughts, high-intensity storms, and flooding (IPCC 2007).

The first step to addressing the problem of water shortage (to increase the available water supply) is to efficiently use whatever water is currently available to its fullest potential. This includes water conservation, water reuse, use of reclaimed water and capture of stormwater and rainwater where feasible and legal.

Rainwater harvesting is an alternative, sustainable, and freely available water resource that has been neglected since the advent of municipal water systems and storm water systems that channel water off-site. Instead of losing this valuable resource, it is possible to expand the use of harvesting techniques to capture rainwater on-site, then use it in landscape features or store it in tanks or cisterns for later use. Countries around the world (e.g., Australia, India, Korea, Japan, the European Union) have been rediscovering this resource and reemphasizing its use. Now the United States, especially the Southwest, is following suit. Many countries require all new development in certain areas to be equipped with rainwater harvesting systems to preserve declining groundwater supplies.

Rainfall patterns contribute to applicability of RWH in a given area. RWH is most applicable where other sources of water are either not available or are too expensive, although the process is often beneficial to mitigate stormwater runoff and complement existing water supplies. Rainwater collected from roof surfaces is stored in cisterns or other tanks and either pumped back into buildings for indoor use or used for irrigation. Indoor uses include toilet flushing, laundry, cooling tower, and boiler makeup.

Rainwater harvesting is ideal for large industrial or commercial/institutional buildings, especially ones with expansive parking lots. For example, a flat-roofed building system could start with siphonic roof drainage, which is less expensive than traditional methods of guttering. Newer flat-roofed building systems have a slight slope to guide water to a guttering system or downspout. The rainwater would be stored in tanks or ponds before use, reducing site runoff. In some areas, the stored water is filtered, treated, and used for all indoor purposes. Where municipal water systems are available, supplementally harvested rainwater is used primarily for landscape irrigation, thus reducing overall demand for municipal water.

Installations and Water Conservation

Water scarcity is expected to worsen in the coming years, nationally and globally (Morrison 2009; Kellman 2009). In the face of coming shortages, Base Realignment and Closure (BRAC) activities are expanding and realigning military installations. This, in combination with responsibilities and requirements of the Global War on Terror (GWOT) forces installations to increase their demands on available water supply, especially in some semi-arid and drought stricken regions. Some installations are already becoming "water-limited," and may need to restrict their consumption. It is essential for military installations to use available water to best effect to address water scarcity and ensure environmental security.

Besides filling their own water needs, installations have many motivational drivers for using water efficiently, including a desire to save energy, and to maintain local control and reliability of the water supply. Other drivers that encourage water efficiency include individual installation sustainability plans, Army Environmental Policy, the Army Energy Campaign Plan, and LEED requirements for Silver in all new construction. Also, EO 13423 requires and directs Federal agencies to reduce potable water use intensity by 2 percent per year through 2015 compared to a 2007 baseline.

The vast majority of water used on installations does not have to be drinking water quality. Major uses are toilet flushing, irrigation, clothes washing, vehicle washing, cleaning, etc. The replacement of potable water with non-potable water from alternative water sources is an easy method to achieve substantial reductions in water use intensity. For example, one might switch to harvested rainwater for toilet flushing within buildings (toilets can use up to a third of the water consumed), or for irrigation of landscaping. These are two primary uses for nonpotable water that currently use potable water.

As the Army becomes more sustainable, one option for increased sustainability is to capture water that would normally be discarded in a local stormwater management system and beneficially use that water for uses such as irrigation, toilet flushing, boiler makeup, or other areas where less than potable quality level water is necessary. Installations will need to adopt and balance the use of alternative water sources with potable water sources to meet their overall water consumption requirements. Additionally, rainwater harvesting (RWH) is applicable in many scenarios where potable quality is needed due to extreme shortages and high expense of water transport.

Reasons for Harvesting Rainwater

Several reasons for harvesting and reusing rainwater today are that:

- Rainwater is a self-sufficient water supply located close to the user.
- Rainwater is soft water with low mineral content.
- Rainwater harvesting augments available water supplies, which is crucial for areas with dropping water tables.
- Rainwater harvesting helps to mitigate urban flooding. Water captured and retained on-site lessens rainwater runoff (or stormwater) that carries pollutants into waterways.
- Rainwater harvesting reduces erosion caused by flooding.
- Simple landscape features that retain harvested rainwater, such as berms, check dams, and basins can slow and infiltrate water on sloped land, which reduces erosion and increases soil moisture to establish or enhance vegetation.
- Water harvesting techniques are easy to learn, low-cost and require little energy input.

There has been a renewed interest in RWH due to the escalating environmental and economical cost of providing water by centralized water systems by the use of pumped groundwater. The U.S. Environmental Protection Agency (USEPA) has been promoting the use of green infrastructure approaches including rainwater harvesting to decrease stormwater runoff. The use of collected rainwater has proven to be cost efficient in numerous situations in the United States

The connection between water and energy is clear. The processes of extracting water from surface or groundwater supplies, bringing it to treatment facilities and treating it to appropriate standards, then delivering it to customers are expensive (primarily due to pumping and treatment costs). The water sector consumes 3 percent of the electricity generated in the United States and electricity accounts for one-third of water utility operating costs. Reducing potable water demand by 10 percent could save approximately 300 billion kWh of energy each year. The reduced water demand provided by rainwater harvesting translates directly to energy savings. Decreasing potable water demand by 1 million gallons can reduce electricity use by nearly 1500 kWh. Similarly, an estimate of reducing potable water demand by 1 million gallons can reduce carbon dioxide emissions 1 to 1.5 tons when fossil fuels are used for power generation.

To be most effective, water harvesting must be coupled with water conservation. Conserving water also saves energy, as water purification and water delivery consumes substantial energy resources

RWH offers the opportunity to decrease water and wastewater costs, which are rapidly escalating in some parts of the country. It can ease the burden of system development charges that are often assessed on new buildings to help pay for expanding municipal and separate storm water management systems. It can turn a potential liability – runoff – into an asset.

Another reason to integrate RWH into a new building's design is increasing interest in green building. RWH is a relatively easy and excellent way to demonstrate environmental stewardship to local communities and facility stakeholders. Also, depending on the design, RWH can help a project garner up to seven points toward the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating, making it easier to achieve Silver, Gold, or Platinum levels.

Rainwater Harvesting vs. Stormwater Recycling

Rainwater harvesting and stormwater recycling are essentially similar processes. RWH usually involves collecting water from cleaner surfaces such as roofs; stormwater recycling is designed to collect ground level runoff. Both require collecting, storing, and conserving rainwater runoff specifically for use at a later date. Many commercial-level systems combine rooftop and surface runoff in the same storage cisterns. These are primarily for irrigation.

External Drivers that Affect Rainwater Harvesting

Policy, Regulations, and Guidelines

Army and Federal Regulations

The Assistant Chief of Staff for Installation Management has established as policy that EO 13423 must be followed. It indicates that the Army must reduce potable water consumption intensity by 2 percent per year from an FY07 baseline. Army water conservation programs follow the FEMP (Federal Energy Management Program) guidelines for water efficiency, which are listed in Table A1; rainwater harvesting is an option.

Army Regulation (AR) 420–1 addresses the topic of water supply and wastewater policy requiring accordance with the Safe Drinking Water Act (SDWA) of 1974 as amended in 19 June 1986 (Public Law [PL] 99–339) and in October 1988 by the Lead Contamination Control Act (PL 100–572) (42 USC 300f, et seq.) and all applicable State and local regulations. Other requirements address nonpoint source (NPS) pollution control and abatement. Measures for NPS pollution control will be included in all construction, installation operations, and land management plans and activities. This allows the incorporation and adaptation of concepts such as integrated water management, low impact development, total water management, and similar possibilities.

AR 420-1 also calls for water supply and wastewater services to be provided at the lowest Life Cycle Cost (LCC) consistent with installation and mission requirements, efficiency of operation, reliability of service, and environmental considerations. The costs for these services are to be held to a minimum through comprehensive water resource planning, management, and an effective water conservation program.

An additional feature is that design criteria and standards for water supply systems and for waste water collection, treatment, and disposal systems will be in accordance with Technical Instructions (TI) 800–01. Alteration and construction projects are to be submitted for review by State regulatory authorities where required by law.

The Federal Energy Management Program (FEMP) and the Green Building initiative are among the Federal initiatives promoting rainwater harvesting. The FEMP Best Management Practices for water conservation (Table A1) indicate other water use and alternate water sources (i.e., rainwater harvesting) are encouraged options.

Table A1. FEMP Best Management Practices for Water Conservation.

1. Water Management Planning
2. Information and Education Programs
3. Distribution System Audits, Leak Detection and Repair
4. Water Efficient Landscaping
5. Water Efficient Irrigation
6. Toilets and Urinals
7. Faucets and Showerheads
8. Boiler/Steam Systems
9. Single-Pass Cooling Equipment

10. Cooling Tower Management
11. Commercial Kitchen Management
12. Laboratory/Medical equipment
13. Other Water Use
14. Alternate Water Sources

These features indicate that the use of rainwater harvesting is an acceptable option for Army installations to increase available water supply. In fact, RWH has been used both to provide potable water and water for uses requiring lesser quality water such as toilet flushing or irrigation. RWH is also widely practiced to maintain a water supply for wildlife and domestic animals.

LEED Opportunities

A building with a RWH system has the potential to garner up to seven LEED points as follows:

- 1 point for installing above-code measures that result in 20 percent water savings
- 1 point for installing above-code measures that results in 30 percent water savings (typically waterless urinals or other unusual measures)
- 1 point (innovation credit) for installing above-code measures that result in 40 percent water savings (RWH system or other water reuse)
- Up to 2 points for storm water reduction (storm water management practices)
- Up to 2 points for water-efficient irrigation
- 1 point for reducing the project's sewage generation from use of potable water by 50 percent or more.

A well-designed rainwater harvesting system integrates several design disciplines, including civil, mechanical and electrical engineering; and architecture and landscape architecture toward the common goal of using a valuable renewable resource. Depending on the application, rainwater becomes the sole or partial source of water for water closets and urinals, landscape irrigation, hose bibs, water features, cooling towers, or secondary fire suppression.

State Regulations

No national standards exist for RWH systems. Therefore, guidance has been provided at state and local levels. Guidance ranges from voluntary guidelines such as Best Management Practices to codes and ordinances stipulating minimum standards for various aspects of RWH.

