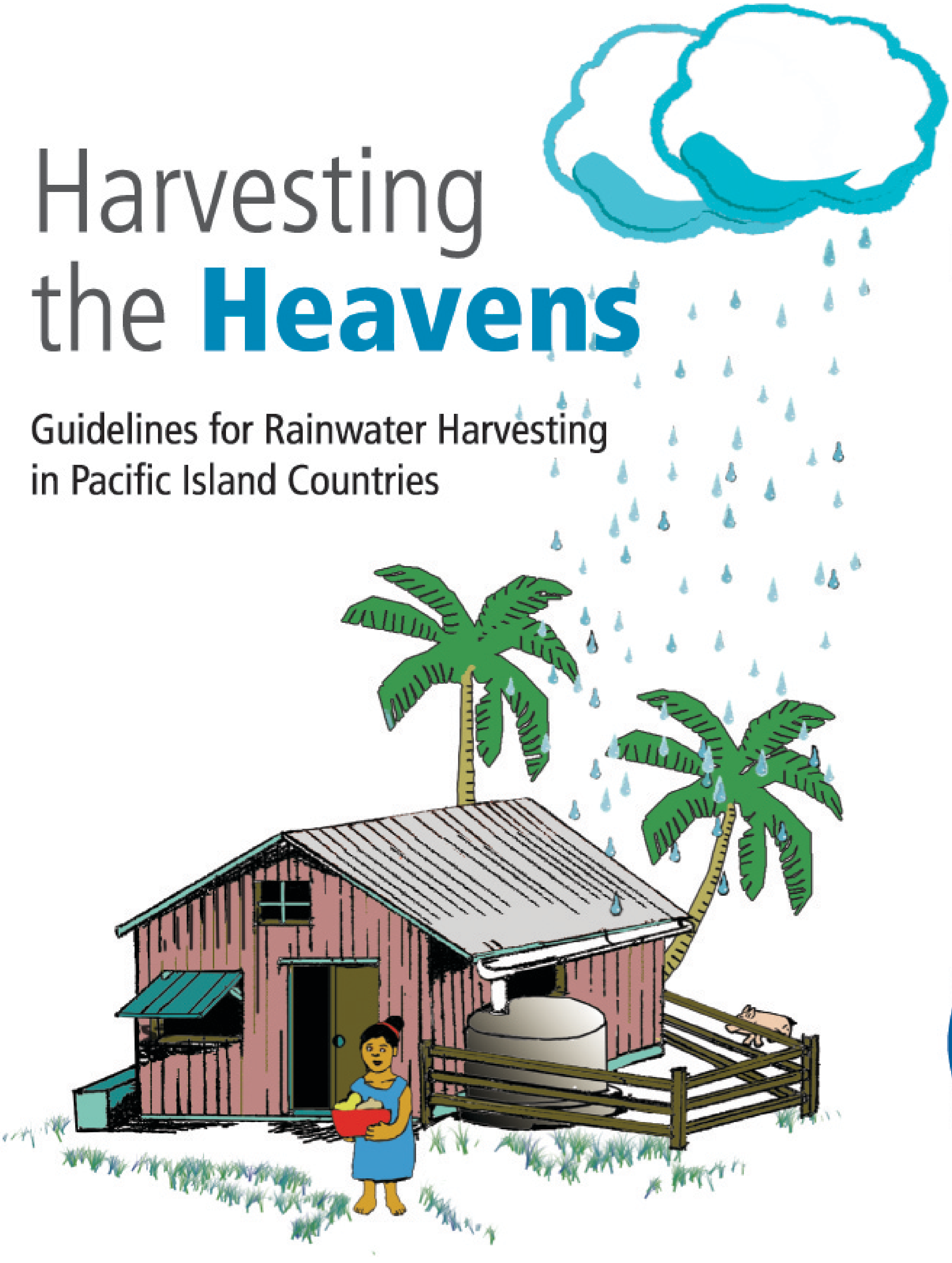
Harvesting the Heavens

Guidelines for Rainwater Harvesting in Pacific Island Countries



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Harvesting the **Heavens**

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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).

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Disclaimer

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List of abbreviations

CBO	Community Based Organisation(s)
EC	Electrical Conductivity
ENSO	El Niño Southern Oscillation
FJD	Fiji Dollar
FSM	Federated States of Micronesia
Gal	Gallon (1 US gallon = 3.7854 litres)
HDPE	High Density Polyethylene
H_2S	Hydrogen Sulphide
IETC	International Environmental Technology Centre (of UNEP)
IGO	Inter-Governmental Organisation(s)
l/p/d	litre per person per day
mg/l	milligram per litre
m^3/day	cubic metres per day
NGO	Non-government organisation(s)
PE	Polyethylene
PLA	Participatory Learning and Action
PRA	Participatory Rural Appraisal
PROWWESS	Promotion of the Role Of Women in Water and Environmental Sanitation Services
PV	Photo Voltaic
PVC	Poly-Vinyl Chloride
RMI	Republic of the Marshall Islands
RRA	Rapid Rural Appraisal
SIDA	Swedish International Development Agency
SOPAC	South Pacific Applied Geoscience Commission
SPC	Secretariat of the Pacific Community
TCDT	Tonga Community Development Trust
TDS	Total Dissolved Solids
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USD	US Dollar
VWDP	Village Women's Development Programme (of TCDT)
WHO	World Health Organization
WSSD	World Summit for Sustainable Development

Preface

The "Harvesting the Heavens: Guidelines for Rainwater Harvesting in Pacific Island Countries" were developed as part of the United Nations Environment Programme (UNEP) demonstration project on "Empowering Women in Rainwater Harvesting" funded by the Government of Sweden through their development agency SIDA and carried out in Africa (Kenya) and the Pacific (Tonga).

These guidelines are for people who are interested in building or maintaining a rainwater harvesting system. They are also for non-government organisations, community-based organisations, regional organisations and donor agencies that are involved in the implementation of rainwater harvesting projects. The intention of the guidelines is to help in the sustainable implementation of rainwater harvesting as well as to assist in improving the quality of the water supply. The guidelines are focused on roof catchment systems for domestic water supply although they might be useful for other systems (e.g. artificially-raised catchments) as well as other uses (e.g. agriculture).

The guidelines capture the lessons learned during the preparation and implementation of the demonstration project executed by the South Pacific Applied Geoscience Commission (SOPAC) and carried out in the island group of Vava'u of the Kingdom of Tonga through the Village Women's Development Programme (VWDP) of the Tonga Community Development Trust (TCDT).

The outputs of the demonstration project aside from the rainwater harvesting systems installed in two communities of Vava'u, include a demonstration video on rainwater harvesting; a manual for participatory training in rainwater harvesting aimed at trainers and focused on awareness and system operation and maintenance; and these guidelines for rainwater harvesting in Pacific Island Countries.

There are four chapters in these guidelines inclusive of an introduction in Chapter 1. Chapter 2 discusses the implementation and sustainability of rainwater harvesting. Chapter 3 examines various design criteria that can be applied for rainwater harvesting systems and Chapter 4 deals with operation and maintenance aspects. Each chapter comprises theoretical sections containing information from various reports, handbooks and guidelines with practical experiences from the Tonga demonstration project in boxes. Each chapter concludes with a box on the lessons learned. Special reference needs to be made of the publication by Gould & Nissen-Petersen (1999) on "Rainwater catchment systems for domestic supply" which was a valuable source of information to establish these guidelines.

