SOPAC

WATER QUALITY OF RAINWATER HARVESTING SYSTEMS

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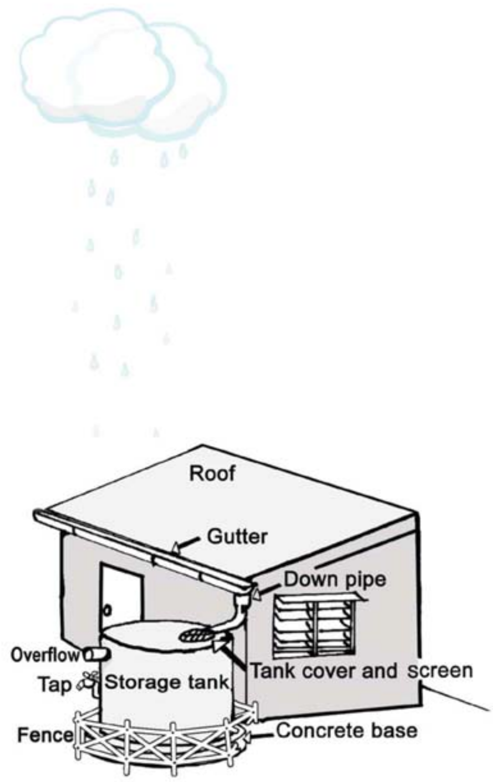

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INTRODUCTION

Good drinking water quality is essential to the health and well-being of all people. Acceptable water quality occurs when:

1. There are no bacteria of faecal origin present that may cause human diarrhoea and other life-threatening diseases (e.g. typhoid fever).
2. There is no levels of chemicals (e.g. heavy metals) or chemical substances that would cause harm to human health
3. Water does not have a bad taste or smell.

To protect human health, water sources must be protected from contamination and the piping system to the consumer must be maintained in good condition (no breaks or leaks). In most municipal water supply systems, water is taken from sources such as boreholes, rivers and lakes. These sources are relatively easily contaminated if human waste from sanitation systems (e.g. septic tanks, pit latrines), or animal waste, is discharged onto the land nearby to the water source. This necessitates water treatment such as filtration and chlorination in order to provide safe drinking water.

Rainwater collection systems are commonly believed to provide safe drinking water without treatment because the collection surfaces (roofs) are isolated from many of the usual sources of contamination (e.g. sanitation systems). In almost all Pacific Island countries properly collected and stored rainwater is likely to be superior to untreated surface and borewater supplies but this may not always be the case. Although roofs are higher than the ground, dust and other debris can be blown onto them, leaves can fall from trees, and birds and climbing animals can defecate upon them. The quality of drinking water can be much improved if this debris is not allowed to enter the storage tank. The purpose of this report is to outline best-practice techniques for rainwater collection systems in order to produce good water quality.

Information is provided on the following subjects:

1. Types of contaminants in rainwater systems
2. Appropriate rain collection surfaces
3. Appropriate storage vessels
4. Filtration screens
5. First-flush devices
6. Tank Maintenance
7. Water Quality Testing

TYPES OF CONTAMINANTS IN RAINWATER TANK SYSTEMS

The types of contaminants commonly found in rainwater collection systems are listed below:

Contaminant	**Source**	**Risk of entering Rain Tank**
Dust and Ash	Surrounding dirt and vegetation Volcanic activity	*Moderate*: Can be minimized by regular roof and gutter maintenance and use of a first-flush device.
Pathogenic Bacteria	Bird and other animal droppings on roof, attached to dust	*Moderate*: Bacteria may be attached to dust or in animal droppings falling on the roof. Can be minimized by use of a first-flush device and good roof and tank maintenance.
Heavy metals	Dust, particularly in urban and industiralised areas, roof materials	*Low*: Unless downwind of industrial activity such as a metal smelter and/or rainfall is very acidic (this may occur in volcanic islands)
Other Inorganic Contaminants (e.g. salt from seaspray)	Seaspray, certain industrial discharges to air, use of unsuitable tank and/or roof materials	*Low*: Unless very close to the ocean or downwind of large-scale industrial activity
Mosquito Larvae	Mosquitos laying eggs in guttering and/or tank	*Moderate*: If tank inlet is screened and there are no gaps, risks can be minimized.