A few states and local jurisdictions have developed standards or guidelines for rainwater harvesting, although it is largely unaddressed by regulations and codes. Neither the Uniform Plumbing Code nor International Plumbing Code directly addresses rainwater harvesting in their potable or stormwater sections. Because of this general lack of specific rainwater harvesting guidance some jurisdictions have regulated harvested rainwater as reclaimed water, resulting in more stringent requirements than necessary. This has created some confusion as to what constitutes harvested rainwater, graywater, or reclaimed water. The lack of uniform national guidance has resulted in differing use and treatment guidelines between states and local governments and has slowed down major adoption of rainwater harvesting as an ancillary water resource. For that reason, the following definitions are presented as used by the Uniform Plumbing Code (UPC):

- **Graywater** includes used water from bathtubs, showers, lavatories and clothes washers.
- **Reclaimed water** is water treated to domestic wastewater tertiary standards by a wastewater treatment plant suitable for controlled use, including supply for toilet flushing or irrigation. Reclaimed water is generally conveyed in purple pipes.
- **Harvested rainwater** is stormwater that is conveyed from a building roof, stored in a cistern and disinfected and filtered before being used for toilet flushing. It can also be used for landscape irrigation.

For example, the state of Texas promotes harvested rainwater for any use including potable uses provided appropriate treatment is installed. The city of Portland, OR, like many other jurisdictions generally recommends rainwater use for nonpotable applications such as irrigation or toilet flushing.

The American Rainwater Catchment Systems Association (ARCSA) has been involved with publishing guidelines for potable and nonpotable RWH systems. The draft guidelines are available at: http://www.arcsa.org/codefinaldraft.pdf

Building Codes

In addition to voluntary efforts, some states and municipalities are choosing to establish rules. Ohio, Kentucky, Hawaii, Arizona, New Mexico, Washington, West Virginia, Texas, and the U.S. Virgin Islands are either considering or have developed rules related to RWH.

Rules, ordinances, building codes, etc. nationwide run the gamut from requiring RWH systems on new construction to prohibiting tanks as an eyesore.

Some examples of the variety of regulations found around the country are:

- Texas, House Bill (HB) 645, passed in 2003, prevents homeowners associations from implementing new covenants banning outdoor water-conserving measures such as water-efficient landscapes, drip irrigation and, RWH installations. The legislation does allow homeowner associations to require screening or shielding to obscure view of the tanks.
- Texas has also passed legislation requiring all new state buildings over 10,000 sq ft to install rainwater harvesting equipment.
- Albuquerque-Bernalillo County instituted in 2008 new standards requiring rainwater harvesting systems for new homes. All rainwater harvesting systems need to capture the runoff from at least 85 percent of the roof area.
- The state of Ohio has the most extensive rules on RWH in the United States, with code on cistern size and material, manhole openings, outlet rains, overflow pipes, fittings, couplings, and even roof washers. Ohio's rules also address disinfection of private water systems (Ohio Department of Health 2004).

Voluntary Guidelines

Many university-level programs have published guidelines helpful to rainwater designers and planners. Among them are Texas Cooperative Extension's guidelines and the University of Arizona's "Harvesting Rainwater for Landscape Use," both of which focus on capturing rainwater for outdoor irrigation. The University of Hawaii College of Tropical Agricultural and Human Resources produced the "Guidelines on Rainwater Catchment Systems in Hawaii," which has information for people using rainwater for potable consumption (Macomber 2001).

Guidelines for potable systems recommend that storage tanks be constructed of non-toxic material such as steel, fiberglass, redwood, or concrete. Liners in storage tanks should be smooth and of food-grade material approved by the U.S. Food and Drug Administration.

Institutional Issues and Barriers

Use of stormwater has remained relatively limited, although it offers environmental and economic benefits. This is caused by a number of perceived and actual barriers. The United States consumes water at a high rate, approximately double that of Europe, However, the cost is approximately half. The cost of potable water in the United States ranges widely. A recent survey (Reuters 2008) found a national average of $2.81/1000 gal with many cities well over $5.00/1000 gal. When the cost of sewer is added (many cities bill sewer at a percentage of the water cost, often up to 100 percent), the total is an average of $7.08/1000 gal.

Testing in Germany demonstrated that the risk of e. coli contact with the human mouth from toilet flushing was virtually nonexistent, resulting in a recommendation that special disinfection procedures were unnecessary for rainwater dedicated to nonpotable use (Ecker 2009).

Regulations and codes also inhibit rainwater harvesting. Plumbing codes are a common barrier. Often they make no provisions for rainwater reuse or require downspouts to be connected to a stormwater collection system, eliminating the possibility of intercepting roof runoff. Code changes are often a necessary first step to implementing RWH. Other regulations that complicate rainwater harvesting are western states' water rights and their "first in time, first in line" philosophy of access to water. For example, Colorado interprets water rights law as prohibiting rainwater harvesting. The state interprets cisterns and rain barrels as devices that prevent runoff from reaching rivers and thereby that decrease a downstream user's allotted water right. Recently, however, there has been limited progress in Colorado allowing limited rainwater harvesting in certain areas as it has been shown that the majority of water (97 percent) falling as rain is lost via evaporation or transpiration before it gets to streams or rivers. Other states and municipalities are more liberal. Many communities for example have rain barrel initiatives and the city of Seattle has a City-wide water-right permit to ensure the legality of water harvesting.

In fact, rainwater harvesting is a water conservation practice that will reduce the overall withdrawal and use of water, freeing up a greater quantity of water for downstream users. Harvested rainwater used for irrigation or other outdoor use reapplies the water similar to normal rainfall. Rainfall collected in the sanitary system is also eventually returned to receiving streams and available for downstream users.

Development of an Active Rainwater Harvesting System

Before an actual rainwater harvesting system can be designed, several basic questions must be answered regarding:

- Will the system be a retrofit to an existing building, or a new integral system?
- Will the system size be large, medium, or small?
- How complex will the system be? (Will it be a "passive" or "active" system?)
- What cost is permissible? Will it be a low cost or complex system?
- What are the system requirements, in terms of:
  N intensity of use
  N level of commitment
  N water security.
- What is the intended use of the system, landscape irrigation and/or potable water?
- What water quality is required?

Retrofitting an existing building or landscape generally is more expensive and costly than it is to design a new integral system. Any system can be designed to fit a site's intended use and supply demands. Systems can range in size from small to very large. Kinkade-Levario (2007) uses the following size determinations to categorize RWH systems:

- Small: <5,000 gal
- Medium: 5001 – 10,000 gal
- Large: 10,001 – 25,000 gal
- Very large: >25,000 gal.

Types of Systems and Levels of Commitment

Systems can be complex or simple, active or passive. Complex active systems require pipes, pumps, pressure tanks, and filtration. Simple systems may have the same components, but on a much smaller level. Passive systems generally refer to gravity landscape systems.

Another categorization by complexity lists four basic types of RWH systems:

1. **Occasional:** Small storage capacity, most of the users' needs are met, alternate water source required, uniform rainfall areas with few days between rainfall.
2. **Intermittent:** Small to medium storage capacity, users needs met for a part of the year, may require alternate water source, single rainy season.
3. **Partial:** Medium to large storage capacity provides all of high quality water needs and some nonpotable needs for at least the historic dry season, dependable and uniform rainfall occurring in one or two short wet seasons.
4. **Full:** Large storage capacity, users needs met for the whole year, no alternate water source available, requires strict monitoring and regulated use of water supply.

Water Balance Analysis

A water balance analysis or water budget allows a designer to determine how much rainwater can be collected by the project catchment area, including rooftop and ground level areas. A water budget provides a supply and demand analysis on a monthly basis and provides water quantities for sizing cisterns. Water budgets will also determine how much, if any, supplemental water is needed to augment a system. A water budget will allow a designer to redesign a project to increase or reduce the catchment area to meet the water demands of a landscape or the amount of potable water desired. An alternate water source may be needed for a few years in addition to rainwater to supplement the water needs of a landscape until plants are established as plants typically require more water early in their life to establish a root system or to establish a new root system after being transplanted.

The basic rule for sizing any RWH system that will be the sole supply source is that the volume of water that can be captured and stored (supply) must equal or exceed the volume used (demand). The variables of rainfall and water demand determine their relationship between required catchment area and storage capacity. In some cases, catchment surface area can be increased by addition of a rain barn or similar facility. Cistern capacity must be sufficient to store enough water to see the system and its users through the longest expected interval without rain. This, of course, applies when there is no backup potable water supply. Installations using rainwater for potable water sources are predominantly in Hawaii and overseas locations. Most situations in the military will have potable water available as a backup. Sizing can then be a balance of non-potable needs. The following sections describe ways to determine the amount of rainfall, the estimated demand, and how much storage capacity is needed to provide an adequate water supply.

Intended End Use

The first decision in an RWH design is to determine the intended use of the water. If rainwater is to be used only for irrigation, a rough estimate of demand, supply, and storage capacity may be sufficient. On the other hand, if the rainwater is to be the sole source of water for all indoor and outdoor domestic end uses, a more precise calculation is required. Use for toilet or fixture flushing lies in between.

How Much Water Can Be Captured?

In theory, approximately 0.62 gal/in. of rainfall per square foot of collection surface can be collected. (Ideally, 1 in. of rain on 1 sq ft of nonpermeable surface equals 0.62 gal of water, i.e., 1 in./[12in./ft] x 7.48 gal/cu ft.) This may not include such minor losses as, for example, gutter overtopping, retention by roofing material, and evaporation or wind blown losses. The collection surface is the "footprint" of the roof and the gutter system.

To ensure a year-round water supply, the catchment area and storage capacity must be sized to meet water demand through the longest expected interval without rain, or otherwise plan for another water source. Another consideration is that most rainfall occurs seasonally; annual rainfall is not distributed evenly through the 12 months of the year. Monthly distribution of rainfall is an important factor to consider for sizing a system. Rainfall data can be found at the National Climate Data Center website: www.ncdc.noaa.gov.

Two different estimators of monthly rainfall are commonly used: average rainfall and median rainfall. Average rainfall is the historical annual average available from the National Climate Data Center website (www.ncdc.noaa.gov). Median rainfall is the amount of rainfall that occurs in the midpoint of all historic rainfall totals for any given month. Median rainfall provides for a more conservative calculation of system sizing than average rainfall and is recommended to estimate water availability for planning purposes.

