Rainwater

Catch it While You Can

A Handbook on Rainwater Harvesting in the Caribbean

Prepared by
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Handbook for Rainwater Harvesting for the Caribbean

A practical guideline featuring best practices for rainwater harvesting in small island Caribbean environments

October 2009

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The finalization of this Handbook was achieved under a second stage of the UNEP initiative where best-practice RWH demonstration models were developed in Antigua and Barbuda. The contents of the Handbook were derived from lessons learnt from the Antigua and Barbuda demonstration project and the vast resources on the subject have been published on-line and in hard-copy publications. CEHI acknowledges these contributions as providing valuable input in the production of this publication.

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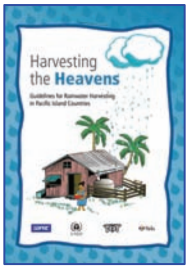
Preface

This rainwater harvesting handbook is intended as a practical guideline to assist homeowners, contractors, architects, farmers, and business owners in offering tips on how they can introduce rainwater harvesting to augment their water supply.

Access to a safe and reliable source of water still remains a number one development priority in the Caribbean. Over the past decades many countries have made tremendous strides toward meeting this priority through the establishment of centralized municipal water supply systems that service the majority of households and businesses. Only in the smallest islands, most notably the Grenadines and some of the Bahamas, rainwater remains the sole source of water. In several of the more arid islands such as Antigua & Barbuda, the Bahamas, and the Virgin Islands, rainwater harvesting is still practised in spite of access to the municipal potable supply, where residents on these islands still favour rainwater in meeting their drinking and cooking needs. In recent years however, some of the water-scarce countries have made significant investments in desalinization technologies, where sea water is converted to fresh water. In this case the availability of a virtually unlimited supply of water is now meeting the development needs for water on these islands, but it comes at a significant cost due to the energy inputs required. On these islands, as well as on many others, with expanded access to potable water whether ground, surface or sea water, there has been a trend to move away from RWH, due to the general perception that the practice is outdated; to be relegated to a past era before the advent of the conventional water supply and distribution system.

The applications of RWH however are gaining prominence in national water resources management planning. This is in the context of the pressures that water resources (both ground and surface sources) have been facing from land degradation and pollution due to expanded urbanization, industrialization, agricultural and other commercial development. If pollution of the region's waters is not addressed, climate change will exacerbate diminishing water availability at a more rapid pace. Rising sea levels will intrude vital coastal aquifers, while the possibility of declining rainfall will negatively affect aquifer recharge rates. The anticipated more frequent occurrence of destructive hurricanes, floods and droughts will compound the situation. The post-Hurricane Ivan experience of Grenada (2005) served to highlight the issue of water scarcity, and how RWH can go a long way towards meeting post-disaster water and sanitation needs. Grenada’s sister island, Carriacou, which is served only by harvested rainwater, was mainland Grenada’s principle source of water in the aftermath of the hurricane.

Policies and attitudes toward the practice of RWH must change if we are to continue to make our communities more water-secure into the future. The Caribbean Environmental Health Institute has been working with partners such as the United Nations Environment Programme (UNEP) and the Global Water Partnership (GWP) in advancing water resources management in the Caribbean region with particular focus on Integrated Water Resources Management (IWRM) where rainwater harvesting is an element. This Handbook is accompanied by a range of general and technical information products that have been developed with the assistance of UNEP and includes policy guidelines for RWH, educational posters, brochures, technical fact sheets, radio public service announcements, a television production, stormwater RWH management recommendations for aquifer recharge and computer-assisted mapping to estimate rainwater harvesting potentials.



The Handbook primarily details the application of domestic RWH systems with emphasis on aspects such as rooftop rainwater capture potential to storage capacity, determining storage capacity based on household size, and reducing contamination of stored water. The guidelines set out in the Handbook were derived from the wealth of resources on the subject from a variety of different websites. The primary reference in the preparation of this document was the guideline **Harvesting the Heavens - Guidelines for Rainwater Harvesting in Pacific Island Countries** (2004) that was compiled by the South Pacific Applied Geoscience Commission (SOPAC) for the United Nations Environment Programme (UNEP) in conjunction with the Tonga Community Development Trust (TCDT) and funded by the Swedish International Development Agency (SIDA). The SOPAC publication is available on-line at http://www.sopac.org/data/virlib/JC/JC0178.pdf

It is anticipated that the Handbook will be utilized by contractors, home-owners, commercial operators, and farmers as an easy guide in the installation and operation of RWH systems. ***Although the material presented in this Handbook is mainly based on single household applications, the concepts can be applied or scaled up to other applications in agricultural, commercial, industrial and municipal services sectors***. Advice from professional engineers, contractors or water services specialists should be solicited when investing in RWH systems.

Patricia Aquing
Executive Director
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Acronyms and units

CEHI	Caribbean Environmental Health Institute
Imp	Imperial gallon
hp	horsepower
km^3	cubic kilometers
m^2	square metres
m^3/d	cubic meters per day
mg	milligram per litre
ml	millilitres
mm	millimeters
PAHO	Pan American Health Organization
PVC	Poly-Vinyl Chloride
RWH	Rain Water Harvesting
SIDS	Small Island Developing States
SOPAC	South Pacific Applied Geoscience Commission
UNEP	United Nations Environment Programme
US$	United States dollars
USVI	United States Virgin Islands
UV	ultraviolet

Glossary

Aquifer	Underground bed or layer yielding ground water for wells and springs
Catchment	The component of a RWH system from which rainwater is collected (especially a natural drainage area). Typical catchment surfaces include building rooftops, roads and pavements.
Chlorine residual	The amount of chlorine that remains in water at the end of a period of time following chlorination
Cistern	A receptacle for holding water typically integrated as a structural part of a building
Conveyance system	The component of the RWH systems that includes the gutters and pipes that carry the water from the catchment to the storage tank. The filter screens and first-flush diverters are also included in this component
Desalination	The removal of salt from sea water to convert to potable water
Disinfection	Treatment process to destroy harmful microorganisms
Down-pipe	The pipe that carries water from the gutter down to the storage
First-flush diverter	An installation typically on the downpipe (from the roof gutter) that diverts the initial 'dirty' wash off the roof when it starts to rain from entering the tank
Groundwater	Water beneath the surface of the earth which saturates the pores and fractures of sand, gravel, and rock formations
Gutter	A channel installed along the edge of a catchment surface that carries collected rainwater toward the storage
Municipal	Of or relating to a town or city or its local government
Potable	Fit to drink
Rational Method	A calculation procedure to estimate the amount of rain that can be captured off a roof surface per year
Runoff	Excess water that runs over a surface
Runoff coefficient	The amount of water that drains from the surface relative to the amount the falls on the surface as rain
Surface water	Water collecting on the ground, in a stream, river, lake, wetland, or ocean
Vector	An organism, such as a mosquito that carries disease-causing microorganisms from one host to another.

1. Background

1.1 Water is life!

Water is our most vital natural resource, supporting life and life support processes. While there is as much as 1,400 million km^3 of water on earth, only one-hundredth of 1% of this amount is easily available for human use. The amount of water available for each person will continue to decrease as the world's population expands. Unfortunately our present and future water supplies in many parts of the world are being degraded by pollution from domestic waste water, solid waste, industrial effluent and agricultural drainage to name a few. As our natural waters become more polluted, less water is available for our needs and the needs of the natural environment. Every year, approximately 25 million people die, by either drinking polluted water or because they do not have enough water to meet their daily needs.

A single person needs at least half a litre (0.11 gallons) per day to meet basic survival needs and two litres (0.44 gallons) per day to avoid thirst. Some 27 to 200 litres (6 to 44 gallons[1]) are needed per person per day for drinking, sanitation, bathing and cooking. Household water needs vary depending on the type of dwelling, number of residents and type of plumbing fixtures.

Traditional sources of water to meet our needs typically include surface waters (rivers and lakes), ground water (water stored below-ground in aquifers) and rainwater. Direct capture, storage and use of rainwater, called Rainwater Harvesting (RWH) is the oldest method of securing water, having been practised by ancient civilisations for more than 4,000 years. This technique continues to be an important means of supplying water in many communities, especially those located far away from municipal potable water supplies. RWH continues to be among the most simple and low-cost means of water supply, employing technologies that are generally easy to install and maintain.

1.2 Rainwater harvesting in the Caribbean

The Caribbean region has a sub-tropical climate with approximately 80% of the annual rainfall concentrated between May to December. Rainfall ranges from 1,500 mm to in excess of 3,000 mm per year, depending on island size and relief[2]. Rainfall accumulations are higher on the larger, more mountainous islands often in excess of 2,500 mm per annum in the interior, with surface and ground waters in relatively good supply. The smaller, low-lying islands on the other hand, tend to be relatively arid

Figure 1 *Typical household rainwater harvesting in the Caribbean*

[1] Gallons mean Imperial gallons in this document

[2] In Dominica, mean annual rainfall in the interior is in excess of 7000mm

with annual rainfall generally less than 1,500 mm. On these islands, free-flowing surface water is scarce.

Before the advent of centralized conventional potable water supply systems, RWH was the only means of water security in all the Caribbean islands. The practice continues to remain the mainstay of water supply in many of the drier islands such as the Grenadines, the Virgin Islands and the Bahamas, although in some of these islands in recent times, there has been a move away from traditional RWH methods to alternative technologies such as desalination and deep-well abstraction. However, these alternative technologies come at a higher cost, and the sustainability of these operations depends on consumers' ability and willingness to pay for these services. The practice is also declining due to a lack of awareness, knowledge and skills to set up systems. Where investment in relatively expensive, water supply options are not viable, and where appropriate knowledge and skills exist, RWH nonetheless remains an attractive low-cost option to meet shortfalls in water supplies during dry months.

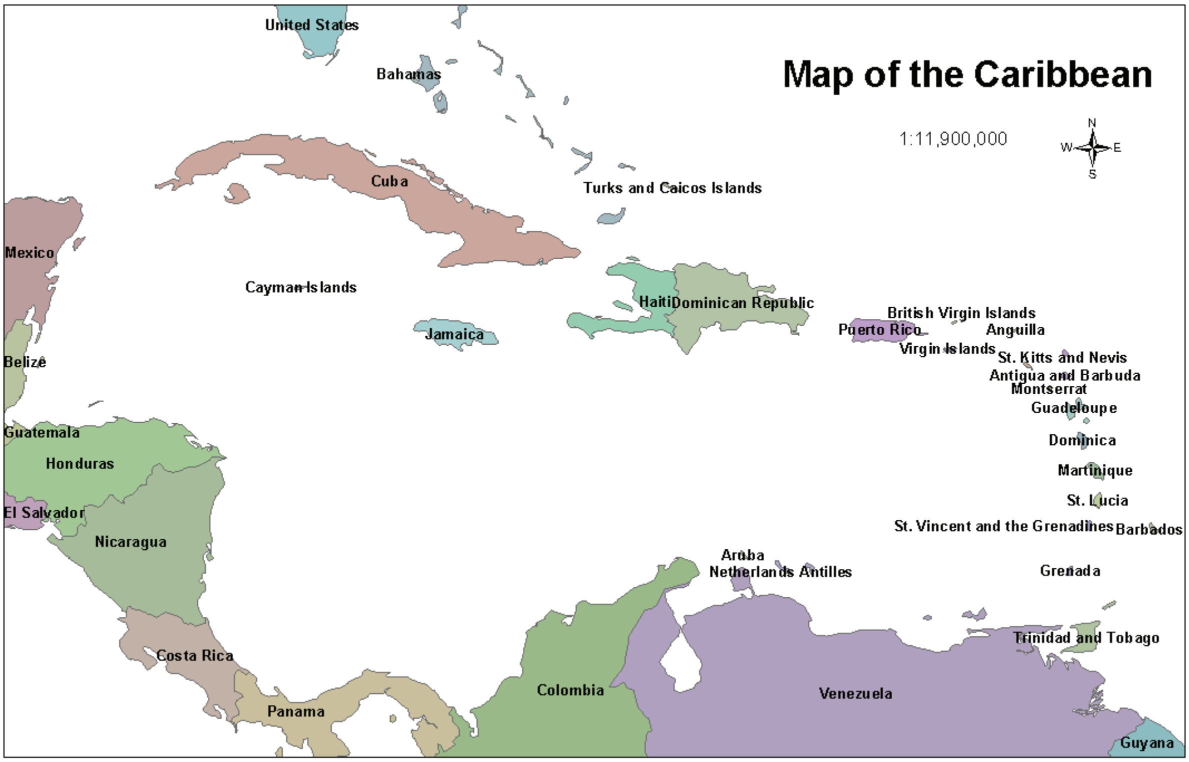


***Figure 2** Map of the Caribbean*

RWH has proven futile during times when conventional water supplies have become polluted or unavailable after natural disasters like hurricanes where the municipal water distribution system is damaged and out of commission for extended periods.