APPROPRIATE RAIN COLLECTION SURFACES

Roofs and guttering should be maintained in good and clean (free of debris) condition in order to reduce contamination entering the storage tank. Contamination of water might arise from the roofing material itself or from substances (e.g. dust, bird droppings) that have blown or fallen onto a roof or into a gutter.

Roofs

Roofs are made of a variety of materials and most, with the exception of those made from grass/reed and potentially toxic materials, are suitable as rainwater catchment surfaces. The typical roofing materials are metal sheets, ceramic tiles, rock slate and Ferro cement. Probably the most common form of roofing in the Pacific Islands is corrugated galvanized steel sheets. Galvanising protects the steel from corroding by coating with zinc compounds. Metal sheet roofs are comparatively smooth and are less likely to retain contamination (e.g. dust, leaves, bird-droppings) than rougher concrete tile roofs. They may also get hot enough in the tropical Pacific islands to sterilise themselves.

Metals such as zinc, copper and lead, can be present at quite high levels in rainwater that has come into contact with metallic roofs (e.g. galvanized iron for zinc) or fittings (lead and copper flashings) (Gould 1993; Thomas and Greene 1993). Fortunately zinc has a low toxicity to humans, so that run-off water from the common galvanized steel roofs should not exceed WHO-permitted zinc levels (Gould 1993; WHO 1996 see Appendix 1). Lead materials are sometimes still used at roofing joints and this may result in hazardous levels of lead in water collected (Yaziz 1989). Therefore lead fittings are *not recommended*. The collection of water from metallic roofs in islands where acidic rain is present should be cautioned as more corrosion and leaching of metals from roofs will occur under these conditions. Metal roofs that are visibly corroded should preferably be repaired or replaced. However, the iron in rain runoff from a rusting roof is unlikely to cause any health problems although it may be unsightly.

Roofing material is often supplied with a paint coating or sometimes painting is performed on site. Certain types of paints may leach toxic compounds so they should be checked for suitability before a roof is painted. New acrylic-based paints designed for exterior and roof use in the tropics are recommended, and their suitability for drinking water collection should be queried. Paints containing lead, chromate, tar/bitumen, fungicides or other toxins should not be used as they may create a risk to health and/or may impart an unpleasant taste to the water. After repainting of a roof, the runoff water from the first rainfall should be prevented from entering the storage tank and discarded or used for non-drinking purposes.

The safety of water harvested from ‘asbestos’ (asbestos-reinforced cement mortar) roofs has been queried, but the consensus is that the danger of developing cancer from ingested asbestos is very slight (Campbell 1993). The danger from inhaled asbestos dust is however sufficiently high that working with asbestos sheeting, for example sawing it, without special protection is now generally banned.

It is recommended that any tree branches overhanging the roof are trimmed to minimize the amount of leaves and bird droppings falling onto the roof. Rodents and mongooses should not be able to get onto the roof as they may introduce pathogenic bacteria to the water. Leaves and other debris should be cleaned off roofs and out of gutters at least once a month. The more you do to keep a roof clean, the better the water quality will be.

Gutters

Gutters are made out of a variety of materials, most commonly PVC plastic and galvanized metal. *PVC gutters are recommended* as they do not rust so water quality will be maintained over a long period of time. The correct installation of gutters is most important so that there are no flat areas where debris and water may pool, as these may provide sites for mosquitoes to breed.

If a large amount of leaf material is present and it is not desirable to remove an overhanging tree, gutter screens may also be used.

APPROPRIATE STORAGE VESSELS

An appropriate storage tank or vessel is needed to hold the water that is collected from roofs and other surfaces. Several types of storage vessels have been used although a large tank is usually required for storing sufficient quantities of water for a household. Appropriate storage vessels include those made of ferro-cement, plastic, metal and fiberglass. Ferro cement tanks have been used successfully for over a century in the Pacific Islands and if well maintained can provide good water quality. Plastic tanks are becoming increasingly used and also provide good water quality. Plastic tanks should be constructed from food-grade plastic material in order to prevent leaching of any potentially harmful compounds into the water.