Calculating Storage Capacity

Once the median or average potential for rainfall capture is known, it will be necessary to calculate storage capacity. The decision of whether rainwater will be used for irrigation, potable and domestic use, or both, will dictate water demand and therefore, capacity.

One simple method to estimate storage capacity used by professional installers of household systems in Texas is to size the system to meet quarterly demand. The system is sized to meet estimated demand for a 3-month period without rain. Annual demand is divided by four to get this number. It is likely to result in a more expensive system due to higher storage costs. In the event that the RWH system is the only water supply, overbuilding ensures a safety margin. Planning for expansion is also a concept that should be considered.

Water Balance Method Using Monthly Supply and Demand

One method of determining feasibility of a proposed system is the monthly water balance method. This method functions similarly to maintaining a monthly checkbook balance. Starting with an assumed volume of water already in the tanks, the volume captured each month is added to the previous balance and the demand is subtracted. The initial volume is provided through hauling water or capturing water before beginning withdrawal from the system. Variables include catchment area and storage. Essentially, catchment area and rainfall determine supply, and demand dictates required storage capacity.

An essential component of any RWH system is a commitment to water conservation through appropriate fixtures, appliances and practices, both indoors and outdoors.

Estimating Demand

A water-conserving household will use between 25 and 40 gal/person/day for potable total indoor water use. The same estimate can be used for individuals in barracks. Preparing an estimated demand will incorporate use as fixture flushing or if it is a potable system demands for bathing, laundry, and personal use such as cooking and cleaning. Fixture flushing applications require substantially less water per person per day. Additional effort in estimating demand could result in more accuracy for given conditions.

Estimating Outdoor Water Demand

Outdoor water demand peaks in hot, dry summers. Often, up to 60 percent of municipal water demand in the summer is attributable to irrigation. Rainwater is often captured for irrigation of vegetable or ornamental gardens. For both health of landscape plants and water use efficiency, the best approach is to water plants according to their needs. Watering infrequently and deeply has been shown to promote plant health. Historical evapotranspiration can be used to estimate potential water demand. The principles of xeriscaping should also be followed. Use of low water consuming plant lists and native vegetation appropriate to an area are additional approaches.

When the focus is on irrigation, four items are needed to prepare a water budget: average annual rainfall data, a site plan, a landscape plan, and an irrigation plan.

Passive Rainwater Harvesting System – Using a Low Impact Development (LID) Approach

Low impact development (or similar concepts known under a variety of names) manages stormwater runoff at the tip of the watershed where multiple small volumes of water can be harvested and integrated into the site, decreasing the volume of water that drains toward one place in the bottom of the site watershed where it is harder to collect and manage, and where it is downhill from most site uses. The on-site watershed can be divided into multiple small watersheds by using existing depressions or reshaping the topography as needed.

The goal of LID or integrated site management is to collect, slow, and infiltrate the stormwater runoff. Slowing and spreading the flow reduces erosion and allows sediment and debris to drop out of the runoff, enriching soil in the water harvesting depressions. Increasing soil surface area increases the possibility of infiltration and allows water to be stored in the soil, the least expensive location to store stormwater. Stormwater stored in the soil should be in a location that supports plant life and does not damage built facilities. Areas where water is stored in the soil should be covered with a 3- to 6-in. layer of mulch to reduce evaporation and increase moisture retention. Excess water produced above the required needs can be infiltrated by mechanical means that are currently available.

There are several ways to slow and infiltrate runoff including the following (many more are available in numerous LID or Green Infrastructure reference materials):

- Microbasins are appropriate for use in locations with low volumes of runoff including areas along sidewalks, in landscapes, and in parking lot planters. They are typically used in areas with localized flows on gentle or nearly flat land.
- Swales or ditches, on-contour, intercept small to moderate volumes of shallow, slow moving stormwater with swales and associated berms constructed on-contour.
- Swales, off-contour, are ditches built at a slight angles from the contour line. These swales move stormwater gradually downslope in a controlled manner to maximize infiltration, support vegetation, control erosion, reduce stormwater velocity, and eventually discharge any excess stormwater.
- French drains are rock-filled trenches that are designed to encourage rapid stormwater infiltration through the sides, ends, and bottom of the trench where soil and water meet.
- Gabions are constructed to create semi-permeable barriers to slow, but not stop, the flow of stormwater in small drainages. Gabions prevent or mitigate upstream erosion, trap rich debris, and allow stormwater to infiltrate.

Rainwater harvested in the landscape can typically fully support native plants, following a few years of supplemental watering to get plants fully established. Harvested rainwater can be used to provide this initial supplemental irrigation and can be used for non-landscape needs.

Potable RWH Systems

Collection of rainwater for potable uses is mainly restricted to cleaner surfaces such as rooftops. The two most important components of potable collection are the catchment surface and filtration. Metal roofs are preferred for potable systems, but other surfaces may be used if they do not contain lead, zinc coatings, or copper. Acceptable roofing also includes reinforced concrete, cement tile, clay cement tile, and plastic/fiberglass shingles. Raincoat 2000 is a three-part roof coating product for flat or semi-flat roofs that is approved by the National Sanitation Foundation (NSF) for potable water harvesting. Rainwater is slightly acidic, which means it can dissolve and carry minerals into the storage system. When a system is intended for potable water collection, the first step should be to collect water collected from a catchment surface to determine its content and what items may need to be removed by a filtration system or if the catchment surface needs to be altered.

Rainwater intended for human consumption should undergo several additional steps including screening, settling, filtering, and disinfecting. Filtering can include any of the following: in-line or multi cartridges, activated charcoal, reverse osmosis, nanofiltration, mixed media, and slow sand. Disinfection processes include boiling or distilling, chemical treatments, ultraviolet (UV) light, and/or ozonation.

When water is being used from storage, sediment filtration should be a maximum of 5 microns, followed by a 0.5 micron carbon filter or an equivalent 1 micron absolute filter. These ultra filters should be approved by the NSF for cyst removal. These filters will remove Giardia and Cryptosporidium from the water supply. UV disinfection is also applicable. If a 1-micron absolute filter is used, then carbon filtration should be installed for taste and odor.

A water test will determine what type of system is needed based on what needs to be removed or treated in the harvested water. Schedule 40 PVC should be the only material used, not just to prevent crushing, but also because it is made from virgin material. No ABS (acrylonitrile butadiene styrene) or DWV (Drain, Waste, and Vent) PVC pipe should be used. Coated aluminum downspouts or plastic PVC downspouts are acceptable, but no copper or galvanized downspouts should be used with potable systems.

Candidate Buildings and Locations

What types of buildings are the best candidates for RWH, and where? Much of the country has sufficient rainfall for some type of harvesting system, even if used strictly for irrigation. Even in areas perceived as dry, such as Arizona and Texas, there are candidates because they receive periodic, intense downpours that allow concentrated collection. Additional details on balancing the amount of rainfall against system size appear below.

Most buildings can accommodate an RWH system. The simplest and most common collection point is the roof; therefore, the larger the roof footprint, the more rainwater that can be collected. This makes low to mid rise commercial/institutional/administrative and residential buildings good candidates because the ratio of roof area to toilets and urinals is greater. This presupposes the main water use for the rainwater is fixture flushing and a demand estimate must be performed. However, rainwater can and is being collected on high-rise buildings. The rainwater is simply pumped to toilets and urinals on the lower floors only, or is used for other purposes such as irrigation, water features, or secondary fire suppression. Taller buildings have the advantage of collecting less debris, such as leaves, in the rainwater.

The most important prerequisite is that the building owner or maintainer has the desire and ability to harvest and use rainwater.

Components of a Rainwater Harvesting System

A system developed to collect and store rainwater typically consists of up to six primary components depending on the degree of water quality required from the system. These components include:

- **Catchment Surface/Collection Area:** The surface upon which the rain falls, usually the roof. Unless the rainwater will be used for potable water, any type of roof material and design will work if it allows rain to be conveyed by gutter or downspout to the storage tank. Some RWH systems collect water from parking lots or similar areas.
- **Conveyance:** The transport channels or pipes from catchment area to storage.
- **Roof Washer (pre-filtration):** Which removes large debris, dirt, and pollutants that have "collected" on the roof since the last rainfall.
- **Primary Settling Tank:** This may be required for large catchment applications such as parking lots, and provides oil-water separation and additional filtering before use.
- **Storage:** Cisterns or tanks where collected rainwater is stored.
- **Distribution:** The system that delivers the rainwater, either by gravity or pump to the point of use.
- **Purification:** Which includes filtering equipment, and/or additives to settle, help filter, and disinfect the collected rainwater.
- **Screens, Debris Excluders, etc.:** This includes all measures to keep out leaves and debris. These may be required in buildings that are less than two to three stories in height.

Depending on catchment surface material and rainfall intensity, a loss of potentially collected rainwater can range from 20 to 70 percent. This loss is due to runoff material absorption or percolation, evaporation, and inefficiencies in the collection process.

Additional capacity can be provided by an open-sided barn or similar option that would also provide storage underneath. Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and the surrounding environment.

Roofing Materials

Metal

The quantity of rainwater that can be collected from a roof is in part a function of the roof texture: the smoother the better. A commonly used product, sold under the trade name Galvalume®, a 55 percent aluminum/45 percent zinc alloy-coated sheet steel. Galvalume® is also available with a baked enamel coating, or can be painted with epoxy paint. One caution is that roofs with copper flashings can cause discoloration of porcelain fixtures.

Clay/Concrete Tile

Clay and concrete tiles are both porous. Although these materials are easily available and suitable for both potable or nonpotable system, they may contribute to as much as a 10-percent loss due to texture, inefficient flow, or evaporation. To reduce water loss, tiles can be painted or coated with a sealant. There is some chance of toxins leaching from the tile sealant or paint, so this roof surface is safer when painted with a special sealant or paint to prevent bacterial growth on porous materials.

Composite or Asphalt Shingle

Due to leaching of toxins, composite shingles are not appropriate for potable systems, but can be used to collect water for irrigation. Composite roofs have an approximate 10-percent loss due to inefficient flow or evaporation (Radlet and Radlet 2004)

Slate

Slate's smoothness makes it ideal for a catchment surface for potable use, assuming no toxic sealant is used; however cost considerations may preclude its use.