The guidelines will be shared with people and organisations in the Pacific region as well as other parts of the world.

Acknowledgements

"Harvesting the Heavens: Guidelines for Rainwater Harvesting in Pacific Island Countries" represents the combined efforts of numerous people involved throughout the implementation of the UNEP project on "Empowering Women in Rainwater Harvesting". The project provided an important contribution to the promotion of rainwater harvesting for communities throughout the region.

Herewith the authors would like to thank the Swedish Government and UNEP for their financial and logistical support for the Pacific Rainwater Harvesting Demonstration Project.

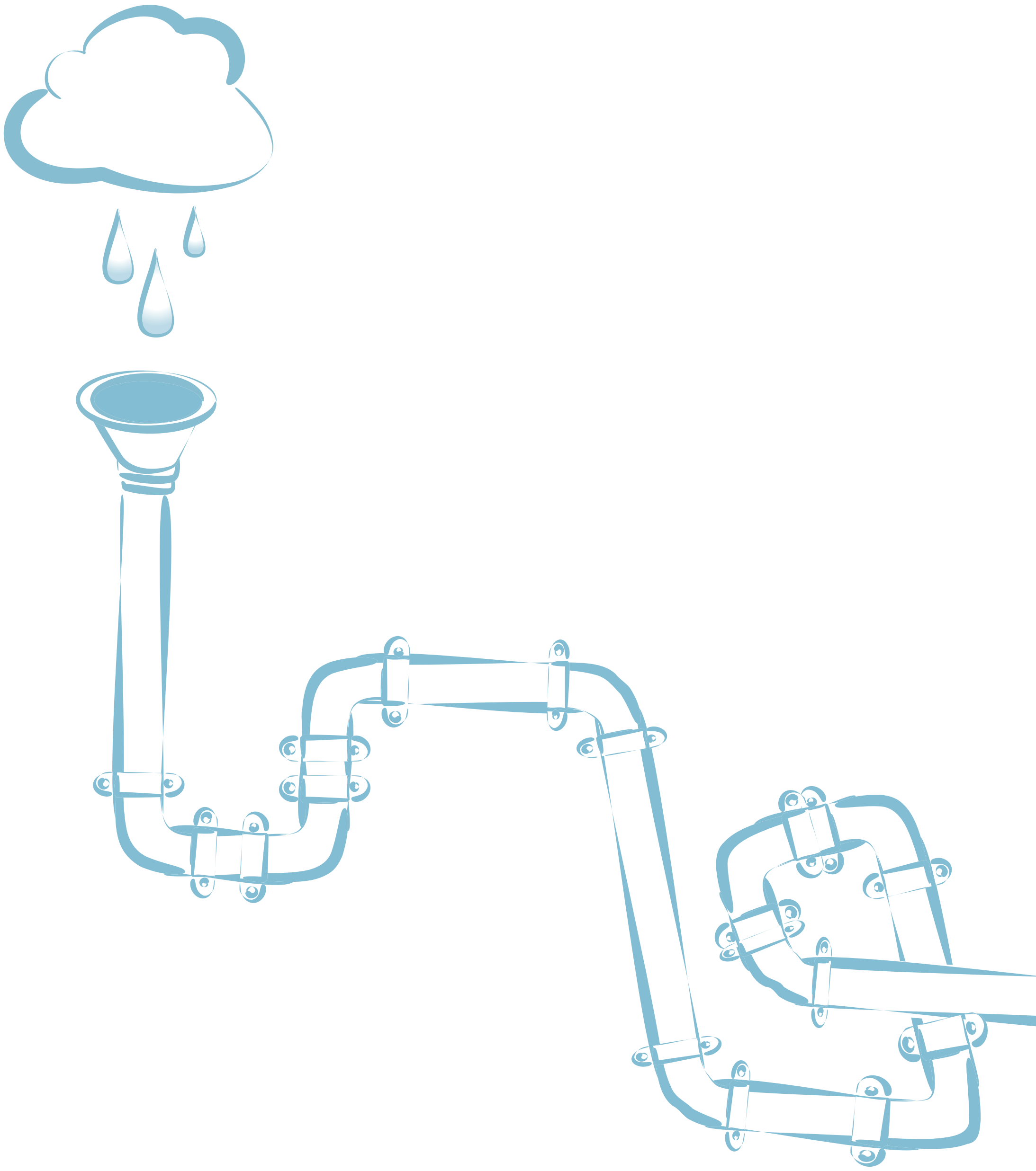
SOPAC wishes to thank our colleagues from TCDT and the VWDP extension workers for the implementation of the Rainwater Harvesting Project and contribution to these guidelines.

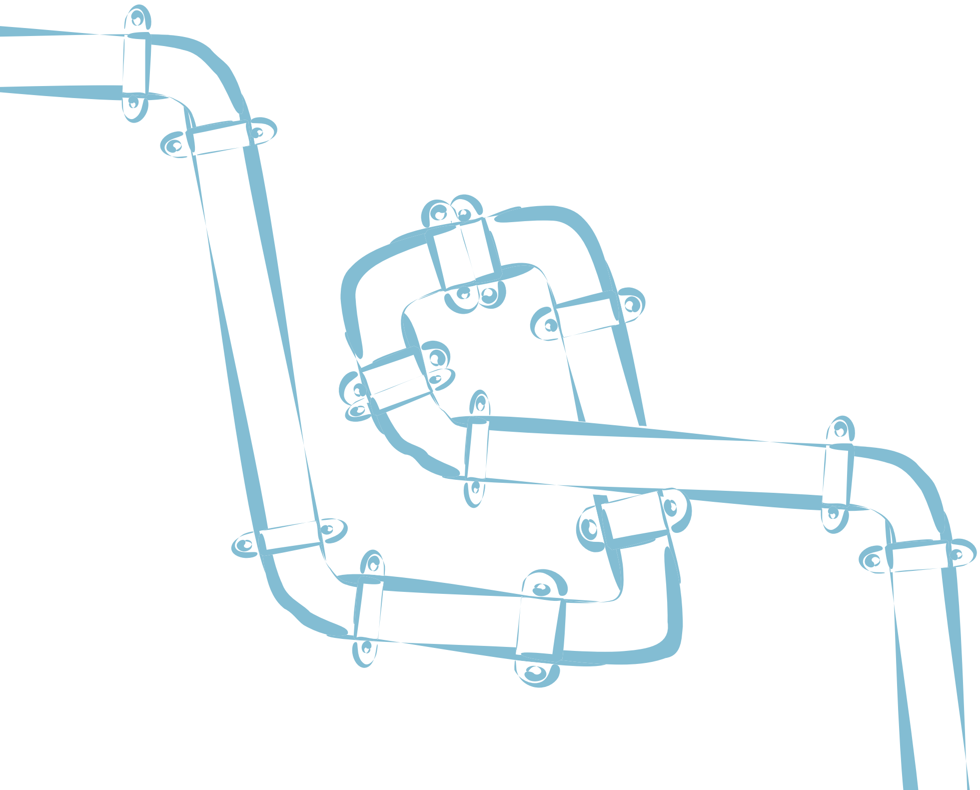
We would like to express our gratitude towards the villages of 'Utungake and Matamaka, the participants of the training of trainers workshop and the evaluation workshop, members of the stakeholders group, Ministry of Health, Tonga Water Board, National Representative of Tonga to SOPAC, Tevita Malolo, Ministry of Lands, Surveys and Natural Resources and all of those who provided valuable contributions to these guidelines.