Open topped vessels such as buckets and drums are *not recommended* for collection of rainwater for *drinking purposes* as contaminants (e.g. leaves and dust) may easily enter into them. It is important that the storage vessel does not introduce contamination into the water from the vessel material itself or remnants of substances that have previously been stored in it. For this reason it is *not recommended* that old oil or chemical drums are used, as these may contain substances harmful to human health.

Storage tank materials should prevent or minimize light penetration to reduce algal growth and other biological activity, which helps maintain water quality. For this reason, *clear plastic or fiberglass* tanks are *not recommended* for use in the tropical Pacific.

The tap for the tank should be protected from animals, which may drink from it or brush against it, leading to subsequent water contamination. The level of the tap in regard to the base of the tank should not be so low that debris from the bottom of the tanks are drawn up with the out flowing water. *Tanks with no tap are not recommended* as water abstraction is typically with a lowered bucket which increases the risk of contamination. An additional tap can be installed in the base of a tank which makes emptying for cleaning easier.

TANK MAINTENANCE

Cleaning

It is recommended that tanks be cleaned on an annual basis, particularly if observations suggest a large amount of debris has entered the tank or a sanitary survey (Appendix 2) indicates a risk. Cleaning will help restore good water quality. To clean a tank, first the water must be drained out to the level of the tap and transferred to another rainwater storage or temporary tank. One litre bottle of household bleach can be added to the remaining water in the tank and the tank bottom and sides thoroughly scrubbed with this solution using a brush. The remaining water and bleach solution should then be bucketed out of the tank, the tank refilled and the water left to settle overnight before use.

For your protection, you should wear proper hand and eye protection when handling chlorine bleach solutions.

DEVICES & TECHNIQUES THAT FURTHER AID IN BETTER WATER QUALITY

Filtration Screens

The quality of stored water can be much improved if leaves and other debris are kept out of the system by the use of a coarse filter or screen. Without screens present, leaves and other material may enter tanks and provide food and nutrients for micro-organisms to survive. In the absence of such nutrients, bacteria eventually (2-20 days) die off from starvation.

A filter or screen should be durable, easy to clean and replace, and should not block. It is essential that there are no gaps in the storage tank inlets where mosquitoes can enter or exit.

Coarse filtration screens (made of stainless steel or synthetic mesh) are the simplest, most inexpensive and widely used technology. Typically these are mounted across the top inlet of the storage tank with the downpipe above the screen.

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.

Coarse filter screens are recommended for all tanks in the Pacific Islands as an economical way to provide some basic water quality improvement.

Finer filter devices have been used to remove small sized sediment which would otherwise either be suspended in the water or settle to the bottom of the tank leaving a sludge. These also effectively remove bacteria (Faisst and Fujioka 1994). The devices usually used are gravel, sand or fine filter screens (e.g. see Macomber 2001). However, in a tropical rain shower, water flow rates off a roof may be very high (> 1.5 $l\ s^{-1}$) and fine filters are often not capable of handling these flow rates without resulting in the filter overflowing and water being lost. Fine filters also require regular cleaning due to their tendency to clog up with particles. For these reasons *fine filtration systems are not recommended* for general use in the tropical Pacific Islands.

First-flush devices

Contaminants such as debris, dirt and dust collect on roofs during dry periods and during the initial period of rainfall this material is washed into the storage vessel. Following this initial 'first flush' of contaminants the water collected is much cleaner and safer to drink (Otieno 1994). First flush water separating systems dispose off the 'first flush' water so that it does not enter the storage tank.