Wood Shingle, Tar, and Gravel

The harvested water is usually suitable only for irrigation due to leaching of compounds.

Conveyance - Gutters and Downspouts

Gutters are used to capture rainwater running off the eaves of a building. Some gutter installers can provide continuous or seamless gutters. For potable systems, lead cannot be used as gutter solder, as was sometimes the case with older systems, due to leaching from rain's acidity.

The most common materials for gutters and downspouts are half-round PVC, vinyl, pipe, seamless aluminum, and galvanized steel.

Gutter Sizing and Installation

When using the roof of a house as a catchment surface, it is important to consider that many roofs consist of one or more roof "valleys." A roof valley occurs where two roof planes meet. A roof valley concentrates rainfall runoff from two roof planes before the collected rain reaches a gutter. Depending on the size of roof areas terminating in a roof valley, the slope of the roofs, and the intensity of rainfall, the portion of gutter located where the valley water leaves the eve of the roof may not be able to capture all the water at that point, resulting in spillage or overrunning. Besides the presence of one or more roof valleys, other factors that may result in overrunning of gutters include an inadequate number of downspouts, excessively long roof distances from ridge to eave, steep roof slopes, and inadequate gutter maintenance.

Guttering systems should be pitched to ensure that all water runs out and the gutter is allowed to dry between rainfall events and free from debris at all times.

Modern filters require extremely low maintenance and cleaning and can efficiently collect more than 90 percent of filtered rainwater. First flush fine filters are recommended when filtering water from gutters before storage. Filters should be self-cleaning and self-drying between rainfall events. The fabric should dry to prevent algae and biofilm growth. Fabrics should also be made of materials that are stable and will not change shape and can withstand temperature changes, ice formation, and frost. Stainless steel is considered the best filter fabric for these reasons. Filters should be inspected 2-4 times per year. Figure A1 shows vortex and downspout filters.

Calming inlets (Figure A2), which reduce inflow speed, are located at the bottom of storage tanks and slow the entering water to prevent it from disturbing fine particulate matter on the bottom of the tanks.

Figure A1. Vortex and downspout filters.

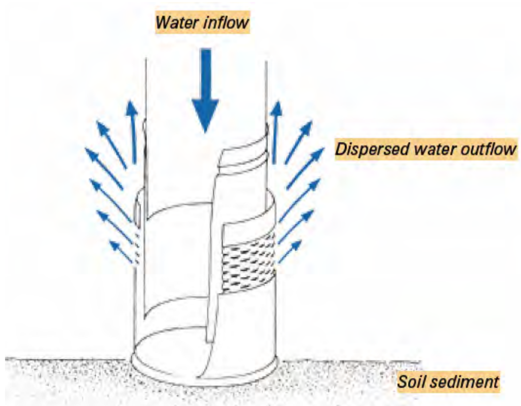

Figure A2. Calming inlet.

Leaf Screens

A series of filters are necessary to remove debris that gathers on the catchment surface, and to ensure high quality water that is suitable for potable use or that will not clog irrigation emitters. Essentially, mesh screens remove debris both before and after the storage tank. Leaf screens must be regularly cleaned to be effective. If not maintained, they can become clogged and prevent rainwater from flowing into a tank. Built-up debris can also harbor products of leaf decay and bacteria. Various types of leaf screens that include: leaf guards, funnel-type downspout filters, strainer baskets, a cylinder of rolled screen, and filter socks are further described in TWDB (2005).

First-Flush Diverters

Roofs are natural collection surfaces for dust, leaves, blooms, twigs, insect bodies, animal feces, and other airborne residues or particles. A first-flush diverter routes the first flow of water from the catchment surface away from the storage tank. The flushed water can be routed to a planted area. While leaf screens remove larger debris, the first flush diverter allows the system to eliminate smaller contaminants such as dust, pollen, and bird feces.

Opinions vary on the amount of water to divert. The numbers of dry days, amount of debris and roof surface are all variables to consider. A rule of thumb is to divert a minimum of 10 gal for every 1000 sq ft of collection surface. Remember to use horizontal equivalent of roof footprint. Each downspout should have first flush diversion. The simplest first-flush diverter is a PVC standpipe (Figure A3). The standpipe fills with water first during a rainfall event; the balance is routed to the tank. Another type of diverter is the ball valve type (Figure A4), which seals off the top of the diverter when the pipe is full.

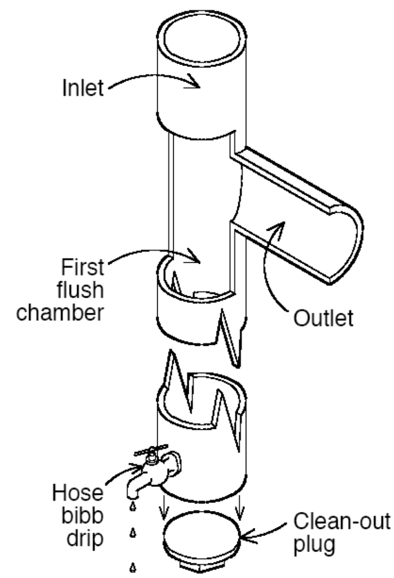

Figure A3. Standpipe first-flush diverter (source: TWDB 2005).

Roof Washers

The roof washer, placed just ahead of the storage tank, filters small debris for potable systems and also for systems using drip irrigation. Roof washers consist of a tank, usually between 30- and 50-gal capacity, with leaf strainers and a filter. (Figure A5 shows one commercially available model.)

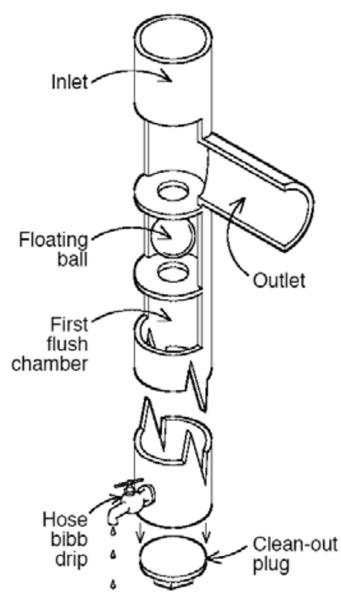

Figure A4. Standpipe with ball valve (source: TWDB 2005).

All roof washers must be cleaned. Without proper maintenance they can clog and restrict the flow of rainwater, and may themselves become breeding grounds for mold and bacteria.

Unlike the older designs, which

require periodic cleaning and yearly filter replacement, modern roof washers require little maintenance and no filter replacement. Figure A6, from VA manual(LaBranche et al. 2007), shows the difference. The newer version must still be monitored for buildup that may occur, depending on environmental conditions. The stainless steel insert can be washed in a dishwasher.

Storage Tank or Cisterns

This is the heart of the system, and also the most expensive. Tanks can be above or below ground and made of epoxy steel, fiberglass, pre-cast concrete, polyethylene, poured-in-place concrete, or other materials. The type of tank is job specific and highly dependent on its location and associated engineering and construction costs. The tank type (and size) is also influenced by whether it is doing double duty for the sprinkler system. Tanks can be located creatively in areas such as under plazas, in parking garages and under driveways. Special care is needed to shade fiberglass tanks so they do not promote algae growth.

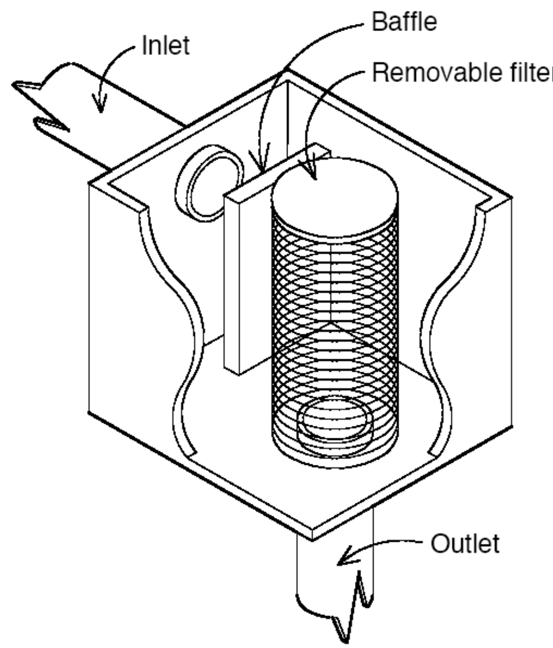

Figure A5. Box roof washer (source: TWDB 2005).

Figure A6. Old (left) and modern (right) filter designs.

A myriad of variations on storage tanks have been used over the centuries and in different geographical regions: earthenware cisterns in biblical times, large pottery containers in Africa, above-ground vinyl-lined swimming pools in Hawaii, concrete or brick cisterns in the central United States or galvanized steel tanks and site-built stone-and mortar cisterns. Many have been used for over a century.

Tank Size

Sizing the tank is a mathematical exercise that balances the available collection (roof) area, annual rainfall, intended use of rainwater, cost, and project budget. In other words, balance what can be collected against how the water will be used and the financial and spatial costs of storage.

Storage Tank Basics

Storage tanks must be opaque, either upon purchase or painted later, to inhibit algal growth. Tanks must be covered and vents screened to discourage mosquito breeding. Storage tanks for potable systems must never have been used to store toxic materials. Also, tanks used for potable systems must be accessible for cleaning.

Storage Tank Siting

Tanks should be located near to supply and demand points as possible to reduce the distance water is conveyed. Storage tanks should be protected from direct sunlight, if possible. To ease the load on the pump, tanks should be placed as high as practicable. The tank inlet must be lower than the lowest downspout from the catchment area. To compensate for friction losses in the trunk line, a difference of 2 ft is preferable. When converting from well water, or if using a well backup, siting the tanks near the well house facilitates the use of existing plumbing.

Water runoff should not enter septic system drain fields. Any tank overflow and drainage should be routed so that it does not affect the foundation of the tanks or any other structures.

If supplemental hauled water might be needed, tank placement should take into consideration accessibility by a water truck, i.e., near a roadway or driveway. Tanks should be placed on a stable, level pad. Unknown soil conditions may require the services of a structural engineer to ensure stability of the soil supporting the full cistern weight. The pad should also be protected from erosion and tank overflow, and should be checked after heavy rain events.