Lastly we would like to acknowledge the input provided to the project by EarthCare Africa Monitoring Institute for exchanging experiences from the Kenyan project and Elizabeth Khaka, the UNEP project officer, for her advice and guidance.

We sincerely hope that the close and fruitful collaboration between UNEP, TCDT and SOPAC can be continued to further promote rainwater harvesting in Tonga and the Pacific region.

Thank you - Malo 'aupito!





1

Rainwater harvesting in the Pacific

1.1 Introduction

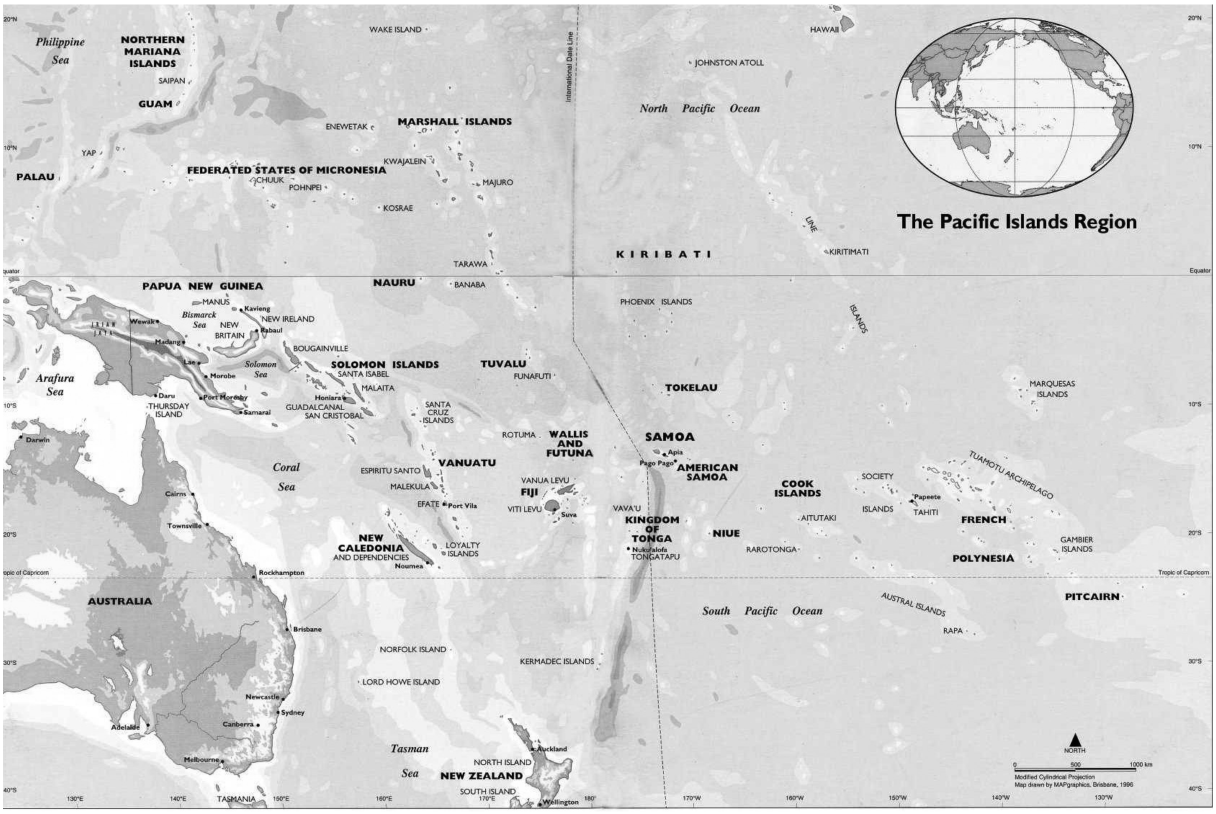
At the 3rd World Water Forum held in 2003 in Kyoto, Pacific island country ministers, delegations and representatives of civil society, reaffirmed their commitment to the United Nations Millennium Development Goals and Targets of halving by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation and the World Summit for Sustainable Development (WSSD) Plan of Implementation.

Promoting the use of rainwater for domestic water supply can assist in achieving those targets. Rainwater harvesting has not generally been given the attention it deserves. It has often been looked upon as a technology of last resort to be used only when no other alternative could be used such as on some of the Pacific low-lying islands lacking fresh surface water or groundwater.

Even when alternative water supplies exist, rainwater can provide a useful supplementary supply and important backup when the main supply breaks down, dries up or becomes saline during droughts. Through the use of rainwater harvesting the demand on existing water resources can be reduced.

While it is true that rainwater harvesting systems cannot generally compete in economic terms with shallow wells, gravity-fed spring supplies or even with conventional reticulated groundwater systems in areas with abundant good quality water, in many other circumstances rainwater can provide a viable option, with a number of advantages that make it preferable. Rainfall generally occurs everywhere in the Pacific in abundant quantity. Since most people live in houses with roofs they already have catchment surfaces from which rainwater runoff can be collected. The individual ownership and control of these systems also helps to ensure their proper operation and maintenance. Due to contamination of surface water as well as groundwater and occurrence of saltwater intrusion in freshwater lenses, the quality of water from rainwater harvesting systems is generally better than that of the alternatives (Gould & Nissen-Petersen, 1999).

Cistern in Savai'i, Samoa



1.2 Roof catchments for domestic water supply

Rainwater can be harvested in different ways such as roof catchments, rock catchments, ground catchments, earth dams etc. These guidelines focus on one technical option for improving domestic water supply provision, namely the collection and storage of rainwater runoff from roof catchments.

In general, household rainwater tanks are one of the most appropriate solutions to improving potable water supplies in the Pacific with an increased level of community involvement and self-reliance in rural water supply schemes but they can also be of value in urban situations.

The vital importance of rainwater is evident in many islands and may in fact be the primary, and in some cases only, source of freshwater (e.g. many atolls in Tuvalu, and some very small islands in Cook Islands and Tonga). In other islands, where average rainfall is moderate and where droughts can last for many months, rainwater can be considered as a useful supplementary water source. The cost of building sufficiently large catchment areas and storage tanks to supply rainwater as a main source of supply in such islands would be prohibitive.