Rainwater harvesting is not only useful for domestic purposes, but can also be used for agricultural and industrial/ commercial applications that have heavy water requirements. RWH will likely see heightened importance as a water security measure in the context of climate change, with the likelihood of changing rainfall regimes, prolonged droughts and extreme storm events. The United Nations Commission on Sustainable Development has called for the use of rainwater harvesting to supplement water supplies in countries around the world.

***Figure 3** Old public water supply cistern and a hillside catchment surface both on St. Thomas, USVI* (photos courtesy Henry Smith)

1.3 Rainwater harvesting – the pros and cons

As with all water supply options, RWH has many advantages but there are a few disadvantages that should be noted. The disadvantages may be minimized with the adoption of a few simple water safety measures.

Advantages:

***Figure 4** Domestic RWH system with cistern in St. Thomas* (Source: H. Solomon and H. Smith, University of the Virgin Islands)

- Rainwater harvesting provides a source of water at the point where it is needed. It is owner-operated and managed;
- It provides an essential reserve in times of emergency and/or breakdown of public water supply systems, particularly following natural disasters;
- The construction of a rooftop rainwater catchment system is simple, and these systems can be built to meet almost any requirement;
- Households can start with a single small tank and add more when they can afford them;
- Installation of concrete cisterns as part of the building foundation can improve the structural integrity of the building substructure;
- The physical and chemical properties of rainwater are often superior to those of groundwater or surface waters;

- Operating costs are low;
- The construction, operation, and maintenance does not have to be labour-intensive;
- Reduces runoff.

Disadvantages:

- Rainwater harvesting depends upon the frequency and amount of rainfall; therefore, it is not a dependable water source in times of prolonged drought;
- Low storage capacity limits the volume of rainwater that can be harvested so that RWH systems may not be able to provide the required water during prolonged dry periods. Increasing the storage capacity raises the construction and operating costs making it expensive (particularly for lower-income households), unless subsidized by government;
- Leakage from cisterns can cause the deterioration of load-bearing slopes that support the building foundation;
- Cisterns and storage tanks can be unsafe for small children if manholes (access points) are not adequately secured;
- Water can become contaminated by animal waste (bird, bat, rodent droppings) and vegetable matter (rotting leaves, fruit).
- Health risks may result where water treatment is not practised prior to use (drinking);
- Cisterns and other storage facilities can be breeding grounds for mosquitoes where not adequately sealed;
- Rainwater harvesting systems increase home construction costs and may add significantly to the cost of a building;
- Rainwater harvesting systems may reduce revenues to public utilities and may cause variable demands on public supplies;
- Rainwater is mineral-free, and may cause nutrition deficiencies in people who are already on mineral-deficient diets.

Figure 5 *Cistern serving apartment building in St. Thomas, USVI*. (Photo courtesy Henry Smith)

2. Rainwater harvesting system design

2.1 Main RWH components

The typical RWH system has four main parts:

1. **Catchment area:** Commonly a roof surface or pavement. Concrete and other impervious pavements may be used for multiple-user community systems and can have applications for agricultural or commercial uses with large water requirements. Figure 6 illustrates such a community catchment surface that provides water to the Ashton community in Union Island, St. Vincent and the Grenadines.
2. **Conveyance system:** Network of guttering and pipes to transfer the rainwater from the catchment to the storage tank. This consists of connections to one or more down-pipes connected to the roof gutters. A key component of the conveyance system to improve the cleanliness of the harvested water is a 'first-flush device' that diverts the dirtiest roof-water away from the storage tank.
3. **Storage device:** A tank situated above, underneath or partially below the ground.
4. **Distribution system:** In the most basic case, this can be simply a container to extract the water from the storage tank or a pipe functioning solely as an outlet. For a household, this will be the piping network that supplies the building with the harvested water. For a community RWH system, this could be a single outlet pipe or a complex network of pipes serving multiple users. A pump may be used to transmit the water throughout the distribution system.

***Figure 6** Surface catchment for communal RWH system at Ashton on Union Island, St. Vincent and the Grenadines*

A typical RWH system can be complemented by a host of other devices and measures to maintain and improve water quality. These include filters, screens, first-flush diverters and storage facilities with special tank inlet and outlet configurations. Disinfection, vector control and overflow management measures can also be installed.

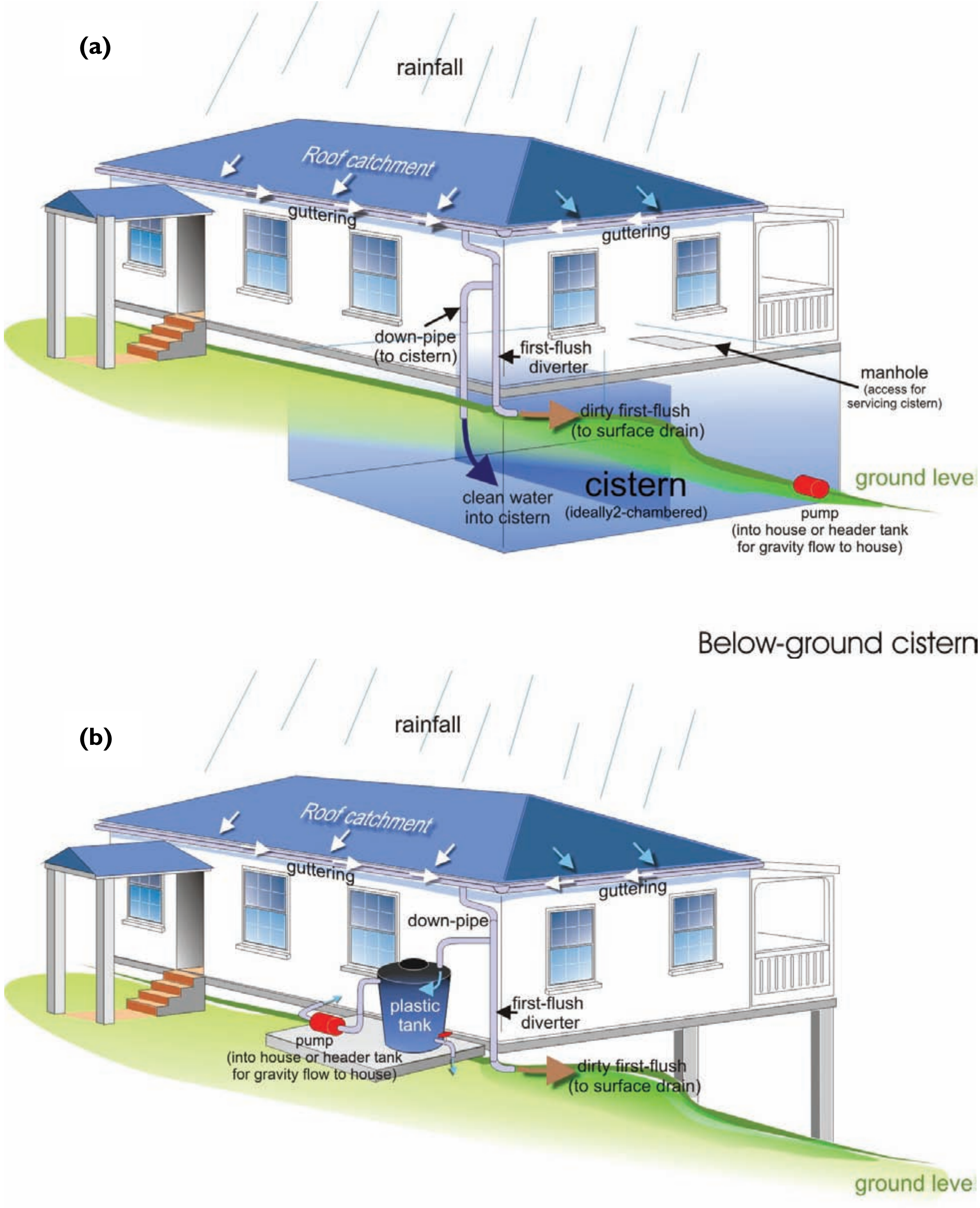


Figure 7 *Typical domestic RWH systems with (a) above-ground and (b) below-ground storage*

2.2 The catchment area

For household/domestic water supplies, the roof of the building is generally used as the catchment area. Some materials used to coat the roof such as bitumen, paints or sheeting containing lead, may pose risk to human health. RWH systems are best-suited where the roofing material is smooth and coated with chemically neutral substances. Non-corrosive sheet metals such as galvanized sheets or aluminium are ideally suited for use with RWH systems. They are less prone to build-up and contamination from dust, leaves, animal droppings and other debris, compared to rougher roof surfaces such as tile, shingles or thatch.

Follow these general guidelines when installing RWH rooftop catchment systems:

- Do not use lead fittings;
- Repair or replace metal roofs that are visibly corroded;
- Check paints for suitability, and where possible use non-toxic acrylic-based paints designed for exterior and roof use. Do not use paints containing lead, chromate, tar/bitumen, fungicides or other toxins as they may pose a health risk and/or may impart an unpleasant taste to the water;
- After roof repainting, do not allow runoff water from the first rainfall to enter the storage tank. Instead it should be discarded or used for non-drinking purposes.

2.2.1 How to calculate the volume of water that can be captured by a roof catchment

To calculate the amount of rain that can be captured off a roof surface per year, a procedure known as the **'Rational Method'** can be applied. All you need to know is the average annual rainfall for your location, the size or area of your roof and the type of roof surface you have. The average annual rainfall should be available from your local Meteorological Service. If you want more precise estimates you may take into account the average, minimum and maximum rainfall on a per-month basis.

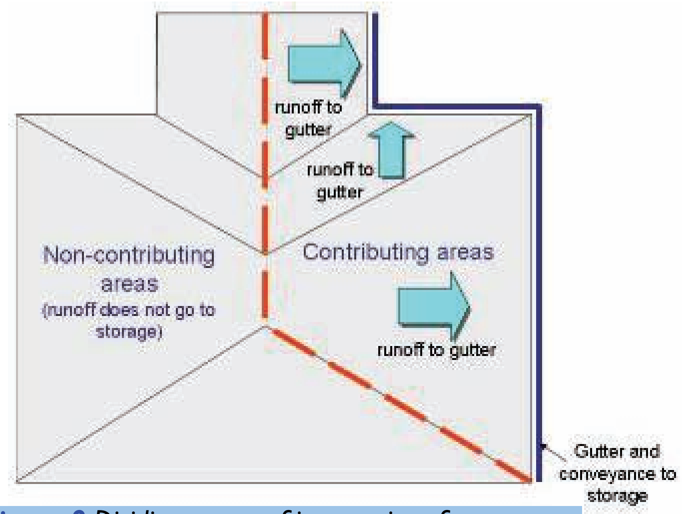


Figure 8 *Dividing your roof into sections for area estimation*

The Rational Method is given as follows:

Supply = rainfall (mm/year) x roof area (m^2) x runoff coefficient = litres per year

The **runoff coefficient** is the amount of water that actually drains free of the surface relative to the amount the falls on the surface as rain. For example a runoff coefficient of 0.8 means that of the total volume of rain that fell on the catchment surface, 80% drained off the surface; the other 20% stayed on the surface. Smooth metal sheet catchments with a steep gradient have higher runoff coefficients than flat concrete catchment surfaces for example, which absorb a higher portion of moisture. Evaporation directly off the catchment surface also affects the runoff coefficient.

The roof surface area available for rainfall harvesting depends on the width and length of the roof surface, and the angle (or slope) of the roof.

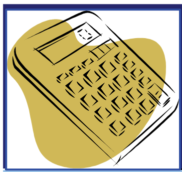
- If your entire roof is flat and all the runoff is captured by surrounding guttering, estimating the catchment area that can contribute to rainwater harvesting is easy. In this case the contributing roof area is simply calculated by multiplying the length of the roof by its width.