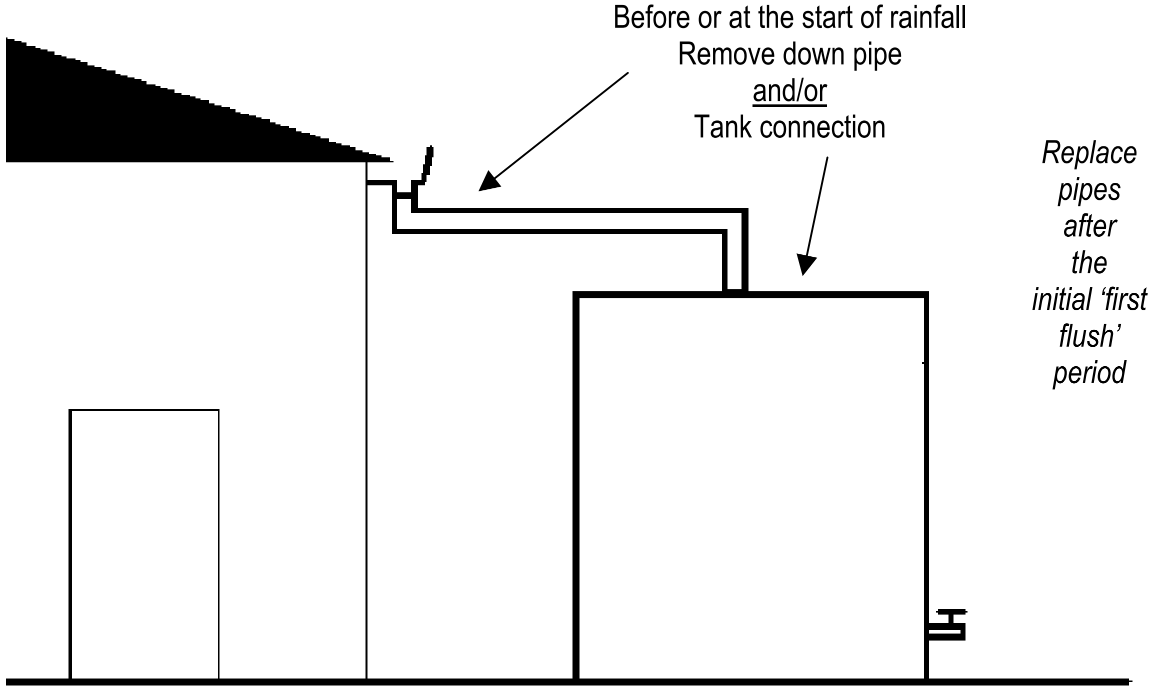
The amount of first flush water that needs to be removed before water is safe to drink has been found to vary between different studies. Yaziz et al. (1989) found that 0.5 mm of rain was sufficient to reduce the faecal coliforms count to zero on two roofs in a Malaysian campus. Coombes et. al (2000) have found that even after 2 mm was flushed, there were still significant faecal coliforms in the runoff from a building located close to a bus depot in Australia. Field studies in Uganda have shown unacceptable turbidity after 2 mm have removed although faecal coliform counts were in the WHO "low risk" category. Despite this uncertainty, first flush systems are considered a very good method of improving the quality of roof runoff prior to storage (Faisst and Fujioka 1993).

Design of First Flush Systems

Several first flush diverters are in use worldwide and commercial systems are available. For the Pacific Islands we recommend choosing a system that has minimum cost, few moving or metal parts, and little maintenance requirements. For this reason we only outline two simple systems:

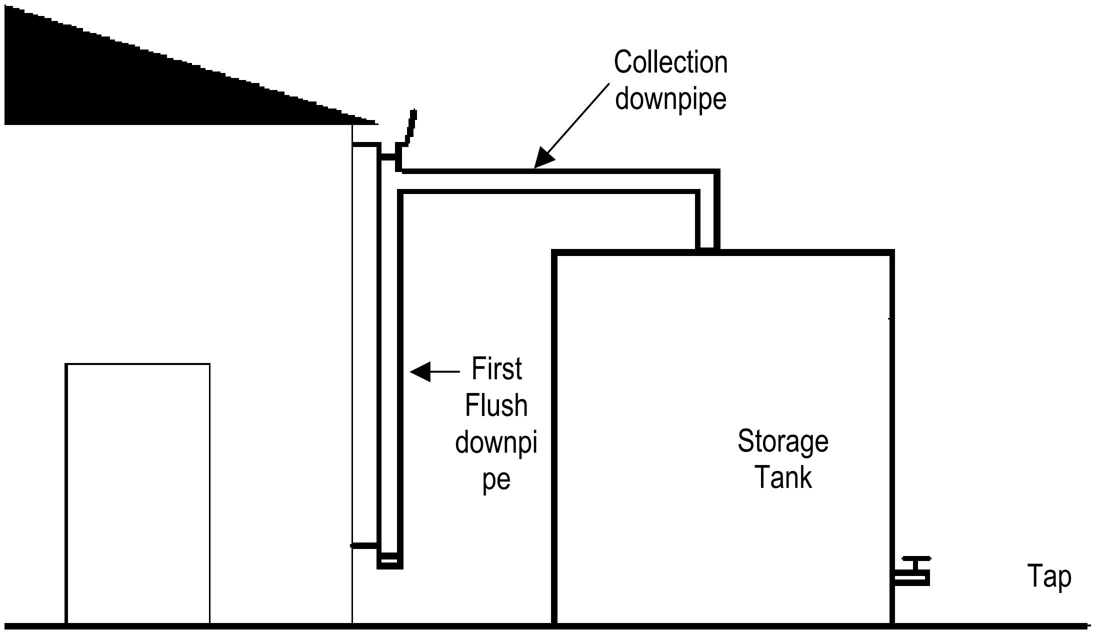
Manual Method: remove down pipe during initial period of rain event

This is a simple manually operated arrangement, whereby the down pipe is manually moved away from the tank inlet and replaced again once the first flush water has been disposed. The advantage of this system is that no extra technology is required but a major disadvantage is somebody needs to be present throughout the initial stages of rainfall events who is capable of removing the downpipe. Otherwise contaminants will enter the storage tank. On volcanic islands it also is advisable to follow these procedures if ash has fallen on the roof.



Semi-automatic Method: Simple down pipe first flush device

A simple first flush system that is not reliant on someone being present at the beginning of rainfall is known as the 'down pipe first flush device'. In this system, a separate vertical pipe is fixed to the down pipe using a "T" junction or similar as shown in the figure below. The initial flush of rainfall (containing the majority of the contaminants) running off the roof washes into the 'first flush down pipe' where it is retained. When this down pipe becomes full water flows down the 'collection down pipe' into the storage tank. The water containing contaminants in the first flush tanks can, depending on its quality, be used for other purposes besides drinking (e.g. cleaning, washing, watering vegetable gardens).



PVC piping and T-joints, widely available and commonly used for standard downpipes, can be used to construct the first flush downpipe.

A minimum design criteria is that the device should divert the first 0.5 mm of the rainfall. To calculate the volume of water needed to be diverted multiply the length and width of your house or collection surface (in metres) by 0.5 (mm).

*Required volume of diverted water (L) = house length (m) * house width (m) * 0.5 (mm)*

For example, a house which is 10 m long by 10 m wide would need to divert at least 50 L of water. This is the amount the simple-pipe first flush device would have to divert to be effective. By dividing the required volume of water to be diverted by the cross sectional area of the pipe (πr^2) the necessary pipe length for the simple first flush device can be calculated from the following equation:

*Pipe length (m) = Required volume of diverted water (L) / (3.14 * pipe radius^2 (mm) * 0.001)*

For the example above (10m by 10m house size, diverting 0.5 mm rain), a first flush downpipe of 100 mm diameter (50 mm radius) would need to be at least 6.4 m long.

If the manual diversion system is used, the equation above can be used as a guide to calculate how many containers of water (e.g. buckets) could be filled before the downpipe is replaced.

The above calculations can also be easily performed in the excel spreadsheet "water quality.xls" on the CD accompanying this document. Once this file is opened, click on the worksheet "first flush" and follow instructions therein.

Water disinfection by adding chlorine (contained in household bleach)

Not all rainwater harvesting systems are constructed or maintained well which results in poor water quality which may pose a risk to human health. Chlorination to kill bacteria is widely recommended as a sterilisation for rainwater collection systems (UNEP 1998; Macomber 2001) but generally chlorinated water is not well liked by users (Fujioka 1994) and the chemicals used can be dangerous if misused. For this reason chlorination of the tank water is suggested only where one or more of the following situations is present:

1. A known bacterial risk has been identified through water testing
2. Individuals are getting sick as a result of drinking the water
3. It is not feasible to completely empty a tank for cleaning
4. An animal, or faecal material has entered the tank.