Household rainwater harvesting systems involving rainfall collection from all or part of the roof and storing it in a small- to medium-sized tank are common. There are many examples of such systems on small islands in the Pacific

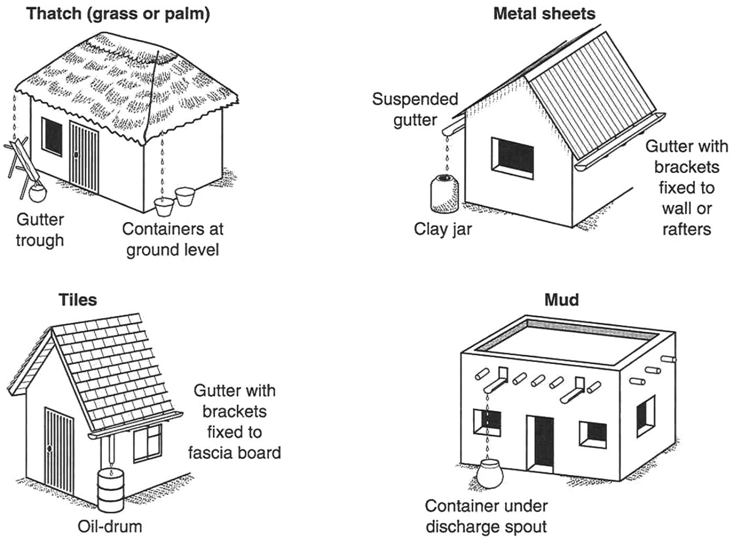


Figure 1.1: *Typical roofing materials and some of the many varieties of informal rainwater collection methods (Source: Gould & Nissen-Petersen, 1999)*

and other regions. Such schemes should continue to be implemented and their application should be promoted.

1.3 Rainwater harvesting projects and guidelines

Rainwater catchment construction projects in rural areas have been the focus of many aid projects in the Pacific. These projects have been implemented with funding from a large number of international and bilateral donors, NGOs and Community-Based Organisations (CBOs). Many involve the construction of ferrocement tanks which can be implemented in community-based construction schemes. In some cases, this may involve local contractors while in others, whole villages have been involved in the process. In some island countries (e.g. Cook Islands, Tuvalu, Maldives), plastic tanks are now becoming more popular than previously used ferrocement, or fibreglass tanks, because of the ease of installation and improved availability and pricing.

Various guidelines have been written, often in the local language, to assist in the training of persons to carry out construction work, examples of which are presented in UNEP/IETC (1998).

Methods for the design of rainwater catchment systems are the focus of a number of reports and papers. In the Pacific some specific design guidelines for particular countries have been developed including Tuvalu (Chapman, 1986; Dawe, 2001) and Federated States of Micronesia (Heitz & Winter, 1996).

In Tarawa, Kiribati, recent building regulations require that new buildings include gutters and minimum rainwater storage of 5,000 L. This measure will assist in the longer term in relieving the water demand on the public groundwater supply system (Metutera, 2002). Similar measures have been previously taken in other islands. In Tuvalu, regulations regarding rainwater harvesting have been in place since 1990. Revision of these regulations have been suggested based on analysis of rainfall data (Dawe, 2001).

In the "Synopsis of Information on Freshwater and Watershed Management Issues in the Pacific Islands Region" (Falkland, 2002), comprehensive and current background information on freshwater resources management was included for each of the prospective project countries for the UNEP demonstration project. Falkland also identified major issues and priority concerns for each country.

Table 1.1: *Country-specific priority concerns related to rainwater harvesting*

Country	Rainwater harvesting related priority concerns
Cook Islands	● Water quality problems ● Limited water resources and sometimes severe shortages during droughts on some islands
Federated States of Micronesia	● Freshwater sustainability especially through droughts ● Water quality problems
Kiribati	● Freshwater sustainability through droughts ● Future water resource development for Tarawa, given the high population increase ● Insufficient use of rainwater for supplementary water ● Water quality problems
Republic of the Marshall Islands	● Need for upgrading of outer island water supplies and for greater use of rainwater catchments for water supply ● Freshwater sustainability especially through droughts ● Water quality problems
Tonga	● Water supply problems in remote islands during droughts, sometimes requiring importation of water by boat ● Water quality problems
Tuvalu	● Issue of sustainability of rainwater catchments through droughts ● Requirement for greater storage facilities, especially for Funafuti as demand rises ● Optimal rainwater catchment design procedures

The wealth of information that is available as demonstrated above, seems to not be widely exchanged with project-implementing agencies or organisations in the Pacific region. The guidelines developed within this demonstration project attempt to provide the combined best practices from the available literature as well as experiences from various projects and compare these with the practical implementation in Tonga with a strong focus on community participation and the use of climate information.

1.4 Community participation in rainwater harvesting

1.4.1 Participation and ownership

Many past rainwater harvesting projects in the Pacific have concentrated on providing or upgrading infrastructure, without considering the operation, maintenance or augmentation of systems into the future. The result is that many systems fall quickly into disrepair, reducing the amount of water and/or compromising the quality of the water available.

The best method for addressing the long-term sustainability of rainwater harvesting projects is to promote the active participation of community members at every stage of the project. Experiences in many countries show that where community participation and ownership are fostered, more will be accomplished at lower costs, people are freed from dependence on others' skills, valuable indigenous knowledge is used, health benefits are maximised, individual projects are more likely to be self-sustaining and further development tends to take place at the initiation of the community because a sense of responsibility is encouraged.

It should be noted however, that the major problem with involving communities in projects is that it can take a long time for a community to make the necessary commitments and decisions and that this time lag does not normally tie in with budgeting and planning constraints of supporting agencies. Project plans commonly refer to community participation but very often the overall form of the project has already been decided by the time consultation with the community occurs and therefore consultation and participation will only have limited effect.

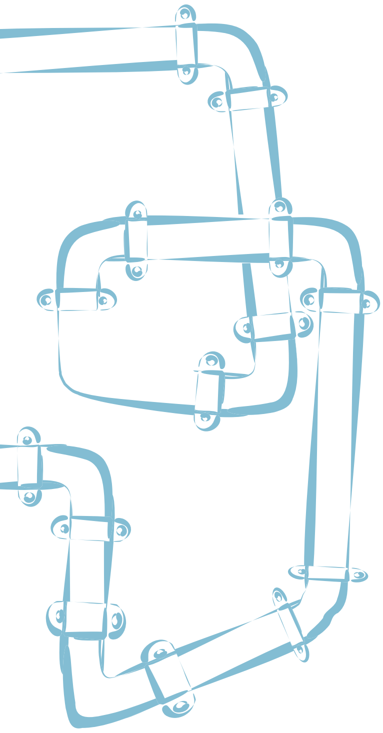
Projects should therefore be implemented over a much longer time-span allowing participatory approaches to take effect and create full ownership by communities.

1.4.2 Recognising gender issues

Women and men use water and are involved in water management in different ways. For example, it is mainly women and girls who use water for domestic purposes, while men and boys may compete for water from the same sources for farming and livestock. Adopting a gender sensitive approach means that the different needs of both women and men are taken into account in the design and management of projects. Gender relations need to be understood in the local context and efforts need to be made to ensure the fullest possible participation of both women and men in all stages of projects. Excluding either group from project consultation or decision-making will have a negative impact on the project's sustainability.

1.4.3 Participatory approaches

There are many *"participatory approaches"* which can be used to bring about community participation. A participatory approach follows the principle that the exercise should be a learning one rather than a judgemental experience for all concerned (Gosling & Edwards, 1995). Often known as learner-centred, the participatory approach has evolved as a means of helping learners take greater control over their lives and their environment by developing their skills in problem solving and resource management.



Unlike traditional teaching methods which have emphasised the transfer of knowledge, messages or content pre-selected by outside specialists, participatory approaches focus more on the development of human capacities to assess, choose, plan, create, organise and take initiatives. These skills can then spill over to many other aspects of the person's life and community (Srinivasan, 1990).