- If the roof is not a simple rectangle, then you will have to divide the area into sections, calculate each area and add them to estimate the total catchment area. Alternatively the area 'footprint' of the building can be used to estimate the catchment area, provided that the rainfall off entire roof area is captured by the guttering.

- If your roof comprises several sloped sections, and if only certain portions of the roof runoff is captured by guttering, then estimating the contributing roof area can be a bit more complicated. As a start it is best to try to draw out your roof plan with estimated measurements for each section that drains to guttering and then determine the sizes of each contributing area. This is illustrated in Figure 8.

If you wish to make more precise measurements of your catchment area, particularly if the roof sections are sloping, you may incorporate the slope or angle of the roof, with the actual linear dimensions in the calculations. In this case you will need to multiply the length by the width (of the roof section) and the sine of the angle (in degrees) of the roof section. To assist in the calculations Annex 1 provides guidance.

See Technical Box 1 for a worked example of the Rational Method and Table 1 for runoff coefficients for different catchment surfaces.



TECHNICAL BOX 1
How to use the Rational Method to calculate the volume of rainwater which could be captured

For the amount of water you can capture in one year you will need to estimate the area of your roof, the average annual rainfall at your location and the runoff coefficient for the surface. The mathematical relationship is given as:

Supply (litres per year) = rainfall (mm/year) x area (m^2) x runoff coefficient
(multiply by answer by 0. 22 to convert the value to imperial gallons per year)

The runoff coefficients for various surfaces are given in Table 1.

Note that if your roof is angled you will need to 'project' the surface to the horizontal to correctly estimate the amount of rain that falls on the roof. For a sloped roof you will need to know the roof angle (see Annex 1 for further details). The roof area is calculated by the following relationship:

Roof surface area (m^2) = roof length (m) x roof width (m) x sine of the angle (in degrees)

A worked example:

- Mean annual rainfall = 1,500 mm per year
- Roof angle = 70 degrees; sine of the angle = 0.9397
- Roof area = 10 m (length) x 8 m (width) x 0.9397 = 75 m^2
- Roof surface is smooth corrugated metal. This surface is assumed to have a runoff coefficient of 0.8

Supply = 1,500 x 75 x 0.8 = 90,000 litres (approx 19,800 gallons) per year.

Table 1 Runoff coefficients for various catchment types
Source: Alphonsus Daniel, pers. comm.

Type of catchment	Coefficients
Roof catchments	
Tiles	0.8 - 0.9
Corrugated metal sheets	0.7 - 0.9
Ground surface coverings	
Concrete	0.6 - 0.8
Brick pavement	0.5 - 0.6
Untreated ground catchments	
Soil on slopes less than 10 percent	0.1 - 0.3
Rocky natural catchments	0.2 - 0.5

2.3 The Conveyance system

The conveyance system consists of the gutters, pipes and screens. The gutters and piping collect drained runoff from the roof catchment into the storage system. Screens prevent leaves and other organic material that may have accumulated on the catchment surface from entering the storage tank or cistern.

2.3.1 Gutters

Polyvinyl chloride (PVC) pipes are commonly used for gutters given their low maintenance requirements. Gutters should not have flat areas where debris can collect and water pool, as these may provide sites for mosquitoes to breed. Gutters must slope toward the direction of the storage tank and the gradient should be equal to or more than **1 centimetre per metre or 1/8 inch per foot.** You will need to regularly clean the gutters to reduce debris collection to catch the most rain, and ensure that leakage is kept to a minimum. To minimize the amount of leaf litter that gets on to the roof and trapped in the guttering, you should trim away overhanging branches. However if you opt not to remove overhanging branches, gutter screens may be used.

Figure 9 *Typical PVC guttering and downpipe*

The size (width) of the gutters should be chosen based on the roof section area. The South Pacific Applied Geoscience Commission (SOPAC) Handbook rainwater harvesting (2004) provides guidance to sizing of the gutters and the downpipes appropriate to handle rainstorms in tropical regions.

Table 2 Guide to sizing gutters and down-pipes for RWH systems in tropical regions
(Source: SOPAC, 2004)

Roof area (m^2) served by one gutter	Gutter width (mm)	Minimum downpipe diameter (mm)
17	60	40
25	70	50
34	80	50
46	90	63
66	100	63
128	125	75
208	150	90

2.3.2 First-flush diverter

The first rains that wash the roof surface will often contain offensive materials, especially following a long dry spell. The material that would have accumulated on the surface will include animal droppings, vegetable matter and dust, all of which can degrade the quality of the stored water should this **'first-flush'** enter the storage tank. One option is to use a first flush diverter to divert this material away before it enters the tank. A **first-flush diverter** is a simple installation that is part of the downpipe, configured to remove the initial wash off the roof so it does not enter the tank. The first flush diverter works by channelling the first flow down the downpipe to its base where it encounters a cap with a small drain hole (the drain hole will allow for gradually drainage else, the system will need to be drained manually). This permits the first flow of water containing the roof debris to settle at the bottom of the downpipe, with the cleaner 'later' water settling on top, permitting relatively clean water to enter the tank.

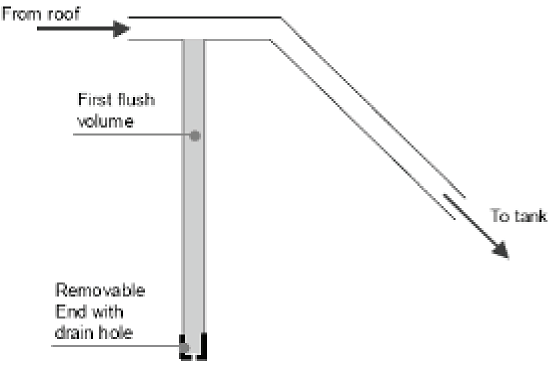
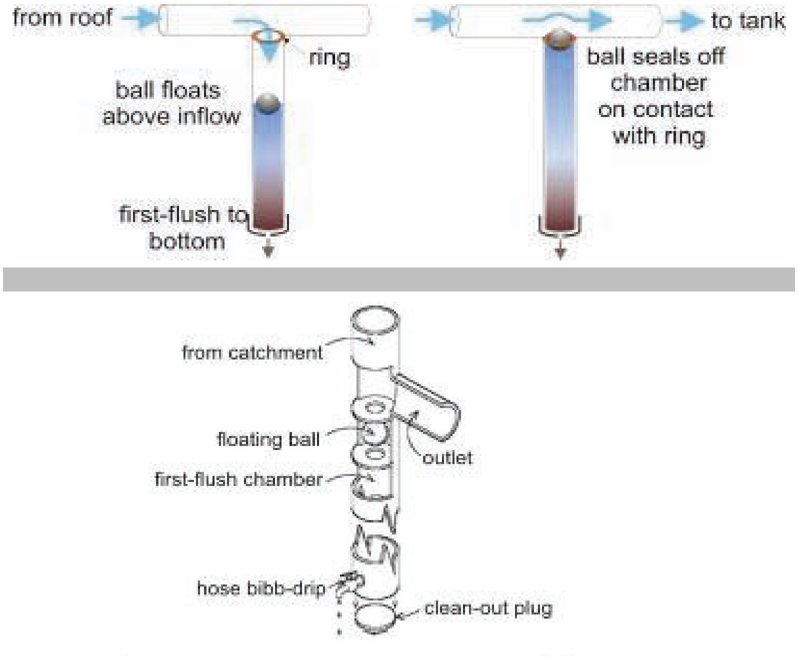


Figure 10 Simple first-flush diverter

Figure 11 First-flush diverter

There are various configurations that can be used for first-flush diverters. Figures 11 and 12 are examples of the simple first-flush diverter. This basic design can be augmented with the use of a floating-ball valve that sits on top of the water column. The ball valve isolates the dirty first flush from the cleaner water once the water column in the downpipe floats the ball to the constriction in the neck of the downpipe. The design is illustrated in **Figure 12**.



Source: Texas Manual on Rainwater Harvesting. On-line at http://www.texashuntfish.com/app/generic-pages/24585/Texas-Manual-on-Rainwater-Harvesting

Figure 12 Examples of first-flush systems using float-ball mechanism

Another design that has been tried in the Caribbean is an upflow-filter (UNEP/CEHI Antigua and Barbuda

RWH demonstration project). In this case the water is forced upwards through the first flush chamber across a cloth filter allowing the dirty water to settle to the bottom for clearing. This design is illustrated in Figures 13 and 14.

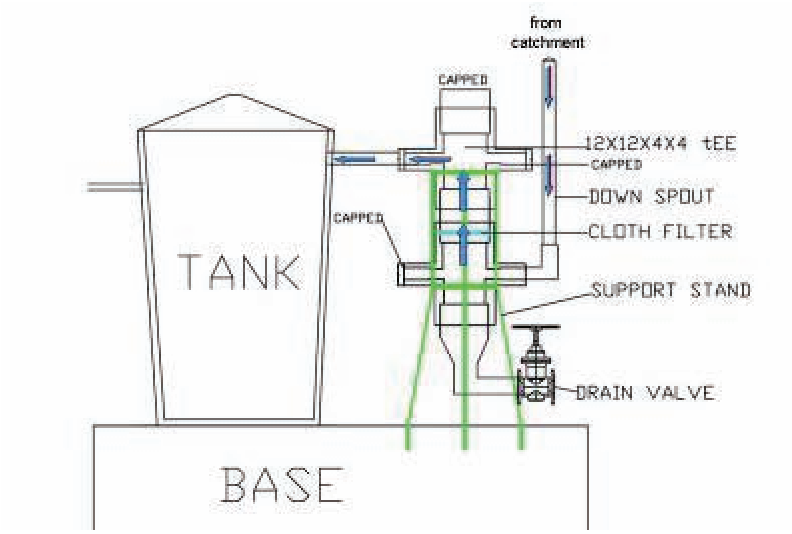


Figure 13 Upflow filter design. Used in UNEP/CEHI RWH project in Antigua and Barbuda
(design by Hastin Barnes, Antigua and Barbuda Public Utilities Authority)

There are a few simple maintenance procedures that are needed for first-flush diverters. You need to ensure that the cap at the end of the first flush pipe is easily removable to facilitate cleaning. You will also need to regularly inspect the pipe to ensure no leaves or other materials have become lodged in the pipe and that the system is draining properly. An inappropriately maintained filter is worse than no filter at all.

The amount of water that needs to be diverted off the roof as first-flush and the capacity or required length of the downpipe can be calculated. To make this calculation you need to know the area of your roof and the diameter of the downpipe. Technical Box 2 shows how to calculate the volume of water to be diverted by a first-flush system.

Figure 14 Examples of up-flow filter first-flush diverters (single and dual tank configurations). Used in UNEP/CEHI RWH Project Antigua and Barbuda

TECHNICAL BOX 2

How to calculate the volume of water you need to divert using a first flush system

It is generally assumed that a depth of rainfall on the roof equivalent to 0.5 mm is required to wash off the accumulated contaminants. You first need to determine the area of the roof and simply multiply by 0.5mm (recall that you calculated the roof area in Technical Box 1). Secondly, to determine the length of first-flush down-pipe diversion requires you divide the required volume of water to be diverted, by the cross-sectional area of the pipe (πr^2), where $\pi = 3.14$ and r is the radius or ½ the diameter of the pipe.

(a) Volume of diverted water (litres) = house length (m) x house width (m) x 0.5 (mm)
(multiply answer by 0.22 to convert the value to imperial gallons)

(b1) Pipe length (m) = Volume of diverted water (l) ÷ [3.14 x pipe radius^2 (mm) x 0.001]
(b2) Pipe length (feet) = Volume of diverted water (gal) x 22.57 ÷ (3.14 x pipe radius^2 (inch)

A worked example:

Roof length = 8 metres
Roof width = 5 metres
Pipe diameter = 150 mm (6 inches), therefore radius = 75 mm (3 inches)

(a) Volume of diverted water (litres)= 8 x 5 x 0.5 = 20 litres (or 4.4. gallons)
(b1) Pipe length (m)=20 ÷ [3.14 x 75^2 x 0.001] = 1.13 m
(b2) Pipe length (ft) = 4.4 x 22.57 ÷ (3.14 x 3^2) = 3.51 ft

Source: South Pacific Applied Geoscience Commission (2004)

2.3.3 Screens

Screens prevent leaves, particulate matter, and other objects from entering the storage tank. If allowed to enter, these materials decompose, providing nutrients or 'food' for potentially harmful microorganisms to multiply. If you can keep the storage tank free of such materials, the less likely nutrients can accumulate; without this nutrient supply, the bacteria eventually die-off from starvation within 2 to 20 days. Screens are therefore among your front-line defences to protect water quality. A huge benefit derived from installation of screens is in the prevention of mosquito entry and breeding.