Types of Tanks

This section describes tanks by their material composition, size, and configuration. Note that many owners use multiple tanks in sequence to meet storage capacity needs. This makes maintenance more convenient. A summary of cistern materials, their features and advisories are provided to assist the harvester in choosing the appropriate type (TWDB 2005, p16). Professional consultation is recommended with an engineer, architect, or professional rainwater system installer.

Table A-2. Cistern Types.

Material	**Features**	**Caution**
	Plastics	
Trash cans (20-50 gal)	Commercially available; inexpensive	Use only new cans
Fiberglass	Commercially available; alterable and moveable	Must be sited on smooth, solid, level footing
Polyethylene/ polypropylene	Commercially available; alterable and moveable	UV-degradable, must be painted or tinted
	Metals	
Steel drums (55-gal)	Commercially available; alterable and moveable	Verify prior to use for toxics; prone to corrosion an rust;
Galvanized steel tanks	Commercially available; alterable and moveable	Possibly corrosion and rust; must be lined for potable use
	Concrete and Masonry	
Ferrocement	Durable and immoveable	Potential to crack and fail
Stone, concrete block	Durable and immoveable	Difficult to maintain
Monolithic/Poured-in-place	Durable and immoveable	Potential to crack
	Wood	
Redwood, fir, cypress	Attractive, durable, can be disassembled and moved	Expensive
Adapted from Texas Guide to Rainwater Harvesting, Second Edition, Texas Water Development Board, 1997.		

Fiberglass

Figure A7. Two 10,000-gal fiberglass tanks (source: TWDB 2005).

Fiberglass tanks (Figure A7) are built in standard capacities from 50 to 15,000 gal and in both vertical cylinder and low-horizontal cylinder configurations. Fiberglass tanks under 1000 gal are expensive for their capacity, so polypropylene might be preferred. Tanks for potable use should have a U.S. Department of Agriculture (USDA) approved food-grade resin lining and be opaque to inhibit algae growth. In addition, fittings on fiberglass tanks are integral, eliminating the potential problem of leaks from aftermarket fittings.

Polypropylene

Figure A8. Low-profile 5,000-gal polypropylene tanks (source: TWDB 2005).

Polypropylene tanks (Figure A8) are commonly sold at farm and ranch supply retailers. Standard tanks must be installed above ground. For underground installation, specially reinforced tanks are necessary to withstand soil expansion and contraction. They are relatively inexpensive and durable, lightweight, and long lasting. Polypropylene tanks are available in capacities from 50 to 10,000 gal. Opaque plastic should be used as polypropylene does not make a good substrate for paint. Fittings are aftermarket modifications.

Wood

Wood tanks offer aesthetic appeal. Modern wood tanks are usually of pine, cedar, or cypress wrapped with steel tension cables, and lined with plastic. For potable use, a food-grade liner must be used. They are available in capacities from 700 to 37,000 gal and are site-built by skilled technicians. They can be dismantled and reassembled at different locations.

Metal

Galvanized sheet metal tanks (Figure A9) are available in sizes from 150 to 2500 gal and are lightweight and easy to relocate. They can be lined for potable use. Most tanks are corrugated galvanized steel dipped in hot zinc for corrosion resistance. They are lined with a food-grade liner, usually polyethylene or PVC, or coated on the inside with epoxy paint. The paint must be approved for potability by the Food and Drug Administration (FDA) and National Science Foundation (NSF).

Concrete

Concrete tanks are either poured in place or prefabricated (Figure A10). They can be constructed above ground or below ground. Poured-in-place tanks can be integrated into new construction under a patio, or a basement, or elsewhere. Their placement is considered permanent.

Concrete may be prone to cracking and leaking, especially in underground tanks in clay soil. Leaks can be easily repaired, although they may need to be drained before repairs. Repair materials should be approved for potable use. If the concrete tank is to be poured in place, it is highly recommended to employ a structural engineer to determine the size and spacing of reinforcing steel.

Figure A9. Galvanized sheet metal tank (source: TWDB 2005).

For potable systems, it is essential that the interior of the tank be plastered with a high-quality material approved for potable use.

Ferrocement

Figure A10. Concrete tank fabricated by stacking rings of concrete (source: TWDB 2005).

Ferrocement is a low-cost steel and mortar composite material. Gunite and Shotcrete can be classified as Ferrocement for this application. Both methods are cost-effective for larger tanks. Tanks made of Gunite and Shotcrete consist of an armature made from a grid of steel reinforcing rods tied together with wire around which is placed a wire form with closely spaced layers of mesh, such as expanded metal lath. A concrete-sand-water mixture is applied over the form and allowed to cure. It is important to ensure that the ferrocement mix does not contain any toxic constituents. Some sources recommend painting above ground tanks white to reflect the sun's rays, reduce evaporation, and keep the water cool. Small cracks and leaks can be easily repaired.

In Ground Polypropylene

In-ground tanks are more costly to install for two reasons: the cost of excavation and the cost of the more heavily reinforced tanks needed if the tank is to be buried more than 2-ft deep in well-drained soils. Burying a tank in clay is not recommended because of the expansion/contraction cycles of clay soil. For deeper installation, the walls of poly tanks must be manufactured thicker and sometimes an interior bracing structure must be added. Tanks are buried for aesthetic or space-saving reasons.

Rain Barrel

One of the simplest rainwater installations is the 50- to 75-gal drum used as a rain barrel for irrigation (Figure A-11). Some commercially available rain barrels are manufactured with overflow ports linking to additional barrels. A screen trap at the water entry point discourages mosquito breeding.

Figure A-11. Rain barrel used for simple irrigation.

Pumps, Filters, Treatment, Valves, Piping, and Controls

In most applications, a duplex pump system is necessary to distribute the harvested rainwater from the storage tank to designated fixtures. Filtering and UV treatment occur before delivery. A bag-type polyethylene filter results in less pressure loss than a cartridge filter. Installation of a reduced pressure backflow assembly protects the connection to downstream domestic water. Control valves monitor the level of rainwater in the tank against pump operation. Many municipalities require that piping to toilets, urinals, irrigation systems and hose bibs be continuously labeled with "Harvested rainwater, do not drink." Note that the pumps, filters, valves and controls require ongoing maintenance, although the time and sophistication required are relatively minor.

Pressure Tanks and Pumps

There is usually a demand for a pump and pressure tank between water storage and treatment and the end use. Standard municipal water pressure is 40 to 60 psi (pounds per square inch). Many home appliances – clothes washers, dishwashers, hot-water-on-demand water heaters – require 20-30 psi for proper operation.

Even some drip irrigation systems need 20 psi for proper operation. Therefore, using gravity to develop pressure is not feasible in many cases. Applicable options include: (1) a pump, pressure tank, pressure switch and check valve, or (2) an on-demand pump.

Pumps are designed to push water rather than pull it. Therefore, the system should be designed with the pumps at the same level and as close to the storage tanks as possible. Figure A12 shows a representative household system.

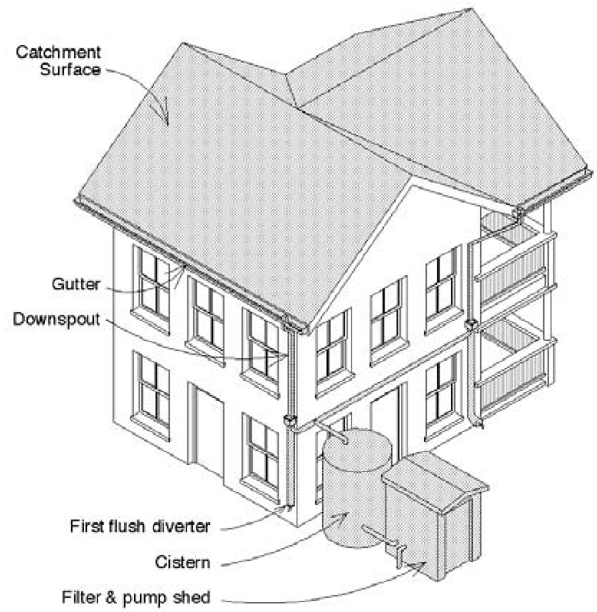

Figure A12. Typical household rainwater harvesting installation (source: TWDB 2005).

Pump systems draw water from the storage tanks, pressurize it, and store it in a pressure tank until needed. The typical pump-and-pressure tank arrangement consists of a ¾ or 1- horsepower pump, usually a shallow well jet pump or a multistage centrifugal pump, the check valve, and pressure switch. A one-way check valve between the storage tank and the pump prevents pressurized water from being returned to the tank. The pressure switch regulates operation of the pressure tank, with a typical capacity of 40 gal, maintaining pressure throughout the system. When the pressure tank reaches a preset threshold, the pressure switch cuts off power to the pump. When there is demand, the pressure switch detects the drop in pressure in the tank and activates the pump, drawing more water into the pressure tank.

Figure A13 shows a cistern float filter that allows the pump to draw water from 10 to 16 in. below the surface. Water at this level is cleaner and fresher than water closer to the bottom of the tank. The device has a 60-micron filter. An external suction pump, connected via a flexible hose, draws water through the filter.

On-Demand Pump

On-demand pumps eliminate the need for a pressure tank. These pumps combine a pump, motor, controller, check valve, and pressure tank function all in one unit.

They are self-priming and are built with a check valve incorporated into the suction port. Figure A14 shows a typical installation of an on-demand pump and a 5-micron fiber filter, 3-micron activated charcoal filter, and a UV lamp. Unlike conventional pumps, on-demand pumps are designed to activate in response to a demand, eliminating the need, cost, and space of a pressure tank. In addition, some on-demand pumps are specifically designed to be used with rainwater.