Further argument for using participatory approaches is that it enables communities to be involved in analysing their own situation, problems, and issues, and start thinking about their own solutions and actions. It enables the external planners to better understand the issues and problems facing communities, leading (hopefully) to the planning and design of a project that is based on reality rather than assumptions and outside views. Working together, communities and planners may be able to achieve the elusive goal of sustainability of water supply and sanitation facilities, safer hygiene practices and, ultimately, better health and living conditions (Gosling & Edwards, 1995).

1.4.4 Tools for participatory approaches

There are many different tools and techniques used to promote community participation. Two commonly used social research techniques are RRA (Rapid Rural Appraisal) and PRA (Participatory Rural Appraisal). RRA is a method used by outsiders for acquiring information about a community quickly while PRA values local knowledge over outsider knowledge and aims at strengthening the analysing and decision-making power of local communities. PLA (Participatory Learning and Action) is another commonly used umbrella term which refers to approaches and methodologies which encourage the full participation of people in the processes of learning about their needs and opportunities, and in the action required to address them.

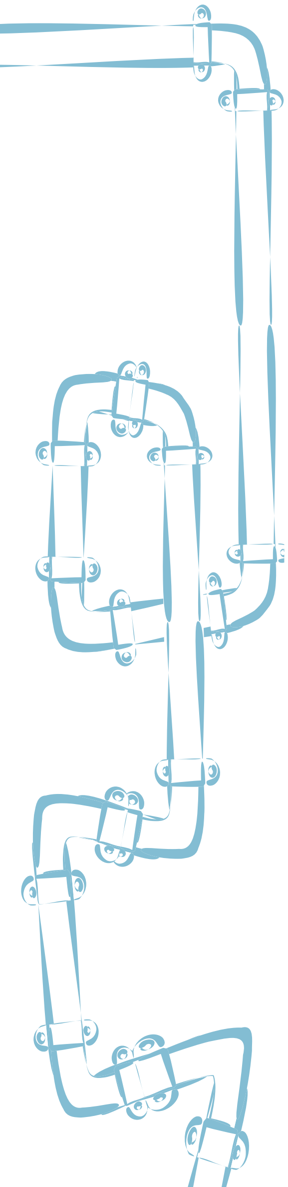
The methods used in PRA, RRA or PLA are many and varied and numerous resources are available. Some useful publications are: Tools for Community Participation. A Manual for Training Trainers in Participatory Techniques (Srinivasan, 1990); Toolkits. A Practical Guide to Assessment, Monitoring, Review and Evaluation (Gosling & Edwards, 1995); and Collaborating for Sustainability. A Resource Kit for Facilitators of Participatory Natural Resource Management in the Pacific by the International Waters Project (Mahanty & Stacey, 2004). The companion manual to these guidelines: “Harvesting the Heavens: A Manual for Participatory Training in Rainwater Harvesting” has been developed specifically for application in rainwater harvesting projects in the Pacific region but would also be useful elsewhere.

1.5 Climate variability and rainwater harvesting

Although small islands within tropical regions generally receive an abundance of rainfall, the climate in these islands can be quite variable depending on geographical location, island size and topography. The climate of small oceanic islands is governed by the regional climate, while small islands closer to continents or large islands may also be influenced by local climatic conditions.

Average annual rainfall varies considerably between islands in the tropical Pacific Ocean with variations between annual rainfalls in excess of 4,000 mm to less than 500 mm. In high volcanic islands, orographic effects can cause much higher rainfall at altitude than in low-lying areas (e.g. Viti Levu, Fiji), while long-term rainfall does not usually vary much across individual low-lying islands.

Two of the most important climatic influences on small islands in the Pacific region are El Niño Southern Oscillation (ENSO) episodes and tropical storms.

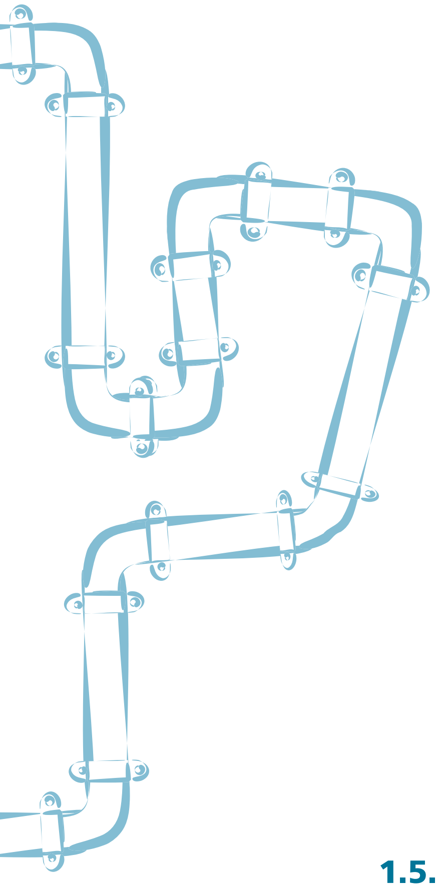


1.5.1 ENSO

El Niño is the term used for the extensive warming of the upper ocean in the tropical eastern Pacific. The negative or cooling phase of El Niño is called La Niña and both events are linked with a change in atmospheric pressure between the western and central regions of the Pacific Ocean known as the Southern Oscillation (SO). A measure of this variation, called the Southern Oscillation Index (SOI) is based on the pressure difference between Tahiti in the South Pacific and Darwin in northern Australia. The term ENSO (El Niño Southern Oscillation) is widely used to refer to the effects of the El Niño and La Niña phases of this natural cycle.

El Niño events have the potential to cause catastrophic droughts in the Pacific region such as in Papua New Guinea and other Melanesian islands as well as the Federated States of Micronesia and the Marshall Islands.

The reverse condition, popularly known as La Niña, occurs when the Southern Oscillation Index (SOI) is positive and the eastern Pacific is rela-



tively cool. The low-equatorial islands of western Kiribati are seriously affected during a La Niña. When the SOI is strongly positive, dry easterly winds are more dominant than usual and their influence may produce prolonged droughts (Scott, Overmars, *et al*., 2002).

These periods of drought pose serious risks to communities that are reliant on rainwater harvesting as a primary source. Also when rainwater is being used as a supplementary source, droughts can seriously affect the availability of freshwater due to depletion of groundwater aquifers resulting in saltwater intrusion in low-lying atoll islands. With limited storage capacities for rainwater as well as shallow groundwater aquifers these atoll islands require careful management of their water resources.

Irrespective of extreme periods of droughts, the variability in rainfall necessitates the application of climate information in the design of rainwater harvesting systems. Specifically when rainwater is the primary source for domestic water supply, the water consumption should be in balance with the amount of rainfall that can be collected. Methods to determine appropriate storage tank sizes based on the analysis of rainfall patterns are provided in Chapter 3.