Tank overflow covered with fine mesh

Typical outdoor drum covered with fine mesh (usually for non-potable use)

***Figure 15** Screens to exclude entry of insects and other potential contaminants*

A filter or screen should be durable, easy to clean and replace. Filtration screens (made of stainless steel or synthetic mesh) are the simplest, most inexpensive and widely used.

These may be mounted across the top inlet of the storage tank with the downpipe above the screen (Figure 15). Alternatively, the downpipe from the roof could enter the tank through an appropriately sized hole at the top of the tank with the filtration screen at the entrance to the downpipe from the gutter (Figure 16). Use both coarse and fine screens to improve water quality.

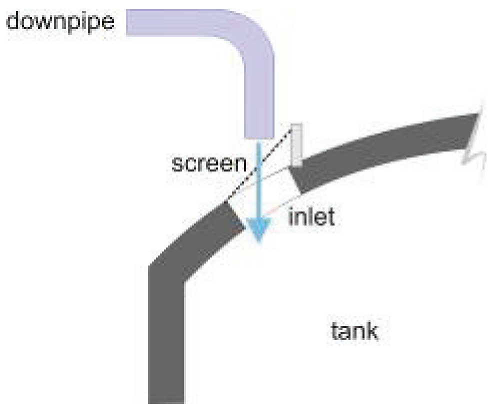


Figure 16 Design configuration for a self-cleaning screen
Source: WELL Resource Centre for Water, Sanitation and Environmental health.
http://www.lboro.ac.uk/well/resources/fact-sheets/graphics/Screen-in-downpipe.jpg

You should use:

- Coarse screens: To prevent larger size material (leaves, large insects, small animals) from entering the tank. A 5mm (0.2inch mesh) installed before the tank entry is typical.

- Fine screens: To exclude mosquitoes and fine particles from entering the tank. Insect-proof mesh or strong standard cotton/polypropylene filters installed at the inlet and outlet of the tank is recommended.

You need to:

- Ensure there are no gaps in the storage tank inlets where mosquitoes can enter or exit.
- Clean screens regularly or install a self cleaning screen (Figure 16).

2.3.4 Baffle tanks

A baffle tank can also be installed ahead of the main storage to filter out debris (Figure 17). These tanks have two screens; the first screen, called the flow baffle, filters out the more coarse material while the second with a finer mesh grade, filters the smaller particles. The filtered residue will settle to the base of the tank while the cleaner water (upper layer) is allowed to flow into the main storage. The sediment build-up in the baffle tank needs to be removed from time to time. This configuration will assist in reducing sediment/sludge build-up in the main storage.

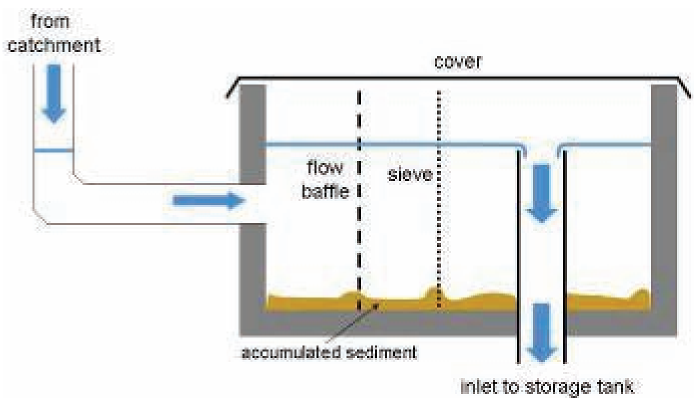


Figure 17 Baffle tank design to trap debris

2.4 Storage

The storage facility is at the core of the RWH system. In addition to having the appropriate volume capacity in relation to the catchment area, rainfall conditions and needs, it must be functional, durable and cost-effective in its installation and maintenance. An ideal or 'universal' storage tank design does not exist; selection of the type of storage facility ultimately depends on purpose of use, affordability, availability of supplies and materials, and know-how in design and installation. The following are key considerations in design and operation of the storage facility:

- Water-tight construction with a secure cover to keep out insects and other vermin, dirt and sunshine (note, exposure to sunlight will cause algal growth in stored water);
- Screened inlet to prevent particles and mosquitoes from entering the tank;
- Screened overflow pipe to prevent mosquito entry and breeding;
- In the case of cisterns, inclusion of a manhole (to permit insertion of a ladder) to allow access for cleaning;
- An extraction system that does not contaminate the water during operation (related to tap and pump installation);
- Soak away to prevent spilt water forming standing puddles near the tank (minimize mosquito breeding);
- In the case of cisterns, a maximum height of 2 metres (related to water depth) to prevent build-up of high water pressure (unless additional reinforcement is used in walls and foundations).

2.4.1 Above-ground versus underground tanks

In the Caribbean, under-ground storage tanks, commonly referred to as cisterns, were popular decades ago before the wide availability of polyvinyl chloride (PVC) storage tanks. Most homes and buildings on islands that relied solely on rainwater (or where municipal supplies were non-existent) were built with cisterns as part of the foundation. Such underground tanks may be safely installed if the soils are stable, as the surrounding ground can support the weight of the stored water. On the other hand, with these underground systems, leaks due to cracking may be difficult to locate and sometimes equally difficult to repair, and structural failures may occur if not addressed in time. The typical causes of failure include intrusion by tree roots, earthquakes, landslides and other earth movements. In these instances, the stored water will drain away or has the potential to become contaminated by surrounding groundwater.

Another problem that is common in the Caribbean with cisterns is entry by vermin where cracks and openings in the masonry work occur and remain unsealed. This also presents a risk to keeping the supply safe. In areas with relatively high water tables, there is a risk of the storage tank, if made of rigid masonry, literally being 'floated' out of position when the tank is empty. This happens because the force of the surrounding water in the soil exerts greater positive pressure on the outside of the tank structure since there is no counteracting pressure exerted by the empty tank. Where flexible materials such as plastic are used for underground systems, this problem may be reduced.

Figure 18 Multiple PVC tanks for rainwater storage

The common PVC tank has emerged as a preferred option in the Caribbean for household water storage, particularly for relatively smaller storage requirements. Depending on the water requirements, more than one tank may be installed as part of the RWH system. These tanks are relatively easy to install and maintain and will typically be a lower-cost alternative. It must be noted that where high volume storage is needed but where space is limited and aesthetic quality is an issue, cisterns may still be the best option as they are installed below the building footprint and therefore hidden.

Table 3 Advantages and disadvantages of aboveground and underground storage systems
(Source: SOPAC, 2004)

	Advantages	**Disadvantages**
Above-ground	• Allows for easy inspection for cracks (masonry structures) or leakage • Cheaper to install and maintain; particularly the case for small volume household supply needs • Water extraction can be done by gravity with extraction by tap; allows for easy draining if needed • Tank(s) can be raised above ground to increase water pressure	• Requires space for installation, particularly if large storage volume is needed; case for commercial and industrial uses • Masonry works exposed to deterioration from weathering • Failure of elevated support structures can be dangerous • Requires the construction of a solid foundation which may be costly
Underground	• Surrounding ground lends structural support allowing lower wall thickness and lower installation costs • Can form part of the building foundation • Unobtrusive - require little or no space above ground; useful where large volume storage is required •	• For relatively small storage requirements, is relatively more expensive • Water extraction is more problematic, requiring a pump • Leaks or failures are difficult to detect; pose risk to building foundation failure if constructed on a slope • Possible contamination of the tank from groundwater intrusion or floodwaters • Possibility of undetected structural damage by tree roots; allows for entry of contaminates or vermin • Cannot be easily drained for cleaning; requires pump-out

2.4.2 Tank materials

Storage tanks may be built using a variety of materials, including ferrocement, bricks and blocks, concrete, metal, plastic, wood and fibreglass. Ferrocement tanks have been used successfully in the Caribbean islands and if well maintained, can provide good water quality. Plastic tanks constructed from food-grade materials are becoming increasingly popular with improvements in durability, and they do not negatively impact water quality. In the case of plastic tanks however, one must ensure that those designed for wastewater storage and other non-drinking purposes are not used, as the chemical constituents used in their manufacture can dramatically reduce the quality of the stored water.

Perhaps the most basic and common type of rainwater tank in the world is the recycled 200-litre (55 gallon) oil drum, which is generally available even in the poorest of communities. However, potential contamination from the original content residues as well as from the environment (as these drums tend not to have taps or covers), make them less than ideal and hence are not recommended. Clear plastic or clear fibreglass tanks are not recommended as light penetration through the tank wall will result in algal growth and other biological activity thereby degrading the water quality. In the warm Caribbean climate, water stored in thinner-walled plastic or metal tanks will heat up, particularly if the tanks are not shaded, and for this reason consideration should be given to placement of the tanks, provision of adequate shading or selection of the construction material. In construction of masonry storage tanks, one must always be mindful of poor workmanship and/or poor selection of materials.

The following provides some information on the different types of storage options.

Ferrocement tanks

Ferrocement tanks have been widely adopted as an easily accessible, durable and low-cost option in countries where cheap skilled labour is readily available. Some level of skill is required in the correct installation of the reinforcement and plaster mixing. It has been noted however, with the increasing costs of weld mesh, chicken mesh and galvanized wire, that in many places, ferrocement tanks now cost much more than alternatives built with bricks. On the positive side, maintenance of ferrocement tanks is relatively simple, where leaks can be easily sealed by coating the interior of the tank with sealants and bonding agents. In the Caribbean, ferrocement tanks have seen applications in the agriculture. Figure 18 shows a typical example of a ferrocement tank.

Figure 19 *Typical ferrocement tank* (source: SearNet – Southern and East Africa Rainwater Network http://www.searnet.org/photogallery/pics/searnetDSC00726.jpg)

Masonry tanks

Masonry tanks can be constructed either from masonry blocks (or special cistern blocks) or solid cast concrete. The following provides a brief description of construction of these types provided by Dr. Henry Smith of the University of the Virgin Islands based on best practice in the Virgin Islands, along with some general recommendations and potential pitfalls.

Best-practice in the USVI:

__(A)__ <u>Masonry block construction:</u> Specially constructed cistern blocks are used; these are generally 8" high by 8" inches wide by 16" inches long. When laid, the center and the single end piece of the block are knocked out (inset). This allows a reinforcing bar of steel (#4 which is ½ inch) to be laid horizontally along that row of blocks, usually completely encircling the cistern; typically it is the alternating rows of blocks that have this steel reinforcement. A bar of steel is also placed vertically in alternating holes of the blocks, tying in to steel from the poured concrete bottom of the structure, to a steel grid that reinforces the top of the structure. Concrete is poured to fill all block holes resulting in a steel reinforced lattice of concrete-filled cistern blocks.

__(B)__ <u>Cast concrete:</u> In this construction, plywood forms are placed to accommodate 8" walls. A 12" by 12" lattice of ½" or 5/8" steel bars is placed in these forms. These bars run horizontally and encircle the entire structure and also run vertically, tying into the steel reinforcing to both the floor and top of the cistern. Concrete is poured and care taken to be sure that all pore spaces are full.
(Source: H. Smith, pers. comm. 2009).

The insides of cisterns should be finished first with a carefully applied mortar mix (often available commercially) and then coated additionally with a non-toxic sealant such as Thoroseal®. These coatings should be allowed a reasonable time to cure not only to achieve maximum strength and density but also in order to avoid leaching which could adversely affect the quality of water that might be stored.

With proper construction, these tanks can be durable but can fail due to a variety of reasons mainly related to insufficient reinforcement and poor plastering. It should be noted that circular designs can make for more stable and durable structures but in the case of underground tanks this may not be practical. One must also ensure that concrete blocks to be used are not damaged as often happens during transport over poor road surfaces or when otherwise not carefully handled.