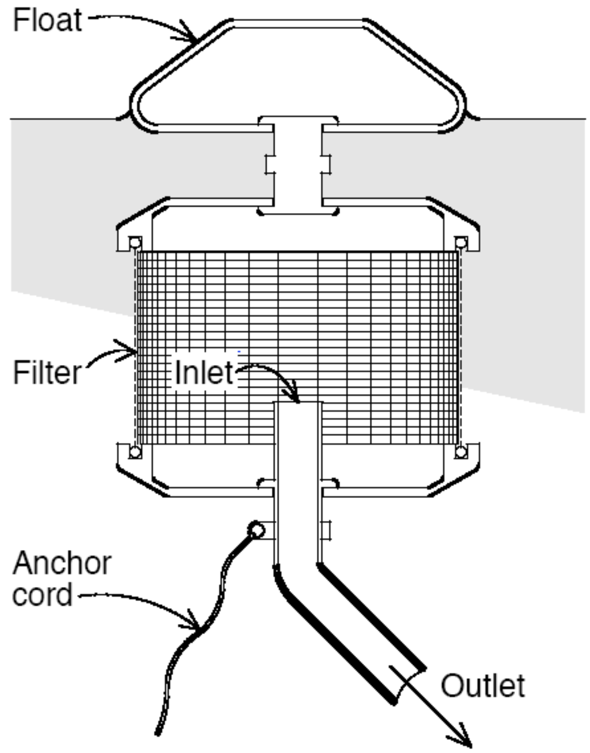

Figure A13. Cistern float filter (source: TWDB 2005).

Treatment and Disinfection Equipment

For a nonpotable system used for hose irrigation, leaf screens and a roof washer and diversion of 10 gal/1000 sq ft of roof is sufficient. Use of drip irrigation may require sediment filtration to prevent clogging of emitters.

Potable water systems require treatment beyond leaf screen and roof washer to remove sediment and potential pathogens. Treatment generally consists of filtration and disinfection processes in series before distribution to ensure health and safety.

Chlorination

Chlorination has been used historically and traditionally in many RWH systems used for potable water. Chlorine should be present at a concentration of 1 ppm to achieve disinfection. Possible concerns include formation of trihalomethanes. Responsible health entities such as the Directorate of Public Works (DPW) or Preventive Medicine should be consulted before installation of any disinfection system. Post filtration by a 1-micron filter may be needed to filter out Giardia and Cryptosporidium in a potable system.

Figure A14. Typical treatment installation of an on-demand pump, 5-micron fiber filter, 3-micron activated charcoal filter, and an ultraviolet lamp (top) (source: TWDB 2005).

Cartridge Filters and Ultraviolet (UV) Light

A common setup for household use is two in-line sediment filters (a 5-micron fiber cartridge filter followed by a 3-micron activated charcoal cartridge filter) followed by UV light. Disinfection set-up is placed after the pressure tank or after the on-demand pump. Regular replacement is essential. Another option for greater through-flow is to use parallel arrays. UV light maintenance involves cleaning of the quartz sleeve. Many units have an integral wiper unit. A 12 gpm rating is sufficient for the basic set-up described earlier. Higher flows should be matched with appropriate lighting. A maximum operating use is 10,000 hrs usually, followed by replacement.

Other Methods

Ozone is another potential disinfectant. Ozone acts as an oxidizer. Membrane filtration (reverse osmosis and nanofiltration), works by forcing water under high pressure through a semi-permeable membrane to filter dissolved solids and salts, both of which are present in low concentrations in rainwater. Reverse osmosis equipment for household use is commercially available through home improvement stores. Chlorination is another method of disinfection. Automatic self-dosing systems are available. A chlorine pump injects chlorine into the water as it enters the house. Appropriate contact time is critical to kill bacteria, usually 2 to 5 minutes.

Regulatory Environment

When considering a system, it is critical to work within the framework of local regulatory requirements and guidelines. States and municipalities are rapidly gaining familiarity with RWH systems. As they outline and refine their regulatory parameters, they are often flexible in helping make systems work within their jurisdictions. For example, some localities prohibit the use of harvested rainwater in toilets because of the potential that untreated tank water could be mistaken for potable water. In these situations, locking tanks and sealed flushometer-type toilets can be viable options as can signage. Use of dye in the water has also been successfully used. With proper treatment, rainwater is being used for hand washing, e.g., at the Chesapeake Bay Foundation's Philip Merrill Environmental Center, in Annapolis, MD.

Maintaining Water Quality and Treatment – Owner Responsibility

Rain is among the cleanest of water sources. However, the environment, catchment surface, and storage tanks affect the quality of harvested rainwater. With minimal treatment and adequate care of the system, however, rainfall can be used as potable water, and for irrigation and other nonpotable applications.

Owners of rainwater harvesting systems should consider the fact that they are essentially becoming owners of "water supply systems," with responsibility for routine maintenance, including filter and lamp replacement, leak repair, monitoring of water quality, and system upgrades. Maintenance of a rainwater harvesting system is an ongoing periodic duty, which includes:

- Monitoring tank levels
- Cleaning gutters and first-flush devices
- Repairing leaks
- Repairing and maintaining the system
- Adopting efficient water use practices.

In addition, owners are also responsible for:

- Changing out filters regularly
- Maintaining disinfection equipment
- Regularly testing water quality.

Water Quality Standards

No Federal or state standards currently exist for harvested rainwater quality. Drinking water requirements can be found at the USEPA website.

When rainwater comes in contact with a catchment surface, it can wash bacteria, molds, algae, fecal matter, other organic matter and/or dust into storage tanks. The longer the span of continuous dry days, the more catchment debris is washed off by a rainfall event. The more filtering of rainwater before storage tanks, the less sedimentation and introduction of organic matter will occur within the tanks. Processes and devices such as gutter screens, first-flush diverters, roof washers and pre-tank filters were previously discussed. Most storage tanks also have manholes to allow access for cleaning. Multiple tanks allow one tank to be taken off-line while another is cleaned.

Cleanliness of the roof in a RWH system directly affects the quality of the captured water. Avoid overhanging branches. For potable systems, a plain galvanized roof or a metal roof with epoxy or latex paint is recommended (TWDB). Composite or asphalt shingles are not advisable, to avoid leaching of toxic components. To improve water quality, several treatment methods are available. Individual advantages and disadvantages should be examined together by the owner and installers. A synopsis is shown in Table A3.

Testing

Harvested rainwater should be tested before it is supplied to users as drinking water, and periodically thereafter. Harvested rainwater should be tested both before and after treatment to ensure treatment is working. Applicable regulations should be followed. Testing can be performed by a commercial analytical laboratory, county health departments, or other approved facilities.

Testing entities and health departments will determine requirements of sample container type and cleanliness, sample volume, numbers of samples needed, and time constraints. On an Army installation, water testing falls under the purview of the DPW or Preventive Medicine.

Economics

The cost of RWH systems varies considerably with the application, but generally runs about $1 per gallon of storage capacity. Paybacks often range from 10 to 15 years. Available case studies show various approaches and costs (Gray and Yudelson 2010). These particular examples were metered. Other determinations of paybacks vary. One school in Texas had a 5-year payback when using for irrigation purposes.

Table A3. Treatment Techniques.

Method Of Treatment	Location	Result
	Screening	
Leaf screens and strainers	Gutters and downspouts	Prevent leaves and other debris from entering tank
	Settling	
Sedimentation	Within tank	Settles out particulate matter
Activated charcoal	Before tap	Removes chlorine*
	Filtering	
Roof washer	Before tank	Eliminates suspended material
In-line/multi-cartridge	After pump	Sieves sediment
Activated charcoal	After sediment filter	Removes chlorine, improves taste
Slow sand	Separate tank	Traps particulate matter
	Microbiological Treatment/Disinfection	
Boiling/distilling	Before use	Kills microorganisms
Chemical treatments (Chlorine or Iodine)	Within tank or at pump (liquid, tablet, or granular) before activated charcoal filter	Kills microorganisms
Ultraviolet light	After activated charcoal filter, before tap	Kills microorganisms
Ozonation	After activated charcoal filter, before tap	Kills microorganisms
Nanofiltration	Before use; polymer membrane (pores 10^{-3} to 10^{-6} inch)	Removes molecules
Reverse osmosis	Before use: polymer membrane (pores 10^{-9} inch)	Removes ions (contaminants and microorganisms)
*Should be used if chlorine has been used as a disinfectant. Adapted from Texas Guide to Rainwater Harvesting, Second Edition, Texas Water Development.		

Budgeting for a RWH system may be as simple as adding up the pieces for each component and deciding what is affordable. Remote facilities without access to existing potable water infrastructure or without access to surface or groundwater supplies may find the following information useful. Cost may vary as a decision is made to determine whether some or all of the water needs must be met through rainwater. Cost comparisons can be made.

The single largest expense is the storage tank itself, and the cost of a tank is dependent on its size and material. Table A4 shows a range of potential tank materials and costs per gallon of storage. Size of storage needed and the intended end use of the water will dictate the materials that are most appropriate. Costs range from a low of about $0.50/gal for large fiberglass tanks up to $4.00/gal for welded steel tanks. As tank sizes increase, unit costs per gallon of storage decreases.

Gutter and downspouts (Table A5) are needed to collect the water and move it to the tank. Small buildings or "do-it-yourselfers" can use vinyl or plastic. Professionally installed materials will range from $3.50 to $12.00 or more per foot of gutter, including materials and installation.

Some method of discarding the first flush of rain from the roof is necessary to remove debris. The simplest method is a vertical PVC standpipe, which fills with the first flush of water from the roof, then routes the balance of water to the tank.

Roof washers consist of a tank, usually 30- to 50-gal capacity, with leaf strainers and a filter. A roof washer is a critical component of potable systems and is also needed to filter small particles to avoid clogging drip irrigation emitters. A wide range of equipment is available with different flow capacity and maintenance requirements (Table A6). It is important that the rainwater harvest designer pick a roof washer that is adequate for the size of the collection area. Table A7 gives a range for pump costs, including pressure tanks. Demand activated pumps may not require a pressure tank. Consideration should be given to possibility of multiple simultaneous demands on the system when determining appropriate pump size. Larger buildings will require larger systems.

Planning a potable or a drip irrigation system must include filtration. Vendors can be helpful in matching equipment with expected demand. For potable end use, it is essential to include disinfection among the treatment components. Costs vary widely depending on intended end use, desired water quality, and user preferences. The data in Table A8 indicate that combined filtration and disinfection costs can exceed $1000.