1.5.2 Tropical cyclones

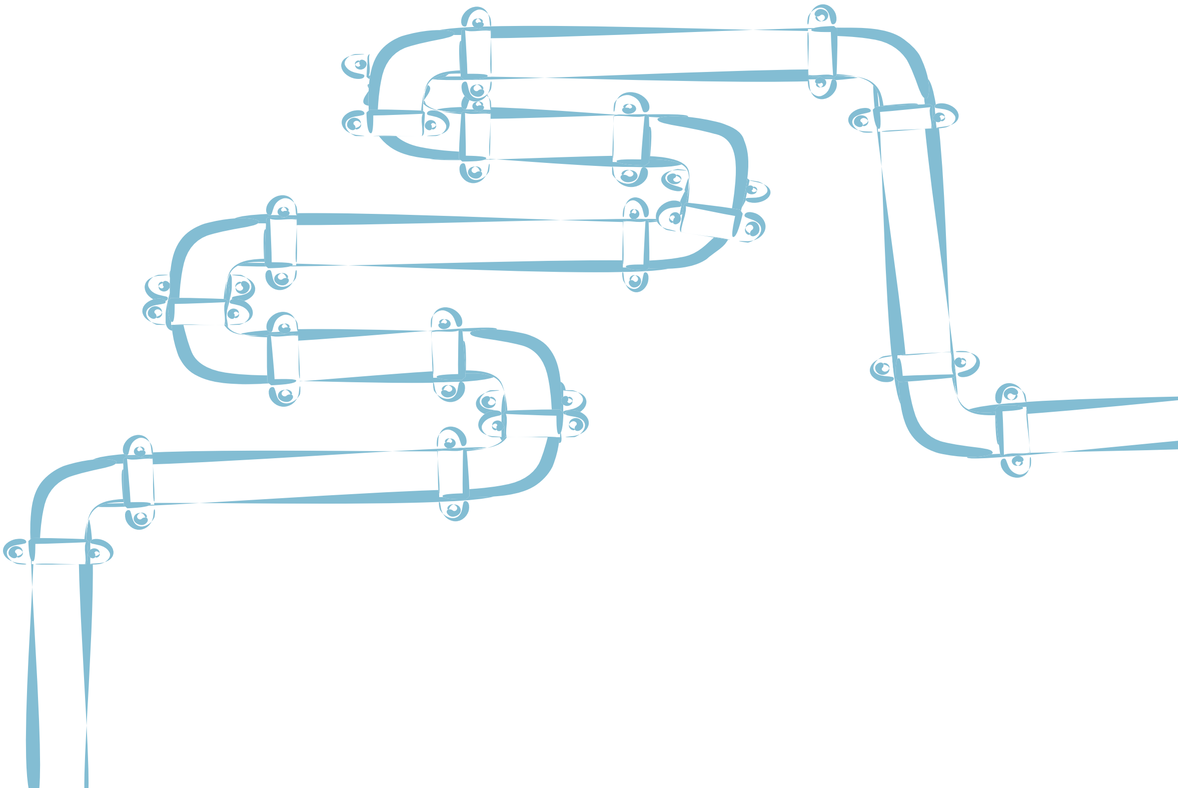
Called hurricanes in the Atlantic and typhoons in the western Pacific, tropical cyclones are large systems of wind rotating around a centre of low atmospheric pressure. Their winds which can reach as high as 200 km/h, torrential rains and high waves, can cause extensive damage to Pacific Island Countries. In the northern Pacific the typhoon season lasts from May to October and in the south Pacific the cyclone season runs from November to April (Scott, *et al*., 2002).

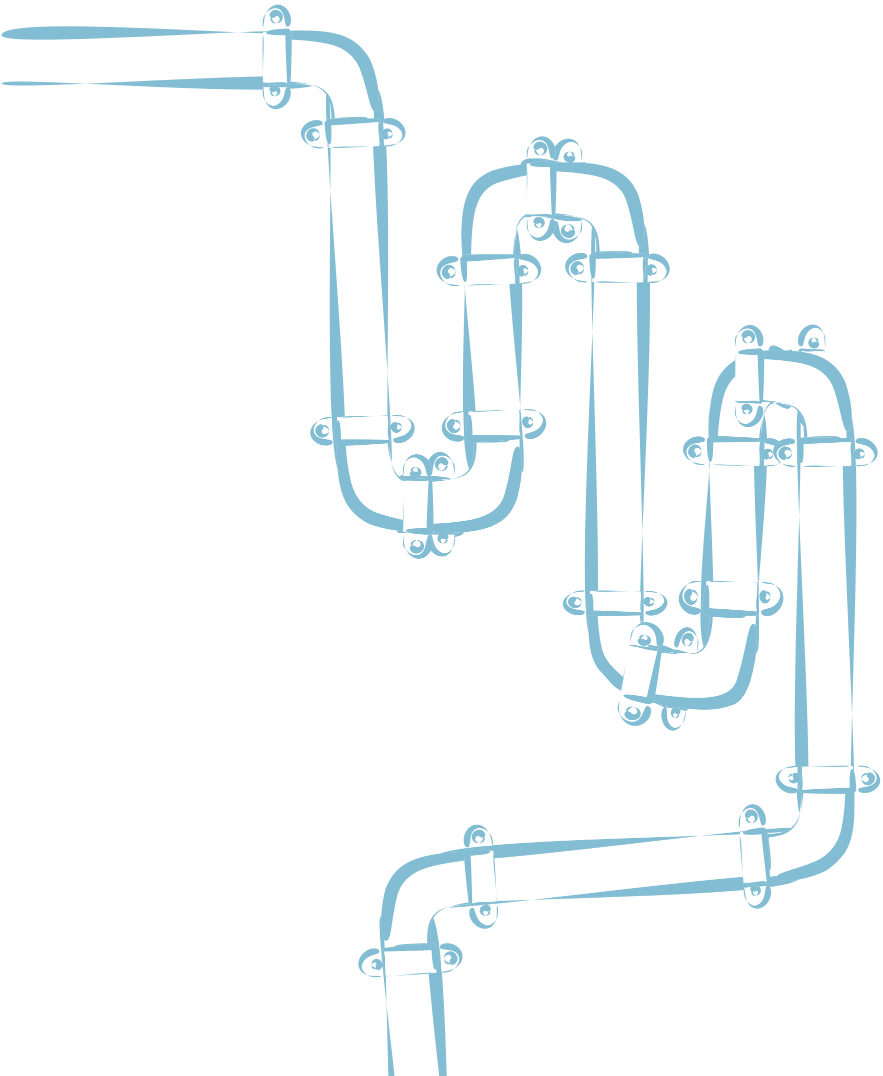
Many small islands are affected by random cyclonic events, which are a major problem for communities, often causing significant storm damage and flooding. Storm surges have inundated land, caused loss of life and severely damaged infrastructure in some small islands, for example, atolls in Tuvalu, the Marshall Islands, Federated States of Micronesia and the northern Cook Islands. During these events, rainwater harvesting systems can be severely affected such as has been shown in Tonga after cyclone Waka hit Vava'u in December 2001 causing damage to the tanks and gutters as well as removing roofs.

While designing and implementing rainwater harvesting systems consideration should be given to requirements for anchorages and reinforcement of susceptible parts.

Lessons learned on rainwater harvesting in Pacific Island Countries

- Rainwater harvesting systems have a long history in the Pacific.
- Rainwater harvesting is an appropriate technology for domestic water supply especially in low-lying atolls or raised limestone islands.
- Rainwater harvesting can be used as a primary source as well as a secondary source and can reduce pressures on existing water resources.
- Lessons learned from other projects are necessary input for improving the sustainability of rainwater harvesting projects.
- Participatory approaches should be encouraged for use as a methodology to engage the community in all aspects of rainwater harvesting.
- Projects should not only focus on assistance for infrastructure but allow development by the community themselves over longer time spans than normally planned.
- Climate information should be used for the design of rainwater harvesting systems.