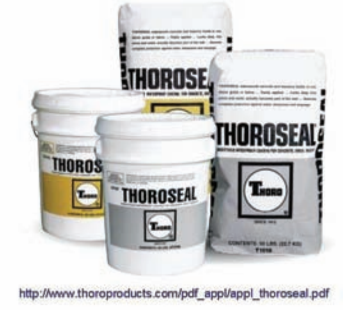


Figure 20 *Example of typical non-toxic concrete sealant for cisterns*

Figure 21 shows examples of block-work cisterns under construction for household dwelling and commercial applications.

Figure 21 *Typical block-type cisterns under construction (a) household (b) commercial applications* (photos courtesy Dr. Everson Peters and Andrew Hutchinson)

Corrugated galvanised-steel tanks are usually pre-fabricated using relatively light-weight components to facilitate quick installation. They are typically used for commercial and industrial purposes. Three factors generally influence their durability; (1) the quality of construction including the thickness of the metal used, (2) the level of protection provided for the tank, e.g. protective paint and (3) the level of exposure to saline or acidic water and atmospheric moisture. On account of these factors, the life expectancy of these tanks can vary considerably, although with good maintenance, can be made to last for more than 30 years. Metal tanks tend to be least-suited to coastal environments or conditions where saline or 'aggressive' acidic water may be mixed with stored rainwater. Some newer polymer-coated tanks specifically developed for water storage can be very cost competitive.

Plastic tanks

Moulded plastic tanks have become popular in recent years as they are relatively light-weight, easily installed, water-tight and do not corrode. Due to improved processes to stabilize the plastic against deterioration resulting from exposure to UV light, these tanks have become much more durable than they used to be. Depending on the volume capacity, the cost can vary, but are quite cost-competitive relative to other water storage options. During the hurricane season in the Caribbean, one must be mindful of the need to properly secure empty plastic tanks to prevent them from being blown away by strong winds (SOPAC, 2004). Figure 22 shows a typical plastic tank installation for a RWH system.

Figure 22 *Typical plastic tanks for household RWH system*

Fibreglass tanks

Fibreglass tanks are popular in some parts of the world and have the advantages of being light and easy to transport, long life expectancy and are easily repairable. However, they are relatively expensive compared to other tank types constructed on-site. They may also develop problems with algal or bacterial growth in tropical climates due to light penetration if not covered with opaque paint.

2.4.3 Tank inlet and outlet configurations

The quality of water resident in the tank generally improves with time. This is because bacteria will die-off within 2 to 20 days and suspended particles fall to the bottom. Incoming rainwater is therefore often of lower quality than stored rainwater. To ensure the separation of these different water qualities, the outflow of the down-pipe should be placed at the near-bottom of the tank so that the older 'improved' water is forced to the top layer. A low-rise pipe surrounding the down pipe called the 'break ring'

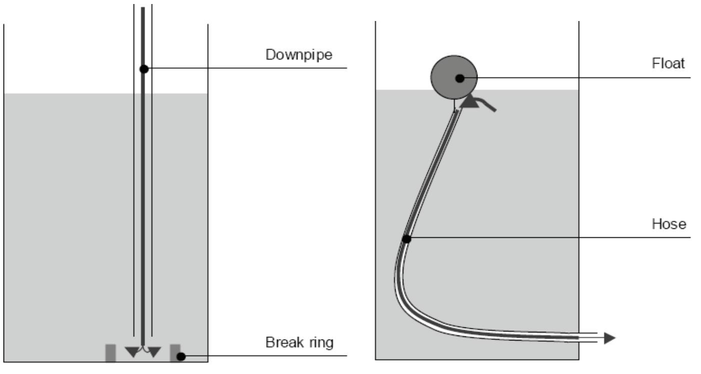


Figure 23 *Design configurations for (a) tank inflow and (b) outflow*
Source: South Pacific Applied Geoscience Commission (2004)

helps break the force of the outflow preventing it from disturbing any sediment that may have accumulated on the tank bottom (Figure 23a). To extract the cleaner top layer of water, a flexible intake hose attached to a float is recommended (as shown in Figure 23b).

2.4.4 Tank overflow configurations

An overflow is installed to reduce the possibility of system collapse during a rainstorm when the tank may fill rapidly. Figure 24a shows the simplest overflow arrangement, although this means that the better quality water at the surface will be lost to the outflow. The configurations shown in Figures 24b and 24c are better solutions as the good quality water within the top layer remains in the tank. The arrangement shown in Figure 24c allows for automatic de-sludging of the tank which is recommended for large tanks. The arrangement shown in Figure 24d allows for the separation of floating material that may still enter the tank. It is recommended that the overflow should be located close to the tank roof so as to avoid 'dead storage' (SOPAC, 2004).

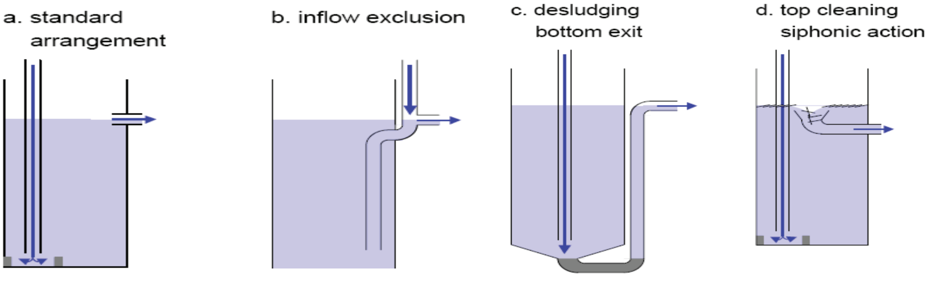


Figure 24 *Design configurations for tank overflows*
Source: South Pacific Applied Geoscience Commission (2004)

2.4.5 Sizing of the storage facility

The size of the storage facility depends on the rainfall regime, the roof material and area, the expected water demand, the cost of construction/installation and the degree of reliability the owner desires. An undersized storage system will not satisfy demands while an oversized one might never be fully utilized. As a rule-of-thumb, it is advised that the system be 'over-designed' to provide at least 20% more than the estimated demand (SOPAC, 2004).

There are several methods that can be used to estimate the size of the storage tank. The SOPAC RWH Manual (2004) lists several and provides examples on how to apply. In this Handbook we will only provide examples of the (1) dry period demand method, (2) the graphic method (an example from Peters, 2003), (3) the simple method and (4) the simple tabular method. An example of the simple tabular method is provided in Annex 1.

Dry period demand method

In this approach, one simply estimates the longest average time period without any rainfall for your particular geographic area. This will typically coincide with the dry season which in the Caribbean islands, generally runs from January to May. Your local meteorological office can be consulted to obtain such estimates. Hence, if your household daily demand in 100 litres (22 gallons) and the dry season runs on average for 120 days, then the size of your storage should be 12,000 litres (2,640 gallons).

Graphical Method
Using the graphical method, one only needs to know the number of persons in the household and the approximate roof area. The graph in Figure 25 can be used to determine the recommended size of the storage. It was developed specifically for Carriacou in the Grenadines but the method can be utilized in other Caribbean islands with a similar rainfall regime. The graph in this example, shows a plot (dashed line) for tank size selection for a roof area of approximately 225 m^2 and a household size of 6 persons. The plot suggests that a 3,000 gallon (13,638 litre) storage tank is recommended.

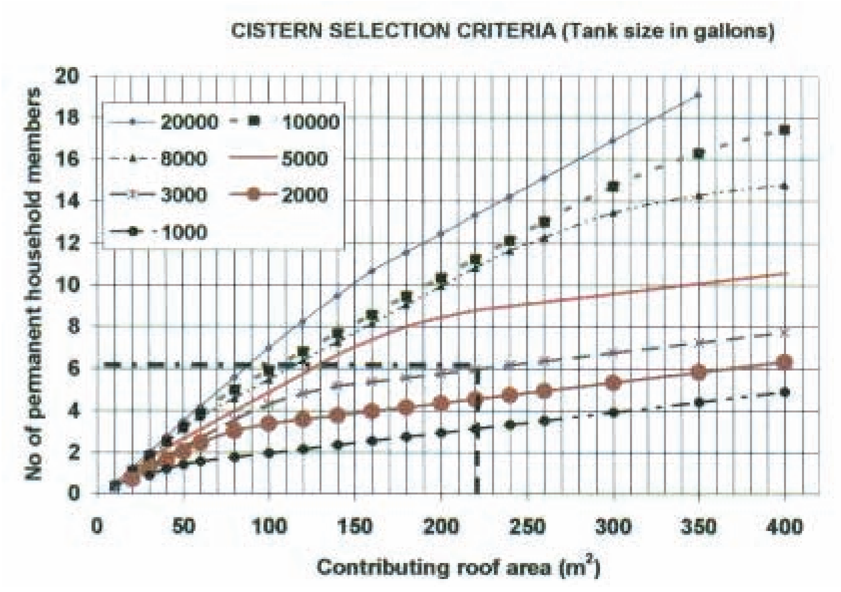


***Figure 25** Graphical guide to tank size selection* (Source: Peters 2003 (http://www.uwichill.edu.bb/bnccde/svg/conference/papers/peters.html)

Simple method
In this method, the average annual water consumption is estimated for the household, based on the number of occupants. The average duration of the longest rainless period is also assumed in terms of number of days. This rainless duration period is in turn expressed as a ratio (of the duration of a year) and multiplied by the annual consumption to estimate the volume of water that will be required for this period. Technical Box 3 illustrates the computation.

TECHNICAL BOX 3
How to estimate the cistern/tank size you need
The Simple Method
(source: School of Engineering, University of Warwick, Development Technology Unit, 2008 http://www2.warwick.ac.uk/fac/sci/eng/research/dtu/rwh/sizing/)

This is based on the consumption rates of the inhabitants of a building without taking the rainfall amount or roof size into consideration. This method is applicable in cases where sufficient rainfall and catchment area are available. It is a rough guide to estimate your tank size.

A worked example:

Consumption per person per day, C = 40 litres (9 gallons)
Number of people per household, n = 5
Longest average dry period = 25 days

Annual consumption (litres) = C x n x 365
Annual consumption 40 x 5 x 365 = 73,000 litres (16, 058 gallons)
Storage requirement, T = 73,000 x 25 / 365 = 5,000 litres (1,100 gallons)

Simple tabular method
This method is used in the estimation of tank size based on rainfall variability and demand over the course of a year. The process comprises of four key steps.

1. Obtain monthly rainfall data for a year that was particularly dry or the rainfall erratic. This data may be obtained from your local meteorological office.
2. Estimate the volume captured off the roof based on the area of the roof and the runoff coefficient.
3. Estimate the monthly demand on the basis of the number of persons using the supply, the individual daily consumption and the average number of days in a month.
4. Use the monthly volume capture and demand estimates to calculate the minimum storage required. This information is assembled in a tabular format that tracks the changes in the cumulative volume captured and stored, the cumulative demand and the total amount that is stored in any given month. The difference between the highest volume stored and the amount left in the tank at the end of the year represents the minimum storage volume.

A worked example is provided in Annex 1.

2.4.6 Pressurized water supply systems

The fact that the storage facility has to be placed below the level of the catchment surface (in the case of households, the roof) pumping will be required to lift the water from storage and maintain pressure in the water distribution network if the water is to be used for internal plumbing. Pumps are usually readily available at hardware suppliers and the size selected can range depending on the number of taps or outlets to be serviced through the building or facility. In general for average homes with two bathrooms a ½ horse power (hp) pump with a 10 to 15 gallon pressurized storage tank and ½ inch pipes throughout the structure will suffice. A pressure switch that will maintain the pressure between about 20 pounds per square inch (psi) and 40 psi should be installed. Buildings with high water demands should increase the size of pumps, tanks and pipes as necessary. For buildings with multiple residential units, separate pressurized systems are recommended for each for ease of management and redundancy purposes. It is advised that you seek advice from a plumber or water engineer to determine the best-suited pump size for your needs.

There are generally two ways to pressurise a water supply system; either through (1) pump pressure only or (2) creation of a pressure head.