Table A4. Potential Tank Materials and Costs per Gallon of Storage.*

Composition	Cost	Size	Comments
Fiberglass	$0.50–2.00/gal	500–20,000 gal	Can last for decades w/out deterioration; easily repaired; can be painted
Concrete	$0.30–1.25/gal	Usually 10,000 gal or more	Risks of cracks and leaks, but these are easily repaired; immobile; smell and taste of water sometimes affected, but the tank can be retrofitted with a plastic liner
Metal	$0.50–1.50/gal	150–2,500 gal	Lightweight and easily transported; rusting and leaching of zinc can pose a problem, but this can be mitigated with a potable-approved liner
Polypropylene	$0.35–1.00/gal	300–10,000 gal	Durable and lightweight; black tanks result in warmer water if tank is exposed to sunlight; clear/translucent tanks foster algae growth
Wood	$2.00/gal	700–50,000 gal	Esthetically pleasing, sometimes preferable in public areas and residential neighborhoods
Polyethylene	$0.74–1.67/gal	300–5,000 gal	
Welded Steel	$0.80–$4.00/gal	30,000–1 million gal	
Rain Barrel	$100	55–100 gal	Avoid barrels that contain toxic materials; add screens for mosquitoes

*TWDB 2005, p 46.

Table A5. Gutters.*

Material	Cost	Comments
Vinyl	$0.30/ft	Easy to install and attach to PVC trunk lines
Plastic	$0.30/ft	Leaking, warping and breaking are common problems
Aluminum	$3.50-6.25/ft	Must be professionally installed
Galvalume	$9–12/ft	Mixture of aluminum and galvanized steel; must be professionally installed

*TWDB 2005, p 47.

Table A6. Roof Washers.*

Type	Cost	Maintenance	Comments
Box Washer	$400-800	Clean the filter after every substantial rain	Neglecting to clean the filter will result in restricted or blocked water flow and may become a source of contamination
Post Filtering w/Sand Filter	$150-500	Occasionally backwash the filter	Susceptible to freezing; a larger filter is best
Smart-Valve Rainwater Diverter Kit	$50 for kit	Occasional cleaning	Device installed in a diversion pipe to make it self-flushing and prevent debris contamination; resets automatically
*TWDB 2005, p 48			

Table A7. Pumps and Pressure Tanks.*

System	Cost	Comments
Grundfos MQ Water Supply System	$385-600	Does not require a separate pressure tank
Shallow Well Jet Pump or Multi-Stage Centrifugal Pump	$300-600	These require a separate pressure tank
Pressure Tank	$200-500	Galvanized tanks are cheaper than bladder tanks, but often become waterlogged; this will wear out the pump more rapidly
*TWDB 2005, p 49.		

Table A8. Filtering/disinfection.*

	Cost	Maintenance	Effectiveness	Comments
Cartridge Filter	$20-60	Filter must be changed Regularly	Removes particles >3 microns	A disinfection treatment is also recommended
Reverse Osmosis Filter	$400-1500	Change filter when clogged (depends on the turbidity)	Removes particles >0.001 microns	A disinfection treatment is also Recommended
UV Light Disinfection	$350-1000; $80 to replace UV Bulb	Change UV bulb every 10,000 hours or 14 months; the protective cover must be cleaned Regularly	Disinfects filtered water provided there are <1,000 coliforms per 100 milliliter	Water must be filtered prior to exposure for maximum effectiveness

	Cost	Maintenance	Effectiveness	Comments
Ozone Disinfection	$700-2600	Effectiveness must be monitored with frequent testing or an in-line monitor ($1,200 or more)	Less effective in high turbidity, can be improved with pre-filtering	Requires a pump to circulate the ozone molecules
Chlorine Disinfection	$1/month manual dose or a $600-$3000 automatic self-dosing System	Monthly dose applied manually	High turbidity requires a higher concentration or prolonged exposure, but this can be mitigated by pre-filtering	Excessive chlorination may be linked to negative health impacts.
*TWDB 2005, p 50.				

Operating Costs

Budgets should also consider operating costs. With filter cartridges, this is manifested as regular replacement of the cartridges, usually based on rate of water flowthrough. Disinfection systems require following of manufacturers' recommendations. Some of the operating costs and time expenditures necessary include cleaning gutters and roof washers, checking for leaks, and monitoring water use rates. In many areas, RWH can be more cost-effective than drilling a well.

Examples of Local Requirements

Cistern design is covered by rules in some states, often embedded in the rules for hauled water storage tanks. For example, in Ohio, cisterns and stored water storage tanks must have a smooth interior surface, and concrete tanks must be constructed in accordance with American Society for Testing and Materials (ASTM) C913, "Standard Specification for Precast Concrete Water and Wastewater Structures." Plastic and fiberglass tank materials and all joints, connections, and sealant must meet NSF/ANSI Standard 61, "Drinking Water System Components."

In the U.S. Virgin Islands, Bermuda, and other Caribbean islands, all new construction and even building expansion must have a provision for a self-sustaining water supply system, either a well or a rainwater collection area and cistern.

The rules for private water systems in the U.S. Virgin Islands state that new cisterns must have a capacity of 2500 gal per dwelling (Virgin Islands Code 2004). There also is a requirement that cisterns for hotels or multi-family dwellings have a minimum capacity of 10 gal/sq ft of roof area for buildings of one story, and 15 gal/sq ft of roof area for multi-story buildings, although the requirement is waived for buildings with access to centralized potable water systems.

The City of Portland, OR, requires a minimum cistern capacity of 1500 gal capable of being filled with harvested rainwater or municipal water with a reduced pressure backflow prevention device and an air gap protecting the municipal supply from cross-connections (City of Portland 2000).

The option of "dual-supply" systems – potable harvested rainwater supplemented with water from a public water system with appropriate backflow prevention – is an option that might be explored for buildings that cannot collect enough rainwater.

Allowing for a connection to the public water supply system could serve to promote harvested rainwater as supplemental water sources to customers already connected to the public water supply infrastructure. Appropriate backflow prevention devices would be essential to protect the public water supply.

For example, the city of Portland has approved supplemental use of public utility water at a residence since 1996. The code includes specific guidance for design and installation of the system. It also limits rainwater to nonpotable uses. The city publishes a guide with relevant code sections and a frequently asked questions (FAQ) (City of Portland 2000).

The state of Washington Building Codes Council in 2002 developed guidelines for installation of RWH systems at commercial facilities. They are similar to the city of Portland's, but require a larger cistern size, determined by the catchment area, which is limited to roof areas. There is also a reduction in stormwater fees for any commercial facility that installed a complying RWH system (Washington State legislature, 2003)

Examples of Locations that Require Rainwater Harvesting in New Construction

Santa Fe County, NM, passed a regulation requiring RWH systems on new residential or commercial structures of 2500 sq ft and larger. Similar legislation narrowly failed passing in state-wide legislature (Darilek 2004, Vitale 2004)

The city of Tucson, AZ, has instituted requirements for water harvesting in its land use code as a means of providing supplemental water for on-site irrigation. "Storm water and runoff harvesting to supplement drip irrigation are required elements of the irrigation system for both new plantings and preserved vegetation" (City of Tucson Code, Chapter 23).

The state of Texas requires all new state buildings over 10,000 sq ft be equipped with rainwater harvesting equipment, strongly encourages rainwater harvesting throughout the state, and even includes subsidies. Texas has also established a committee to recommend minimum water quality guidelines and standards for potable and nonpotable indoor uses of rainwater, to recommend treatment methods for indoor uses using RWH in conjunction with existing municipal systems, and to promote RWH statewide.

Military Experience and Examples

The Air Force has issued guidance on captured rainwater and approves captured rainwater for irrigation (subsurface, spray, and drip systems) and for toilet and urinal flushing. They have rigorous requirements and a focus on non-potable applications.

The system requirements are:

- Vehicle parking areas or other areas subject to chemical contamination must not be used for collecting rainwater for toilet and urinal flushing.
- A cross-connection test will be performed on installation of the system and once every 2 years. They spell out their procedure.
- Piping must be identified as non-potable. Pipe and valve identification will comply with section 608.8 of the International Plumbing Code (IPC).
- Water used for toilet and urinal flushing must be filtered (media filter, diatomaceous earth filter, or sand filter) and disinfected.
- The system (i.e., tanks, cisterns, valves, pipes, connections, devices and disinfection system) will be inspected monthly, which will include checking the residual disinfection levels and disinfection chemical supply.
- System designers should consider using a "roof washer" or other similar device that diverts the first few gallons of rainwater away from the storage tank. This will remove dirt, debris, contaminants, etc. that have built up since previous rain.

- Systems used to flush toilets and urinals will have provisions for makeup water in case of drought.
- Consultation is required with (Air Force) civil engineer (CE) or bioenvironmental engineer (BE) (Directorate of Public Works [DPW] or Preventive Medicine in Army) to determine if any state or local sampling requirements apply or if any other sampling for pathogens or biological or chemical constituents is required for the captured rainwater system. Sampling frequency will be determined by the responsible party.
- The Air Force requires a minimum residual disinfection level in the rainwater storage tank to be maintained at an average 0.25 ppm of free available chlorine (or equivalent residual levels for other forms of disinfection); however, higher residual disinfection levels will be maintained if required by the bioenvironmental engineer.

All bathrooms using captured rainwater will be identified with signs stating:

- "To conserve water, This Building Uses Non-Potable Water To Flush Toilets and Urinals."
- Tank-type toilets flushed with captured rainwater will be labeled: "Non-Potable water – Do Not Drink."
- Hose bibs are prohibited on rainwater systems.
- Rainwater systems used solely for irrigation that use open ponds (lined or unlined) for water storage are exempt from the sampling and disinfection requirements of the Air Force Engineering Technical Letter (ETL). Those types of systems may also use vehicle parking areas or other paved surfaces for water collection.

Army Examples

Army experience is limited with rainwater harvesting. Hawaii and Guam have systems that capture and use rainwater for potable purposes. In the continental United States (CONUS), applications tend to be focused on nonpotable applications. Fort Lewis, WA is a leader in the Army. The Corps of Engineers designed several new company buildings and barracks for Fort Lewis, which met the Army's requirements for LEED Silver equivalency. There were requirements for rainwater capture vaults that would collect water to be used for toilet flushing and irrigation.

The rainwater reuse system at For Lewis presented some design challenges, which were complicated by the fact that installation maintenance personnel were not properly trained in their use. Maintenance personnel were already fully occupied with demands of existing maintenance, peak seasonal landscape maintenance requirements, and new facility turnover. In short, the maintenance staffs' found it difficult to meet all these needs and additionally to find time for training on the new systems.

Fort Lewis, WA has recently included systems for rainwater retention. As of August 2009, there are more than 3000 m^3 (790,000 gal)of water storage dedicated to irrigating landscaping with non-potable water and an additional 500 m^3 (132,000 gal) of water storage dedicated to flushing toilets with non-potable water.