2 Rainwater harvesting projects

2.1 When is rainwater harvesting appropriate?

Tools like Rapid Rural Appraisal, Participatory Rural Appraisal or Participatory Learning and Action could all identify improvement of the domestic water supply as one of the priority needs of a community and even identify actions to address these.

But when is rainwater harvesting appropriate for the given circumstances keeping in mind that it would only serve as a supplementary water source in most situations? Wouldn't investing in improvements of the main water supply system be much more cost-effective? Wouldn't water conservation or hygiene-awareness programmes be much more beneficial for the community?

Of course the considerations by the community and the project implementation agencies have to be carefully evaluated. The following checklists might be useful to help in assessing the advantages and disadvantages of, and pre-conditions for, rainwater harvesting as a domestic water supply option.

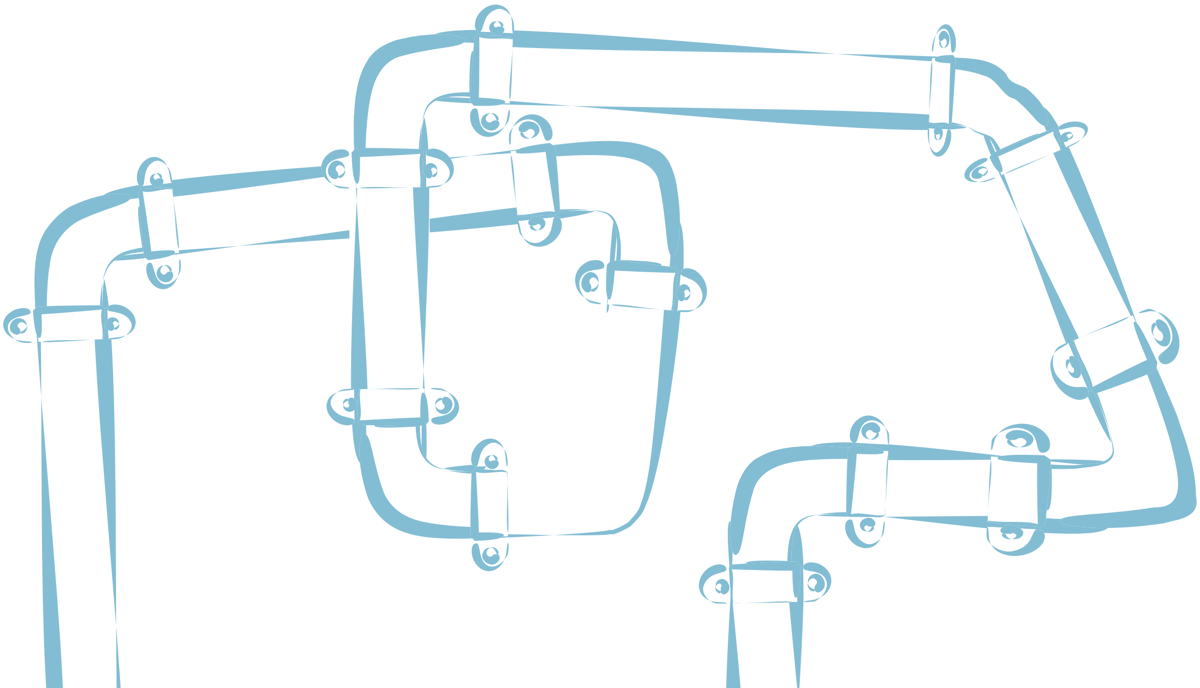


Table 2.1: *Overview of the advantages and disadvantages of rainwater harvesting systems for domestic water supply*

Advantages	Disadvantages
1. **Convenience** Provides a supply at the point of consumption.	1. **Expensive** When compared with alternative water sources, where these are available, the cost per litre for rainwater is frequently higher.
2. **Good maintenance** The operation and maintenance of household catchment systems are under sole control of the tank owner's family.	2. **Supply is limited** Both by the amount of rainfall and size of catchment area.
3. **Low running costs** These are almost negligible.	3. **High initial costs** The main cost of rainwater catchment systems is almost wholly incurred during the initial construction, when a considerable capital outlay is required.
4. **Relatively good water quality** Better than traditional sources, especially for roof catchment.	4. **Unattractive to policy makers** Rainwater projects are invariably far more cumbersome to administer than single large projects, e.g. a dam.
5. **Low environment impact** Rainwater is a renewable resources and no damage is done either to the environment or to future supplies through its introduction.	5. **Supply is susceptible to droughts** Occurrence of long dry spells and droughts will adversely affect the performance of rainwater harvesting systems.
6. **Ubiquitous supply** Rainwater collection is always a water-supply alternative wherever rain falls.	6. **Water quality vulnerable** The quality of rainwater may be affected by air pollution in the vicinity of certain industries. Contamination from animal or bird droppings, insects, dirt and organic matter can also be a problem.
7. **Simple construction** The construction of rainwater catchment systems is simple and local people can easily be trained to build these by themselves; this reduces costs and encourages community participation.	
8. **Flexible technology** Systems can be built to almost any requirement. Poor households can start with a single small tank and add more when they can afford it.	

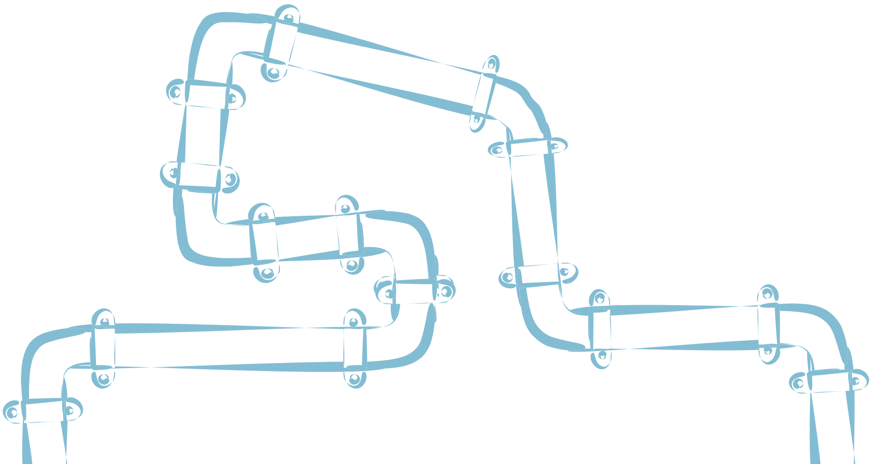


Table 2.2: *Checklist for assessing appropriateness and viability of rainwater harvesting systems*

Desirable pre-conditions for rainwater harvesting projects
Technical feasibility Rainfall and catchment area must be sufficient to meet demand Design should be appropriate Skills or training potential must be available locally
Social and economic feasibility A real felt need in the community for better water provision Designs should be affordable and cost-effective The community should be enthusiastic and fully involved Experiences with previous projects should have been positive Existence of social cohesion (not conflict) essential
Environmental feasibility and health The project should have an acceptable level of environmental impact The project should be designed to enhance the environment The project should improve both the quantity and quality of water available and should have a positive impact on the health of the community
Alternatives considered All reasonable alternative means of water provision should be investigated Consideration should be given to using more than one alternative in combination
Institutional arrangements The community should have the institutional capacity to manage the development and operation of the system Local human resources should be available to ensure the institutions continue to function effectively once any external agency assistance is withdrawn
Traditional and current practices Consideration should be given to traditional rainwater harvesting practices Existing approaches to rainwater utilisation and possible upgrading should be investigated