Pressurized system
A stand-alone pressurised system is composed of a pump, a pressure tank (Figure 26), a pressure switch and a check valve. The system draws water from the rainwater harvesting tank and stores it in a pressure tank until needed. A one-way valve (check valve) between the water tank and the pump prevents the water from returning to the tank. It also ensures a closed system up to the taps. Upon opening a tap, water will flow freely because of the pressure in the tank. The pressure will drop immediately, causing the pressure-switch to turn the pump on when the lower pressure limit is reached, so as to ensure a continued flow of water. After closing the tap, the pressure in the tank will build up very quickly, causing the pressure switch to turn off the pump when the upper pressure limit is reached. It must be noted that upon opening two

***Figure 26** Pressure tank (left) and pump*

or more taps, the water pressure will drop as the pressure and flow of the pump are limited.

Head pressure system

Another option to create pressure in a water supply system is to pump the water from the rainwater tank into another storage tank elevated 2 to 3 meters above-ground thereby creating a "natural head" for the water supply system that allows water flow by gravity. With this system, sufficiently large piping is necessary to reduce pressure loss in the supply system. In this case a pressure tank is not required, as the "potential energy" required to drive the system will be stored through the elevated storage tank.

Figure 27: *Typical header tank arrangement.*

The power of the pump system does not need to be large as it just pumps the water from the main storage to the elevated storage tank. The pump needs to be switched off when the elevated tank is full to avoid spillage. It also needs to be switched off when the lower tank is empty, to avoid it running dry and being destroyed. The second tank adds to the total storage volume of the system, so both tanks can be half the size of what would otherwise be required in the pressurized system. An advantage of this system is ability to maintain pressure at two or more opened taps. A disadvantage however is the requirement for a large second tank as well as, in some cases, the need to build a (hurricane-proof) structure for it.

Integrating renewable energy sources to power RWH systems

With the increasing costs of fossil fuels, use of renewable energy sources to power the pumping requirements to move water from the storage system through to the point where the water is eventually needed is an attractive option. This is a particularly useful consideration for RWH systems supplying water to facilities in remote locations.

Power to drive pumping systems include photo-voltaic (PV) systems using solar panels or by small wind turbines. These renewable energy options require battery storage to meet the power requirements during periods when there are no direct energy sources available such as during overcast conditions, at night, or when there is no wind. It must be noted that battery storage adds to the cost of operation and maintenance of renewable energy solutions. To avoid the need for expensive batteries, water is commonly pumped to a tank at a high elevation at times when the renewable energy resource is available. Through gravity the water can then be supplied to the place of consumption.

Figure 28: *Solar powered irrigation (from surface RWH catchment)*

PV arrays need no special maintenance apart from a regular cleaning of the panel's glass surface. Wind turbines require yearly maintenance on all moving parts. If batteries are used, the acid level in the batteries needs to be checked regularly. An advantage of PV over wind is that it is easier to install, however site specifics such as solar insulation (sunshine) and average wind speed are more important factors. Costs for these energy supply systems can range from US$1,000 to 2,000 depending on the volume and flow required. As a rule of thumb, renewable energy systems with a flow of less than 1 m^3 per day are more cost-effective over their lifetime if powered by solar or wind energy instead of fossil fuels. The cost effectiveness of solar or wind systems will depend on available monthly and yearly wind speed and insulation. Cost effectiveness will also depend on the fluctuations in wind and sunshine versus fluctuations in water demand. It is recommended that specialists in renewable energy in your country be consulted if you are interested in pursuing this option.

2.5 Post-storage filtration

Special filter systems can also be added to the RWH system improve removal of finer particulate matter (including microbes) that will not be addressed by the screens. These filter systems are typically installed after the storage before the extraction point for use. Low-tech custom-built filter systems using layered gravel, sand and charcoal can provide good filtration capacity but their application is limited by the challenges in sourcing the filter media and the fact that off-the-shelf filter systems and water purifying devices are easily available. There is a very wide range of such solutions on the market and they vary in level of sophistication and cost. Figure 29 shows an example of a filtration system using combination charcoal and cotton filters installed in parallel before end-of-pipe use. It must be noted that filters with clear housings must be placed in a light-excluding cabinet as algae will eventually grow within the housing, reducing the effectiveness of the filter and degrading the quality of the water.

***Figure 29:** Off-the-shelf water filters*

Without proper maintenance, the water quality through the filters will deteriorate, due to bacterial growth and accumulation of particulate matter within the layers. In fact the water quality with a poorly maintained filter can be worse than if there was no filter at all. In the case of the custom-built mixed-media filter systems and off-the-shelf systems, the filter media need to be replaced when showing signs of heavy fouling. The rate of replacement will depend on the cleanliness of the incoming water.

3. Maintenance and vector control

Rainwater is nearly pure water with zero hardness and, therefore excellent for drinking, laundry or irrigation. However contamination is invariably a possibility when the water comes into contact with the catchment surfaces, the conveyance and storage components. Of concern is microbiological contamination (bacteria, viruses, and protozoa) originating from faecal deposits from birds, rodents, bats and other animals on the catchment surface. Dirt, soot and other deposits on the catchment surface, in the gutters or in the tank will also degrade water quality. Residents in close proximity to industrial zones and solid waste facilities will need to be mindful of potential contamination from airborne particulate matter (from burning and industrial emissions) that may settle on the catchment surfaces. The use of screens, filters, first-flush and water extraction measures (from the tank) will serve to reduce the entry of harmful materials into your RWH system.

Although aspects of vector control and maintenance tips for your RWH system were introduced in previous sections, the subject will be discussed in greater detail here.

3.1 Contamination sources

3.1.1 Contamination from the atmosphere

Rainwater is generally a very pure form of water. However, pollutants in the air can be absorbed by raindrops, a problem in highly industrialized and/or urbanized areas that are characterized by high pollution emissions. Although this tends to be less of an issue in the Caribbean as compared to more developed regions of the world, there are many communities within heavily urbanized and industrial areas where elevated airborne pollutant levels from vehicle operation, industrial and waste disposal operations to name a few, impact the ambient air quality and in turn, the rainwater itself. An emerging concern in the Caribbean is the risk of pollutants associated with Saharan dust in the atmosphere that traverses the Atlantic toward the Americas. With increasing aridity in regions of sub-Saharan Africa, driven by climate change, the potential for greater influxes of dust may be increasing and perhaps warrants consideration in rainwater harvesting.

3.1.2 Contamination during rainwater capture

Catchment contamination can be chemical or biological. Chemical contamination may occur if the catchment is manufactured from, and/or coated with materials that may leach or dissolve into water flowing across the catchment surface. A common concern relates to the use of roofing sheets coated with toxic paints (containing lead and other compounds). Although the manufacture of paints using lead-based pigments was banned several years ago, many older buildings may still have roofs coated with these paints.

Figure 30 *An example of a rat guard along a gutter to a storage tank in the Grenadines*

As noted previously, noxious chemical compounds originating from nearby industrial areas as air-borne emissions may become deposited on catchment surface, posing a contamination hazard.

Biological contamination is often associated with either the transmission of harmful pathogens directly from faecal deposits on the catchment surface by birds, bats, rodents, lizards, etc., or from contact by these animals with human faecal matter and subsequent transmission of associated pathogens on to the catchment surfaces. In general, since most faecal pollution from man and animals occurs at or below ground level, water collected from raised roof catchments is likely to be of better bacteriological quality than that collected from ground-level catchments.

3.1.3 Contamination during storage

It is important to prevent mosquitoes from breeding inside the storage tank, so as to reduce the likelihood of diseases spread by these vectors such as dengue and malaria. In addition, other animals need to be excluded from access to the water storage such as vermin (rodents, other insects), frogs and toads, as they too can transmit potentially harmful pathogens. Once storage tanks are fitted with properly fitting lids, all openings are screened, and water extracted using a tap or pump, the likelihood of contamination can be reasonably reduced. With control on the introduction of new contamination (through use of screens and first-flush diverters), any bacteria and other pathogens that are in the tank will eventually die-off, resulting in improvement of the stored water over time.

Additional risks exist in the case of below-ground storage facilities located in areas that may be prone to flooding. Should polluted flood waters, particularly when contaminated with human septage, inundate underground storage, this will render the water unusable and will need to be drained and the tank disinfected. Precautionary structures to exclude flood waters from contaminating ground storage tanks should be installed in high flood-risk zones.

3.1.4 Contamination during maintenance (mainly for masonry cisterns)

When performing maintenance tasks such as de-silting, tank cleaning, cleaning screens, catchment surfaces and sediment traps, it is possible to inadvertently introduce these accumulated residues into the system, contaminating it in the process. In cleaning out cisterns, there is a possibility of introducing noxious substances and faecal matter that may be carried on the soles of ones feet or on footwear if not careful. Washing feet or footwear with soap is strongly recommended before entering the cistern.

The water tank should be cleaned once a year. The following is required:

- Liquid chlorine/bleach such as Sodium Hypochlorite 3%, 4%, 5%, or 5.5% by weight (these are most common on the market) or chlorine tablets such as Calcium hypochlorite and trichloro-s-triazinetrione (40%, 70%, up to 90% active chlorine). If household bleach is used, it should be the un-scented and un-coloured type.
- Bucket
- Scrub-brush
- Eye and hand protection (glasses, rubber gloves)
- A helper to monitor the person inside the tank (guard against accidents)

Cleaning procedure:

- Drain any water in the tank to the level at the tap. If this is being done during the dry season to avoid loss, transfer water to a clean, contaminant-free storage or temporary vessel. If tanks are cleaned during the rainy season, any lost water will soon be replaced. For two-chambered cisterns, there is the advantage of cleaning one chamber at a time.

- Once inside the tank use the scrub brush to thoroughly scrub the bottom and sides of the tank. Make sure that ventilation is adequate and that the helper is watching should any emergency arise.
- Remove the water and bleach solution remaining below the tap with the bucket.
- Refill the tank with water.
- Leave the water to settle overnight before use.
- Disinfect as outlined in Section 4 to ensure that any contamination from entry into the tank is minimized.

3.2 Summary: Protecting collected rainwater from contamination

Good system design and proper operation and maintenance will reduce the possibility of contamination of the water supply. The following are summary best-practice guidelines in maintaining water quality:

- Use an appropriate roofing material and ensure that it is kept clear of dirt and soot. When this material accumulates, it promotes the growth of moss, lichen or other vegetation. Use a clean brush to sweep roofs and gutters especially before the start of the rainy season and at other times as necessary;

- Replace rusted roofing as needed. Fix any holes to realize maximum runoff. If minor rusting is present, paint using lead-free paint;

- Remove branches from overhanging trees to prevent leaf debris from falling on and accumulating on the catchment area. Branches also provide roosting for birds (with the increased opportunity for defecation), and access to the roof by rodents and other animals;

- Keep gutters clear. If the gutters sag or leak, they need to be repaired. Sagging gutter systems will retain water, providing breeding sites for mosquitoes. Leaking gutters will also cause valuable water to be wasted. Ensure guttering is slanted toward the down-pipes to ensure steady flow;

- Install a coarse filter and/or first-flush device to prevent dirt and debris entering the tank. Inspect and clean/drain these devices periodically;

Figure 31 *An example of a poorly-maintained gutter*

- Cover all openings to tanks with mosquito mesh to prevent insects, frogs, toads, snakes, small mammals or birds entering the tank. You must inspect and clean the mesh periodically;

- Install taps or draw-off pipes above the tank floor to avoid entraining any settled material into the water flow that is to be used;

- If the tank is exposed to sunlight, make sure that it is covered or made of opaque materials or painted with opaque paint. This will exclude light and prevent the growth of algae and micro-organisms;

- Clean and disinfect the tank annually (See Section 4). A tank floor sloping towards a sump and washout pipe can greatly aid tank cleaning;

- Tree roots can intrude underground masonry including water tanks causing them to leak. Trees in close proximity to the water tanks should be pruned or cut to restrict advancement of encroaching tree roots;

- If mosquito breeding is observed in the tank (larvae present), it is best to seek advice from your environmental health department for assistance on control measures.

- In the event when the water is contaminated by a dead animal, the tank should be drained immediately, cleaned, and disinfected with chlorine;

- Monitor tanks for leaks and repair as needed;

- Hygienically store and dispense water within the household. Usually water collected from the storage tank is stored for short periods in small containers in the home. To protect the quality of this water:
  - Place storage containers out of reach of small children and animals
  - Keep containers covered or sealed.
  - Ensure containers are clean
  - Draw water from containers in a hygienic manner.