Adding small quantities of chlorine to your water tank is the cheapest and most effective means of disinfection. Chlorine can be added in various forms such as common (unscented and not coloured) household bleach (e.g. Janola). Different bleaches have different levels of active ingredient. The amount of bleach to add, based on a 4% active ingredient, is shown in the table below relative to the <u>amount of water</u> in the tank.

Volume of water in tank (L)	Amount of bleach to add (mL with 4% active ingredient)
1000	125
2000	250
3000	375
4000	500
5000	625
6000	750
7000	875
8000	1000
9000	1125
10000	1250
11000	1375
12000	1500

For example, an 8,000 L tank that is half full contains approximately 4000 L of water so you would add 500 mL of bleach. If you do not know your tank volume you cannot easily calculate the amount of bleach to add. However, tank volume calculations can be easily performed in the excel spreadsheet “water quality.xls” on the CD accompanying this document based on measurement of the size of the tank (separate calculations for round and square/rectangular tanks). Once this excel file is opened, click on the worksheet “tank volume and chlorine” and follow instructions therein. The height of water in the tank is used to calculate the volume of water, and this can be measured with a clean dry stick.

If your bleach has a different level of active ingredient you will have to adjust the amount of bleach added for a particular tank size. For example, if your bleach has 8% active ingredient, you would halve the amount of bleach listed above for a particular water volume. These calculations can also be performed in the excel worksheet “tank volume and chlorine” in the “water quality.xls” spreadsheet.

The above bleach amounts are based on the fact that enough chlorine should be added to provide a free chlorine residual of around 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 necessary you can test the chlorine residual with a swimming pool test kit or dip strips, which may be locally obtainable. Chlorine dosing is less effective if pH levels are over about 8.5 (Macomber 2001) so the pH level should also be checked if possible.

Be sure to read and follow safety and handling instructions on all chlorine or bleach containers. For your protection, you should wear proper hand and eye protection when handling or preparing chlorine solutions.

Remember to allow **24 hours after the time of chlorination** for the chlorine to disinfect the tank before you drink the water. Chlorine is heavier than water, so it will tend to sink towards the bottom of the tank. Any chlorine smell and taste in the water should dissipate after a short time.

If you find the taste of chlorine unacceptable, boiling of water for at least 5 minutes before drinking is a suitable alternative to provide safe drinking water.

TESTING OF WATER QUALITY

Water quality testing should ideally be regularly carried out by a relevant in-country agency, such as the Ministry of Health. Relevant WHO water guidelines to compare results to are shown in Appendix 1. Unfortunately, testing of the quality of rain tank water in the Pacific Islands is not often performed as these systems are not part of the municipal water supply and hence are often considered the responsibility of the individual householder. However in some locations (e.g. Tonga) the Ministry of Health conducts testing and public education on rainwater tanks. Where testing is not performed, communities should lobby relevant government agencies to begin conducting regular testing. This can provide guidance as to when tanks need to be cleaned or disinfected. Simple water quality testing equipment (e.g. hydrogen sulphide, H_2S, tests) could be supplied to communities so they can self-test their water. These tests have been shown to correlate well with faecal coliform levels in rainwater tanks (Faisst and Fujioka 1994).

If water quality testing is possible, the main focus should be on microbiological testing using tests such as faecal coliforms, Enterococci, and the simple H_2S test. World Health Organization guidelines (WHO 1996) state that faecal bacteria should not be detectable per 100 mL of sample. However, Fujioka (1994) stated that a more realistic standard may be 10 faecal coliforms/100 mL. A sanitary survey (Appendix 2) determines that the rainwater tank is unlikely to have contamination from human faecal wastes. Total coliform tests are not considered a reliable indicator of risk to human health in the tropics as they are naturally present and can reproduce in the soil and water (Fujioka 1994; WHO 1996).