Projects with rainwater harvesting used both design-bid-build and design-build acquisition strategies. Experience found that rainwater harvesting will not typically be provided on a design-build project if it is not a contract requirement. The current Army requirement to meet LEED Silver can be achieved with low flow water fixtures and other LEED points that can be more easily achieved to pursue the Silver level.

Although there is a potential to retain a large volume of rainwater at Fort Lewis through the systems that have been installed, questions remain about how many of the systems are currently in operation. Issues associated with operation and maintenance of these systems can be mitigated through the provision of adequate training of O&M staff and leadership support of the water conservation measures being taken.

For two FY03 projects (whole barracks renewal), the precast vaults that were built were substantial, one of 1640 m^3 (433,000 gal) for a barracks and another of 1142 m^3 (301,000 gal) water storage for a Company Operations Facility (COF) site.

The toilet flushing vaults consisted of three precast concrete vaults, two for the barracks site and one to serve the COF site, each with 146 m^3 (38,500 gal) of storage.

For a FY04 whole barracks renewal project, the final construction had 1240 m^3 (327,000 gal) of storage. The project was built using a design-build acquisition strategy. There were no contract requirements for the use of non-potable water for landscaping; the contractor chose to pursue that aspect of the project.

For FY05, a whole barracks renewal project with irrigation and toilet flushing vault designs to include pumps, controls and vault was designed. Unfortunately, with an option price of $402,000 in the April 2005 bidding climate, the irrigation vault portion was not awarded, as a cost-saving measure. Two rainwater harvesting vaults were installed for flushing toilets at Company Operations Facilities (COF). One vault was installed per two company buildings (each building holds two companies) for a total of two vaults installed on this project. Each vault had a 84 m^3 (22,000 gal) storage capacity. The project was constructed using a design-bid-build process. Total additional cost was $97,405 following two modifications.

For FY06 another Barracks project was designed with a toilet flushing vault including pumps, controls, etc. They were not installed due to cost restrictions. Option costs were $132,000 for the barracks for one 80 m^3 vault and one 100-m^3 (26,000-gal) vault. Company building options were $27,000 for medium company (10 m^3 storage and large company $30,000 for 10-$m^3$ (2600-gal) storage system and a large brigade system for $49,000 with a 40-$m^3$ (10,500-gal) storage capacity.

Lessons Learned from Fort Lewis

Technical lessons included a suggestion to use AMAID Filtration Systems (or equal) instead of the smaller Rainbird automatic filters used. The newer filters can be programmed to purge automatically rather than by the more complicated Rainbird procedure.

During construction, it should be ensured that rainwater system components are effectively protected to prevent accumulation of dirt before the initial start of the system. Adequate flushing should also be ensured (especially of water containment vaults) before running water from the vaults to the toilets.

Lessons learned through the three design cycles were used to improve pump design, to increase coordination between all engineering disciplines (mechanical, civil, and electrical), and to improve technical drawings. It is absolutely essential for the design team to be familiar with rainwater retention technologies. If the team does not have technical capabilities to design the system, the system could be contracted out to an architect/engineer (AE) or contractor with industry experience to ensure the system will work appropriately or consult with a Corps District or Laboratory (such as ERDC-CERL) with experience in the topic.

It is also essential that O&M staff need thorough training in these new systems. O&M staff may not be familiar with the control schemes included in rainwater harvesting systems. Effective and consistent training is critical to ensure the systems will be operated and maintained properly. It is also suggested to bring O&M staff on site during construction to see the progress of the systems being installed. This will help them to be familiar with the system before training is provided towards the end of the contract.

Another essential item is buy-in and a team commitment from the designers, construction and operation and maintenance staff to be aware of the water reduction goals of the project and committed to meeting them. Fort Lewis experience has shown that the systems would go unused for years if there is no full team commitment to the principles of the project. For example, the FY03 rainwater irrigation vaults were turned off, which created a high mortality rate for landscaping installed on that project.

It is critical to track down reported O&M problems and determine their accuracy. For example, there were reports about toilet staining in the FY03 project, but an on-site investigation found no toilet staining. An easy solution for staining is to consider periodic addition of a cleaning agent such as bleach or chlorine. Another example that had been reported was that the systems were not being used as designed. A report had come that the systems had been switched over to fully domestic water. However, an on-site visit found that the non-potable components were being used.

Among the money saving opportunities are to incorporate lessons learned and to ensure a thorough review of design documents before awarding the contract, to reduce possible construction modifications.

Unfortunately, most Fort Lewis projects are not pursuing rainwater collection and reuse due to the higher first cost associated with these systems. Additionally, there are many low flow fixtures on the market that make it easy to achieve 1, 2, or 3 LEED efficiency credits in the Water Efficiency category simply by using low flow fixtures such as waterless or 16-ounce flush urinals and high efficiency toilets (1.28 gal/flush).

With the move towards using design-build acquisition strategy for nearly all projects, contractors will try to score other "low hanging" LEED points rather than incurring the cost associated with these rainwater collection and reuse systems. Future use of rainwater harvesting will have to be encouraged by requiring it in the request for proposal (RFP) and emphasizing life cycle costs.

Lessons Learned from Other Facilities

- Use of rainwater in cooling towers may need minor treatment for biological growth prevention.
- One industrial operation with four story buildings found that dust would settle in the tank at one end, but not at the other end.
- It is essential to have good, sealed joints.
- Try to avoid copper piping, avoid metals, may need to use anodes to avoid corrosion.
- Screen organics out of system, simplify the process and equipment to reduce maintenance. For example, use 30-degree slope screens.
- Screen water. The use of filters and booster pump are recomended.
- For the first flush tank, use a 200 micron sock filter so that only dust gets into cistern.
- Tanks must be light-tight to avoid algal growth.
- In one residential example near Austin TX, the residence had 6500 sq ft of roof of standing seam metal with screens on the gutters that did not work. It is essential to have a dry system that permits no standing water. Also, there must be some method to bleed water off. For storage, owner used six 5000-gal tanks with valves on every tank so they were manifolded together. The system supplied all the user's potable and non-potable needs for the year. The system's costs were:
  - costs for 5000-gal tank are now about $3200,
  - 20,000-gal metal tank about $9000.
  - costs were estimated o be $1.25 - $1.50/gal of storage.
- The Boerne, TX shopping center has three 10,000-gal tanks (and estimates about $100/yr for maintenance).
- A Boerne, TX school has two 25,000 gal tanks. Systems details are:
  - The system was designed for irrigation of the athletic complex and landscaping.
  - This system catches runoff from the ground and roofs, and also collects rooftop package air-conditioning handlers, which contributes several thousand gallons per day.
  - A 5-ft diameter drain pipe, 800 ft long, made water tight was adapted for storage

N A high tech weir was added for another 250,000 gal of on-site storage.
N This user recommends using a self-flushing filter on out-flow (sand filter).
N This system had a 5-yr payback.
N Potable water costs $9.50/1000 gal.
N This user estimates $3500 for O&M, electricity, and man-power, including weekly checks of the irrigation system heads.

Summary

In summary, numerous drivers currently exist to promote water efficiency. Rainwater harvesting is one option that can enable Army installations to reduce their use of potable water. Federal policy encourages the use of rainwater harvesting and it is becoming widely accepted throughout the country as states and municipalities realize the benefits of increasing water supply through use of this alternative. Regulations, policies, and codes are being changed to accommodate this option. Rainwater can be effectively used for both potable and non-potable needs, although designs and components have to be matched with the end use.

Rainwater harvesting has been demonstrated on Federal facilities and Army installations, and has been widely used in many states -- not just in arid and semi-arid states like Texas and New Mexico, but also, for example, in Virginia, Oregon, and Washington, where the practice is encouraged.

When designing for Army applications in new construction projects, the requirement for rainwater harvesting must be spelled out in the request for proposal and enforced to ensure that prospective contractors use this option. Otherwise, the use of low-flow fixtures (mandatory in new Army construction) will enable the contractor to avoid this alternative as more construction goes towards the Design-Build option.

The use of rainwater harvesting is efficient and cost-effective in meeting needs for potable water in remote locations without adequate potable water supply. It can also provide a substantial supply of water for a range of non-potable applications, from within-building uses like toilet flushing and cooling towers, to external uses for irrigation or vehicle cleaning.

Appendix B
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Appendix C
Acronyms and Abbreviations

Term	**Spellout**
ABS	acrylonitrile butadiene styrene
AE	Architect/Engineer
ANSI	American National Standards Institute
AR	Army Regulation
ARCSA	American Rainwater Catchment Systems Association
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BE	(Air Force) Bioenvironmental Engineer
BRAC	Base Realignment and Closure
CA	component and activity
CE	(Air Force) Civil Engineer
CERL	Construction Engineering Research Laboratory
COF	Company Operations Facility
CONUS	Continental United States
DA	Department of the Army
DC	District of Columbia
DOD	U.S. Department of Defense
DPW	Directorate of Public Works
DWV	Drain, Waste, and Vent
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
ETL	Engineering Technical Letter
FAQ	Frequently Asked Questions
FDA	Food and Drug Administration
FEMP	Federal Energy Management Program
GWOT	Global War on Terror
HB	House Bill
HQUSACE	Headquarters, U.S. Army Corps of Engineers
ICC	International Code Council
IPC	International Plumbing Code
IPCC	Intergovernmental Panel on Climate Change
LCC	Life Cycle Cost
LEED	Leadership in Energy and Environmental Design
LID	Low Impact Development
NPS	Nonpoint Source
NSF	National Sanitation Foundation
O&M	Operations and Maintenance
PDF	Portable Document Format
PL	Public Law
POC	Point of Contact
PVC	polyvinyl chloride
PWTB	Public Works Technical Bulletin
RFP	Request for Proposal
RWH	Rainwater Harvesting
SDWA	Safe Drinking Water Act
TI	Technical Instructions
TWDB	Texas Water Development Board
UFC	Unified Facilities Criteria

Term	**Spellout**
UFGS	Unified Facilities Guide Specification
UPC	Uniform Plumbing Code
URL	Universal Resource Locator
USACE	U.S. Army Corps of Engineers
USC	United States Code
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGBC	U.S. Green Building Council
UV	Ultraviolet