4. Managing water quality

In general, when the system is in a good shape, and adequately protected from contamination, it is not necessary to disinfect rainwater. Where rainwater harvesting systems are not well constructed or maintained, disinfection is required to safeguard human health. In cases where the water has a bad odour or colour, the tank should be emptied and disinfected. Disinfecting the water before consumption is also recommended for persons with weakened or compromised immune systems, such as the ill, the very young or very old, and recovering patients. Boiling and chlorination are common means of disinfection. Disinfection by ultraviolet (UV) light exposure is very effective as well but requires an energy supply. A UV lamp is relatively expensive, ranging in cost from US$300 to over US$1,000. Figure 32 shows a typical ultra-violet lamp on a RWH installation.

Figure 32 *A typical ultra-violet lamp on a RWH installation (before entry to building)*

4.1 Disinfection by boiling

Boiling is the best way to kill potentially harmful agents without the use of chemical additives. It is recommended to boil the water for 3 minutes at 100°C.

4.2 Disinfection by chlorinating

Adding small quantities of chlorine to the water tank is the cheapest and most effective means of disinfection. Chlorine is an effective agent against most bacteria and viruses and provides residual protection. However, some bacteria can survive chlorination by forming resistant colonies that settle on the tank wall hence the necessity to clean the tank on an annual basis.

You should disinfect your water if one or more of the following situations occur:

- A known bacterial risk has been identified through water testing;
- Individuals are getting sick (sore stomachs; diarrhoea) as a result of drinking the water;
- An animal or faecal material has entered a tank;
- Inability to completely empty the tank for cleaning.

Instructions for disinfecting a rainwater storage tank using household bleach are detailed below. Be sure to read and follow safety and handling instructions printed on chlorine or bleach containers. Proper hand and eye protection should be worn when handling or preparing chlorine solutions to avoid burning skin and damaging eyes.

4.2.1 Chlorine disinfection procedure

1. Calculate the volume of water in your tank.
2. Add ½ bottle (125 ml) of plain household-grade unscented and uncoloured bleach (with 4% active chlorine) to every 1,000 litres (220 gallons) of water currently in your tank. Different bleaches have different levels of active ingredient, which is usually marked on the container.
3. Wait 24 hours after putting in the chlorine to allow enough time to disinfect the water before you drink it. Any chlorine smell and taste in the water will go away after a short time. If you find the taste of chlorine unacceptable, an alternative is to boil the water for at least 5 minutes before drinking it. The amount of bleach to add, based on a 4% active ingredient, is given in Table 4 below relative to the amount of water in the tank.

Table 4 Chlorine disinfection mixing ratios for stored water

Adapted from SOPAC (2004)

Volume of water in tank		Approximate amount of bleach (with 4% active ingredient) (cups)
Imp. gallons	Litres	
200	909	½
400	1,818	1
800	3,637	2
1,000	4,546	2½
2,500	11,365	5½
5,000	22,730	11½
10,000	45,461	22½
20,000	90,922	45½

Depending on the percentage of active ingredient, the amount to be added will need to be adjusted accordingly. For example, using bleach with 8% active ingredient would halve the amount of bleach listed in the above tables for a particular water volume (based on use of 4% active ingredient). The recommended bleach dosing seeks to ensure that enough chlorine be added to provide a free chlorine residual of approximately 0.5 parts per million (0.5 mg/l) after 30 minutes. As a general guide, an initial dose of 5 parts per million (5 mg/l) of chlorine will provide this residual. If desired, the chlorine residual can be tested using a swimming pool test kit or dip strips, which may be locally available at a pool supplies or hardware store.

5. Cost of installation of RWH systems

Rainwater harvesting system costs vary considerably depending on location, type of materials used, and RWH system capacity desired. In the Caribbean the cost of a plastic tank varies between US$0.53/gallon (imp.) to over US$0.74/gallon (imp.), depending on size, quality and manufacturer (2007 prices). Catchment area costs (e.g. rooftops) and the most economical solution for a RWH system will depend on layout, topography, and elevation of the catchment areas with respect to the area allocated for cisterns or storage tanks. The cost for the conveyance system (guttering and down-pipes) and the first-flush system will vary, based on the configuration or physical layout of the development/household. The most expensive component is always the cistern or storage tank. If incorporating an underground cistern, the cost depends on the size of the cistern, and the volume and difficulty of excavation. For rocky foundations the excavation requirements can inflate installation costs to US$1.11/gallon (imp.) (Daniel and Daniel Engineering Inc., 2006).

Based on experience in Grenada where construction costs are reflective of the majority of the Caribbean islands, the average cost (inclusive of material and labour) for the installation of reinforced concrete tanks approximates US$0.74/gallon (imp.). In addition to material and construction costs, materials transportation must be factored in. The figures cited above, that is the US$0.74 to US$1.11/gallon (imp.) range can generally be used as a guideline in estimating the cost for installation of a RWH system. Budgeting at the upper end of the range should be considered to take into account difficulties that may likely be experienced during construction, including costly transportation of construction materials, elevated labour and equipment costs. Tables 5 and 6 provide indicative cost for installation of RWH systems.

Table 5 Estimated unit costs for standard supplies used in RWH systems in the Caribbean (2008 prices) Source: Daniel and Daniel Engineering

Item	Retail cost US$
6" down-pipe (13 foot long) and guttering	25.20
90° bends for guttering	14.80
32° bend for guttering	11.90
Guttering to down pipe fitting	7.40
90° bend for down pipe	4.40
45° bend for down pipe	4.40
200 gallon plastic tank	166.70
400 gallon plastic tank	185.20
600 gallon plastic tank	351.90
800 gallon plastic tank	463.00
1,000 gallon plastic tank	555.60

Table 6 Typical cost of rainwater system installations
Source: Daniel and Daniel Engineering, Inc, 2006. Based on data collected by Peters (2006) in the Grenadine Islands of Bequia and Union Island, (St. Vincent and the Grenadines) and Carriacou, (Grenada).

No. of permanent household members	Contributing roof/ catchment area (m^2)(sq ft)	Size of cistern required (imp. gallons)	Approx. cost of RWH system using polyethylene tanks as cisterns ($US)	Approx. cost of RWH system using reinforced concrete tanks as cisterns ($US)
1 (Single)	50 (538)	400-500	556	741
2	100 (1,076)	1,000	963	1,148
3	150 (1,614)	1,500	1,185	1,556
4	180 (1,937)	2,000	1,593	1,963
5	200 (2,152)	2,500	1,926	2,482
6	220 (2,367)	3,000	2,296	2,852
7	250 (2,690)	4,000	2,889	3,630
8	280 (3,012)	4,500	3,111	4,037

These costs include an adequate first-flush system and the preparation of a solid level surface for tanks to be installed on compacted rock/hard core, stones or mass/reinforced concrete. It also encompasses screens in overflow pipe but not the optional filtration system.

6. Non-domestic RWH applications

6.1 Municipal applications

Rainwater harvesting can be used in a variety of municipal applications. Direct roof capture off city buildings or capture of excess runoff from paved surfaces can be used to fill cisterns and other storage facilities that can be used for irrigation of green spaces and recreational facilities, washing and cleaning of streets and facilities, or for fire fighting. Such bulk water storage can be used to augment emergency water supplies following natural disasters when the potable supply may be out of operation. In this case filtration and treatment will need to be applied before distribution. Figures 33a and 33b show a few examples.

(A)

(B)

***Figure 33 (A)** Rainwater capture from a municipal facility in Charlotte Amalie, St. Thomas, USVI; **33(B)** Rainwater harvesting for irrigation of Kensington Cricket Oval, St. Michael, Barbados (runoff from field and roof catchments diverted to perimeter sub-surface drain - see inset)* (photos courtesy: Henry Smith and Andrew Hutchinson)

6.2 Agricultural applications

Crop irrigation and livestock watering have heavy water demands. In the Caribbean agricultural production is predominantly rain-fed with the exception of larger commercial farm holdings where water is abstracted from irrigation drains, natural watercourses and wells. Under rain-fed production, crop yields will drop significantly during the dry season unless supplemental irrigation is applied. Livestock production is similarly impacted where water is in short supply. RWH from farm building catchments and constructed surfaces can greatly contribute to meeting water demands during the drier months for sustained production. Figure 34 shows a typical example of using irrigation from harvested rainwater.

***Figure 34** Rainwater harvesting off a greenhouse for irrigation purpose*
(source: Technology Informatics Design Endeavour (TIDE) http://www.tide-india.org/products/06polyhouse.html)

6.3 Commercial and industrial applications

Rainwater harvested off roofs and surface catchments such as roads and parking lots can be stored and used as required to offset the need for use of the potable supply for non-drinking purposes. Typical applications will include washing and cleaning, cooling, fire fighting, bathing pool recharge and irrigation. Where water may be required for food preparation and other manufacturing processes, treatment will need to be applied. Figure 35 shows an example of RWH and storage by a commercial enterprise in Barbados.

Figure 35 *Rainwater harvesting diverted to surface storage at Mount Gay Distilleries, St. Lucy, Barbados; irrigation and firefighting purposes* (photo courtesy: Andrew Hutchinson)

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Annexes

Annex 1: Quick reference calculations

Quick Reference:

Calculating the amount of water you can capture off your roof

Using the *Rational Method* to calculate the volume of rainwater which could be captured

For the amount of water you can capture in one year you will need to estimate the area of your roof, the average annual rainfall at your location and the runoff coefficient for the surface. The mathematical relationship is given as:

Supply (litres per year) = rainfall (mm/year) x area (m^2) x runoff coefficient

(multiply by answer by 0. 22 to convert the value to imperial gallons per year)

Note that if your roof is angled you will need to 'project' the surface to the horizontal to correctly estimate the amount of rain that falls on the roof. For an sloped roof you will need to know the roof angle (**see overleaf**) The roof area is calculated by the following relationship:

Roof surface area (m^2) = roof length (m) x roof width (m) x sine of the angle (in degrees)

The runoff coefficients for various surfaces are given below.

A worked example:

- Mean annual rainfall = 1,500 mm per year
- Roof area = 10 m (length) x 8 m (width) x sine (of 70 degree slope) = 75 m^2
- Roof surface is smooth corrugated metal. This surface is assumed to have a runoff coefficient of 0.8

Supply = 1,500 x 75 x 0.8 = 90,000 litres (19,800 imp. gallons) per year.

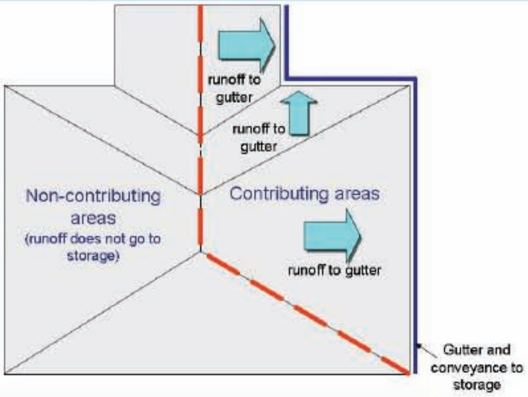
Type of roof surface	Runoff coefficients*
Tiles	0.8 - 0.9
Corrugated metal sheets	0.7 - 0.9
Concrete	0.6 - 0.8

*Source: Alphonsus Daniel, pers. comm. 2008

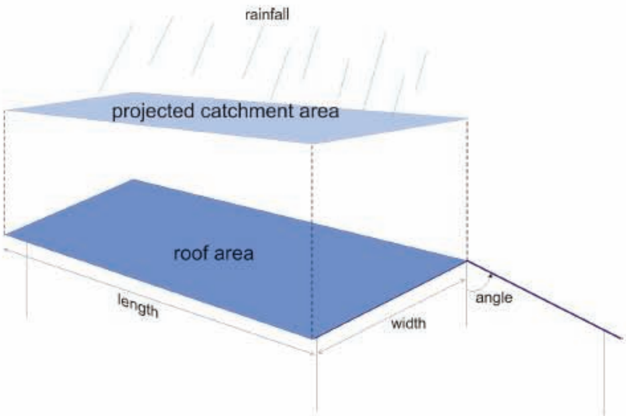
Quick Reference:

Calculating the amount of water you can capture off your roof

Mapping your roof areas – determining the contributing catchments

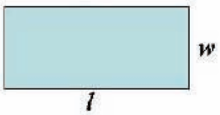


Projecting the sloped roof area to horizontal catchment area



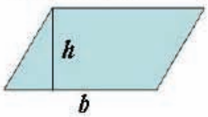
The following are formulas to estimate the areas of roof section shapes

Rectangle



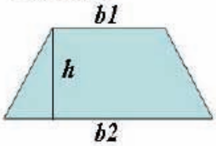
Area = l x w

Parallelogram



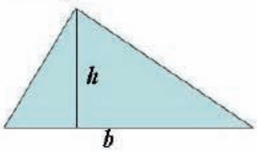
Area = b x h

Trapezoid



$$\text{Area} = \left(\frac{b1 + b2}{2}\right) \text{x h}$$

Triangle



Area = ½ b x h

Projecting the sloped roof area to horizontal catchment area – Sine of the roof angle; multiply by roof dimensions

Sine of roof angles from 1 to 90 degrees

Angle (degrees)	Sine (angle)	Angle (degrees)	Sine (angle)	Angle (degrees)	Sine (angle)	Angle (degrees)	Sine (angle)	Angle (degrees)	Sine (angle)
1	0.0175	21	0.3584	41	0.6561	61	0.8746	81	0.9877
2	0.0349	22	0.3746	42	0.6691	62	0.8829	82	0.9903
3	0.0523	23	0.3907	43	0.6820	63	0.8910	83	0.9925
4	0.0698	24	0.4067	44	0.6947	64	0.8988	84	0.9945
5	0.0872	25	0.4226	45	0.7071	65	0.9063	85	0.9962
6	0.1045	26	0.4384	46	0.7193	66	0.9135	86	0.9976
7	0.1219	27	0.4540	47	0.7314	67	0.9205	87	0.9986
8	0.1392	28	0.4695	48	0.7431	68	0.9272	88	0.9994
9	0.1564	29	0.4848	49	0.7547	69	0.9336	89	0.9998
10	0.1736	**30**	0.5000	**50**	0.7660	**70**	0.9397	**90**	1.0000
11	0.1908	31	0.5150	51	0.7771	71	0.9455		
12	0.2079	32	0.5299	52	0.7880	72	0.9511		
13	0.2250	33	0.5446	53	0.7986	73	0.9563		
14	0.2419	34	0.5592	54	0.8090	74	0.9613		
15	0.2588	35	0.5736	55	0.8192	75	0.9659		
16	0.2756	36	0.5878	56	0.8290	76	0.9703		
17	0.2924	37	0.6018	57	0.8387	77	0.9744		
18	0.3090	38	0.6157	58	0.8480	78	0.9781		
19	0.3256	39	0.6293	59	0.8572	79	0.9816		
20	0.3420	**40**	0.6428	**60**	0.8660	**80**	0.9848		

Quick Reference:
Estimating Storage Requirements

Method 1. Dry period demand

In this approach one simply estimates the longest average time period without any rainfall for your particular geographic area. This will typically coincide with the dry season which in the Caribbean islands, generally runs from January to May. Your local meteorological office can be consulted to get such estimates. Hence, if your household daily demand in 100 litres (22 gallons) and the dry season runs on average for 120 days, then the size of your storage should be 12,000 litres (2,640 gallons).

Method 2. Simple method

In this method, the average annual water consumption is estimated for the household, based on the number of occupants. The average duration of the longest rainless period is also assumed in terms of number of days. This rainless duration period is in turn expressed as a ratio (of the duration of a year) and multiplied by the annual consumption to estimate the volume of water that will be required for this period.

A worked example:

- Consumption per person per day, C = 40 litres (9 gallons)
- Number of people per household, n = 5
- Longest average dry period = 25 days
- Annual consumption (litres) = C x n x 365

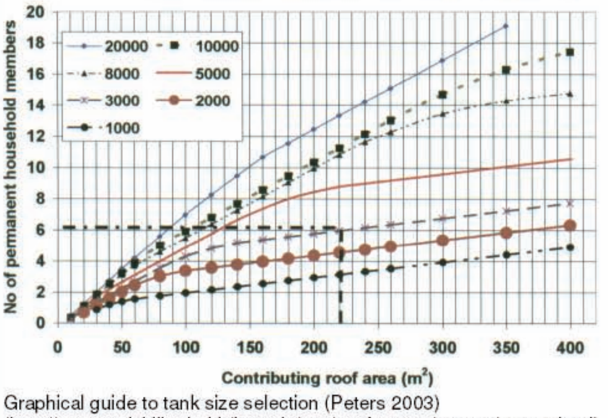
Annual consumption 40 x 5 x 365 = 73,000 litres (16,060 gallons)

Storage requirement, T = 73,000 x 25 / 365 = 5,000 litres (1,100 gallons)

(**source:** School of Engineering, University of Warwick, Development Technology Unit, 2008 http://www2.warwick.ac.uk/fac/sci/eng/research/dtu/rwh/sizing/)

Method 3. Graphical Method

Using the graphical method, one only needs to know the number of persons in the household and the approximately roof area. The graph in below can be used to determine the recommended size of the storage. The graph shows a plot (dashed line) for tank size selection for a roof area of approximately 225 m^2 and a household size of 6 persons. The plot suggests that a 3,000 gallon (13,638 litre) storage tank is recommended.



Graphical guide to tank size selection (Peters 2003)
(http://www.uwichill.edu.bb/bnccde/svg/conference/papers/peters.html)

Quick Reference:

Estimating Storage Requirements: Method 4 - Simple Tabular Method

STEP 1: Obtain rainfall data for your area. This may be obtained from your local meteorological office. It is recommended that you use data from a notably dry year so as to better ensure considerations are made for prolonged dry spells (SOPAC RWH Manual 2004). It is also noted that average values should not be used (however in this case we will use average rainfall data from Union Island in St. Vincent and the Grenadines solely for illustration. Data source: Peters, 2003)

STEP 2: Estimate the potential volume of water that can be harvested from your roof. Assume the following:
Roof area: 80 m²
Runoff coefficient: 0.9 (for a metal sheet roof)
Volume captured (litres) = rainfall (mm) x roof area (m³) x runoff coefficient)
Volume captured in January (litres) =
66 mm x 80 m2 x 0.9 = 4,752 litres (1,045 gallons)

STEP 3: Estimate monthly demand.
Assume the following:
Number of persons in the household: 5 persons
Average water consumption per day: 40 litres (9 gallons)
Average number of days in the month: 30.4 days
The total monthly demand (litres) = No. persons x daily water consumption x no. days per month
Total monthly demand (litres) = 5 x 40 x 30.5 = 6,080 litres (1,337 gallons)

Rainfall data & capture

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall (mm)	66	46	36	40	63	105	130	148	122	154	165	104	1179
Vol capture (litres)	4,752	3,312	2,592	2,880	4,536	7,560	9,360	10,656	8,784	11,088	11,880	7,488	84,888

A	B	C	D	E	F	G
Month	Volume captured in month	Cumulative volume captured	Volume demanded in month	Cumulative demand	Total amount stored *(column C minus column E)*	Deficit/surplus for month *(column B minus column D)*
April	2,880	2,880	6,080	6,080	-3,200	-3,200
May	4,536	7,416	6,080	12,160	-4,744*	-1,544
June	7,560	14,976	6,080	18,240	-3,264	1,480
July	9,360	24,336	6,080	24,320	16	3,280
August	10,656	34,992	6,080	30,400	4,592	4,576
September	8,784	43,776	6,080	36,480	7,296	2,704
October	11,088	54,864	6,080	42,560	12,304	5,008
November	11,880	66,744	6,080	48,640	18,104	5,800
December	7,488	74,232	6,080	54,720	19,512*	1,408
January	4,752	78,984	6,080	60,800	18,184	-1,328
February	3,312	82,296	6,080	66,880	15,416	-2,768
March	2,592	84,888	6,080	72,960	11,928	-3,488
	84,888					11,928

NOTE: If when constructing the table (as was the case in this example), column F contains some negative values, then it means the correct month was not chosen to begin the calculations. The minimum storage volume can still be found by finding the largest negative number, changing it to a positive figure and adding it to the largest positive number in column F (SOPAC Manual, 2004). In this case the figures in column F denoted by asterisks were changed from -4,744 to 4,744 and from 19,512 to 24,256 respectively.

STEP 4: Use the volume capture and demand estimates to calculate the minimum storage needed (steps above). This calculation is best assembled using a spreadsheet. The data is contained in the table to the left.

The minimum storage required is the maximum value in column F minus the surplus water left at the end of the year. The surplus water in the tank is the final value in column F.
Minimum storage tank volume = 24,256 – 11,928 = 12,328 litres (2,712 gallons)

Annex 2: Planning guide for water use

Type of Establishment	Unit	Water used (litres/day)
Airport	Per passenger	11-19
Apartment (multiple family)	Per resident	227
Bathhouse	Per bather	38
Camp	Construction semi permanent (per worker)	189
	Day no meals served (per camper)	57
	Luxury (per camper)	379-568
	Resort day and night, limited plumbing per camper	189
	Tourist central bath and toilet facilities (per person)	132
	Cottage, seasonal occupancy (per resident)	189
	Court, tourist, individual bath units (per person)	95
Club	Country (per resident member)	379
	Country (per non resident member)	95
Dwelling	Boarding house (per boarder)	189
	Additional kitchen requirements for nonresident boarders	38
	Luxury (per person)	379-568
	Multi-family apartment (per resident)	151
	Rooming guesthouse (per resident)	227
	Single family (per resident)	189-284
Estate	Per resident	379-568
Factory	Gallons per person per shift	57-132
Highway rest area	Per person	19
Hotel	Private bath (2 persons per room)	227
	No private baths	189
Institution other than hospital	Per person	284-473
Hospital	Per bed	946-1514
Laundry	Self serviced (gallons per washing per customer)	189
Livestock Per animal	Cattle (drinking)	45
	Dairy (drinking and servicing)	132
	Goat (drinking)	8
	Hog (drinking)	45
	Horse (drinking)	45
	Mule (drinking)	45
	Sheep (drinking)	8
Motel	Bath, toilet and kitchen facilities (per bed space)	189
	Bed and toilet per (per bed space)	151
Park	Overnight, flush toilets (per camper)	95
	Trailer individual bath units no sewer connection (per trailer)	95
	Trailer, individual baths, connected to sewer (per person)	189
Picnic	Bathhouses, showers and flush toilets (per picnicker)	76
	Toilet facilities only (per picnicker)	38
Poultry	Chickens (per 100)	19-38
	Turkeys (per 100)	38-68
Restaurant	Toilet facilities (per patron)	9-11
	Bar and cocktail lounge (additional quantity per patron)	8
School	Boarding (per pupil)	284-379
	Day, cafeteria, gymnasiums and showers (per pupil)	95
	Day cafeteria, no gymnasiums or showers (per pupil)	76
	Day no cafeteria, gymnasiums or showers (per pupil)	57
Service station	per vehicle	38
Store	per toilet room	1514
Swimming pool	per swimmer	38
Theatre	Drive in (per car space)	19
	Movies (per auditorium seat)	19
Worker	Construction (per person per shift)	189
	Day (school or offices per person per shift)	57

Annex 3: Useful websites

Chennai Metro Water – Rainwater Harvesting
http://www.chennaimetrowater.com/rainwatermain.htm

eToolkit on Rainwater Harvesting http://www.rainwater-toolkit.net/index.php?id=75

International Rainwater Catchment Systems Association (IRCSA)
http://www.eng.warwick.ac.uk/ircsa/

Rainwater Harvesting http://www.rainharvesting.com.au/rain_water_harvesting.asp

Rainwaterharvesting.org http://www.rainwaterharvesting.org/

SearNet – Southern and East Africa Rainwater Network
http://www.searnet.org/searnetfinal/home.asp

Technology Informatics Design Endeavour (TIDE) http://www.tide-india.org/products/06polyhouse.html (example of RWH for agricultural greenhouse)

The Web of Rain - Online resources on rainwater harvesting
http://www.gdrc.org/uem/water/rainwater/rain-web.html

YouTube videos on rainwater harvesting
http://www.youtube.com/results?search_type=&search_query=rainwater+harvesting

United Nations Environment Programme
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UNEP

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CEHI
CARICOM