The physical parameters, pH and turbidity should also be measured and compared to WHO guidelines. Rain is considered acidic when the pH is <5.6, and levels below this may cause corrosion of metal roofs and fittings. Heavy metals (e.g. lead, copper, cadmium, zinc) should also be monitored periodically, particularly where volcanic or industrial discharges to the air are present.

Given the current lack of testing for rain tank water, it is imperative that households are given good education (workshops, printed material) on maintaining their tanks. This should be an integral part of any rainwater tank installation project in the Pacific Islands. An example of a printed public awareness brochure used in Tonga is shown in Appendix 3.

REFERENCES

Website:
Useful website with a number of documents relating to rainwater harvesting
http://www.eng.warwick.ac.uk/DTU/rwh/
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Appendix 1: World Health Organization (WHO 1996) guidelines

Selected WHO guidelines relevant to water quality of rainwater systems. Critical values for some parameters are given in order to protect human health. Values are also given for some parameters that are levels that are likely to result in consumer complaints (e.g. due to poor taste) but may not necessarily be toxic.

Parameter	Guideline value
Faecal coliform of E. coli	Not detectable in a 100 mL sample
Aluminium	0.2 mg/L (level likely to result in consumer complaints)
Cadmium	0.003 mg/L
Copper	2 mg/L
Chloride	250 mg/L (level likely to result in consumer complaints)
Fluoride	1.5 mg/L
Iron	0.3 mg/L (level likely to result in consumer complaints)
Lead	0.01 mg/L
Sodium	200 mg/L (level likely to result in consumer complaints)
Sulphate	250 mg/L (level likely to result in consumer complaints)
Turbidity	5 NTU (level likely to result in consumer complaints)
Total dissolved solids	1000 mg/L (level likely to result in consumer complaints)
Zinc	3 mg/L (level likely to result in consumer complaints)

Appendix 2: Rainwater Collection Systems Sanitary Survey

Country and Island:____

Date:____________

Name of family:______________________________ **Name of community:** ____________________________

Number of people in family that drink water from this tank: ______________

	SCORE
1. Condition of ROOF: good (0)____; fair (1)____; poor (2)____	
2. Condition of guttering: good (0)____; fair (1)____; poor (2)____	
3. Guttering sloped to drain: yes (0)____; no (2)____	
4. Inlet screened or protected: yes (0)____; no (2)____	
5. Interior tank clean: good (0)____; fair (1)____; poor (2)____	
6. Condition of tank: good (0)____; fair (1)____; poor (2)____	
7. Method of withdrawal by tap: yes (0)____; no (2)____	
8. Tap and other plumbing in good repair: yes (0)____; no (2)____	
9. Method for diverting first flush available: yes (0)____; no (2)____	
10. Vegetation overhanging roof catchment area: yes (0)____; no (2)____	
TOTAL:	

<u>OTHER INFORMATION</u>:

1. Type GUTTERING: vinyl ____; PVC ____; metal ____; other [describe]: ____________________
2. Type TANK: fibreglass ____; poured concrete ____; ferrocement ____; PVC ____; galvanized iron ____; other: [describe]____________________
3. Location of tank: On raised platform ____; at ground level ____; partially below ground ____; majority of tank below ground ____
4. Estimated capacity of tank, in m^3: ________ ($V=\pi r^2 h$)
5. Date constructed: ______________ Date when last cleaned: _______________
6. Method of withdrawal: ____________________________________
7. Describe method for diverting first flush, if available (sketch on reverse):

RECOMMENDATIONS:

____

____

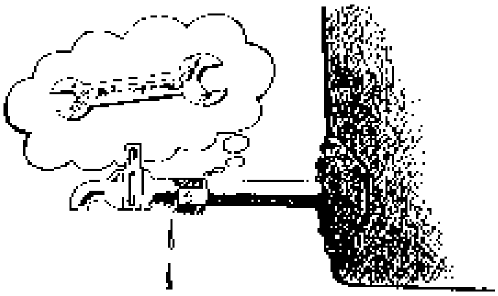
____

Sanitary Survey- Risk Score: __________

<u>Relative risk</u>=1+2: low (<5)____; moderate (5-10)____; high (>10)____

If the tap leaks, fix it up so you do not lose rainwater

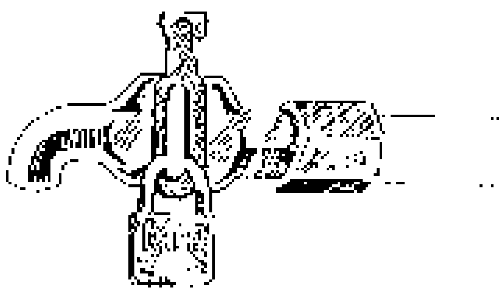
Kapau ‘oku tafetafe ha vai’I he tepí pea ngaohi leva ia ke ‘oua na’a toe mole ‘a e vaí



Use water sparingly, particularly during the dry season or when there is a drought

Get a tap with a lock so no-one can use your rainwater

Omai ha tepi mo hano loka ke malu’i’aki hano ‘utu noa’ia ho’o vai



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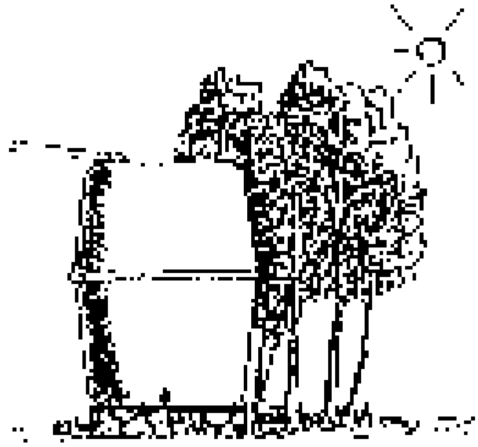
Adapted with permission from AusAID Haapai Water Tanks Project publication

Appendix 3

Caring for your Rainwater Tank



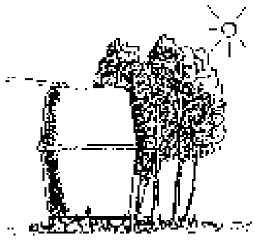
Your rainwater tank will only give clean, safe water if you look after it

SOPAC/TCDT/UNEP

Don’t let trees grow over your roof as you want to try and keep leaves and bird droppings from falling onto your roof and washing into your rainwater tank.

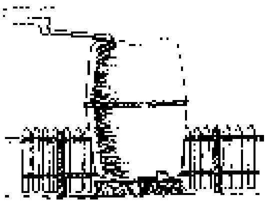
Plant shady bushes near your tank to help keep the water cool in the tank

Tö ha ngaahi’akau fakamalumalu ofi ki he sima vaí koe’uhi ke mokomoko’a e vai’I he simá



Build a fence around your tank to keep pigs and other animals away

Ngaohi ha ‘ä ‘o e simá ke ‘oua ‘e ofi ki ai ‘a e fanga puaká

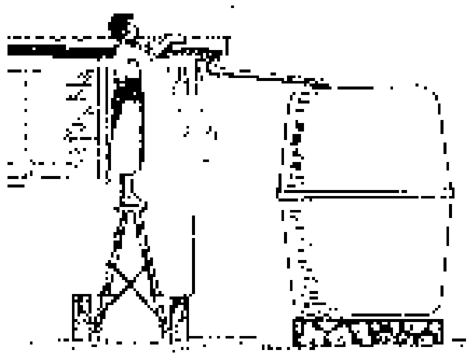


Regularly clean away the leaves from the top of your tank

Tafi ma’u pë ‘a e lau’i’akau ‘I he fungasimá

Clean out your roof gutters once per month

Fufulu to’o taha ‘I he mähina ‘a e ‘u fakatalí



Make sure that you buy some extra guttering so that the whole roof will give rainwater to your tank

Tokanga ke fakatau ha fakatali ke fakatali kotoa ho fale ‘koe’uhi ke tänaki e vai ‘uha mei he ‘ato kotoa ki ho simá

If a cyclone is coming, disconnect your downpipe from the roof to the tank to stop salt water getting into your tank

Ka ‘I ai ha fakatokanga afä, pea to’o ‘a e fakatali ki he simá na’a hü ki loto ha vau fio tahi