2.2 Implementation strategy

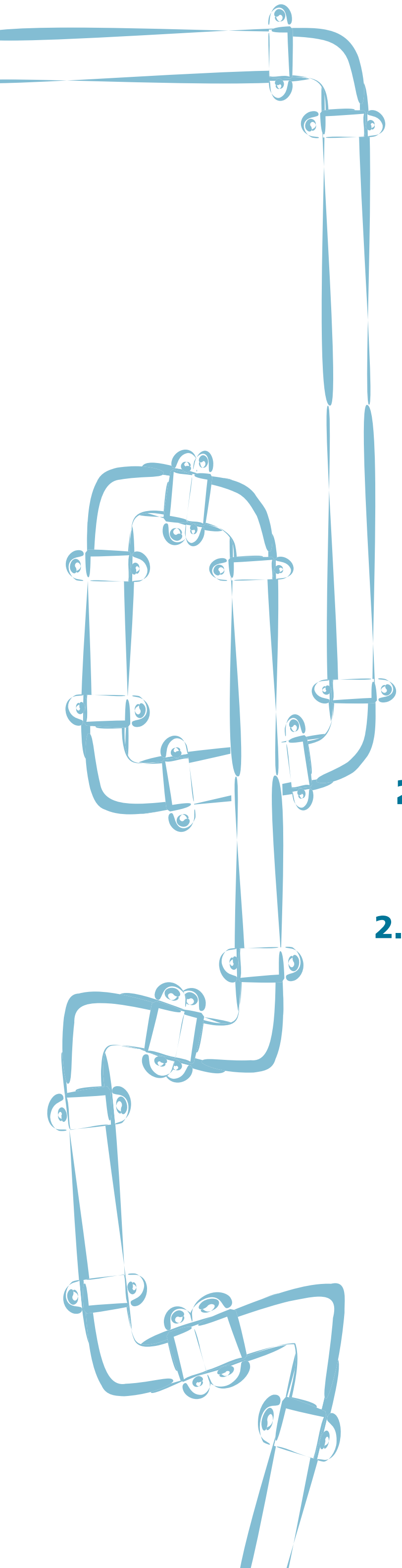
There is no single prescription that can be followed when implementing any particular rainwater harvesting project. The strategy will vary depending on the type and scale of the project, the technology used, and the nature of the community involved. There are however, some principles, which apply to all projects. The implementation of domestic rainwater harvesting systems in any development project just represents one component of a broader effort to achieve a number of development objectives.

For example, a rainwater harvesting implementation project might lead to:

- improved health and hygiene awareness in the community;
- development of new skills and employment;
- development of capacity in project planning, implementation, management, operation and maintenance;
- development of community leadership, involvement of men and women in decision-making;
- development of financial management and fundraising skills;
- growing sense of self-esteem, self-confidence and self-reliance within the community.

Very often, project success is measured in terms of the successful implementation of the technical hardware, with less attention being given to social development. This is partly because social benefits are less obvious, harder to measure, and less easy to demonstrate as evidence of a successful project.

The implementation strategy for successful projects involves a partnership approach in which all parties will have different things to offer. For example, the community may provide local knowledge and contribute to project management and operational input as well as providing labour and local materials to keep costs down. External agencies will normally offer technical and organisational know-how related to the technology alternatives. They may also advise on the construction and maintenance implications of different options as well as providing financial support and/or assistance in establishing financing mechanisms for the project. Furthermore, they will usually support training activities and provide support if unforeseen problems arise.



2.3 Implementation stages

The key stages in any project implementation strategy include the following:

2.3.1 Identification

The first stage in project initiation involves the identification of both appropriate project partners and appropriate technologies. Identifying partners may involve a donor, NGO, CBO or government agency approaching a community that needs assistance with improving water provision, and opening a dialogue with them.

It is preferable, however, that it is the community that organises itself, identifies the specific issues with which it needs assistance, and seeks out partners. Once a partnership is formed it is essential that the community remains engaged as an equal partner throughout the project planning, design and implementation stages. Eventually the community should take over the responsibility entirely for the operation and maintenance of any implemented technology.

Project arrangements and partner identification

SOPAC signed a project agreement with UNEP to implement a demonstration project on rainwater harvesting in the Pacific.

During the project identification phase a decision matrix was developed to evaluate potential host countries of the project. The matrix included: practical implementation as well as technical, economic, social, health and environmental considerations. Based on the responses from questionnaires and other available information, the countries were ranked on their suitability to host the project.

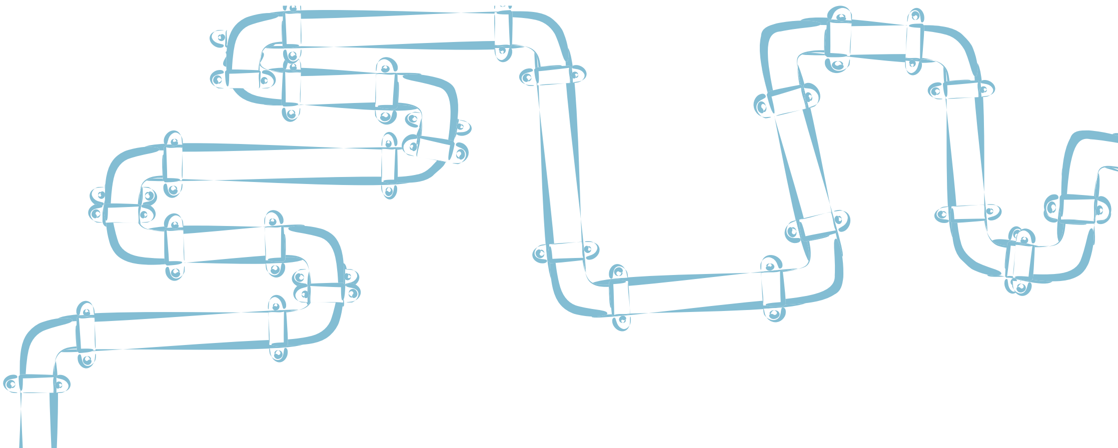
Following the outcomes of the selection process it was decided that Tonga could host the demonstration project through the Tonga Community Development Trust (TCDT), a local NGO who had facilitated the implementation of rainwater harvesting projects in Tonga for more than 20 years through their Village Women's Development Programme (VWDP).

Discussion during the identification phase between SOPAC and TCDT suggested that implementation of the project should take place in a peri-urban and a rural community.

Building on the existing VWDP network, the need for improved water supply was identified within two communities in the island group of Vava'u, namely 'Utungake (peri-urban) and Matamaka (rural).

2.3.2 Management and administration

Once a partnership has been formed between a community and a donor, NGO, CBO or government agency, it is essential that an effective management structure be put in place to ensure the efficient administration of the project. The organisational structure should include substantial community representation and involvement, preferably using existing mechanisms.



Project management and administration

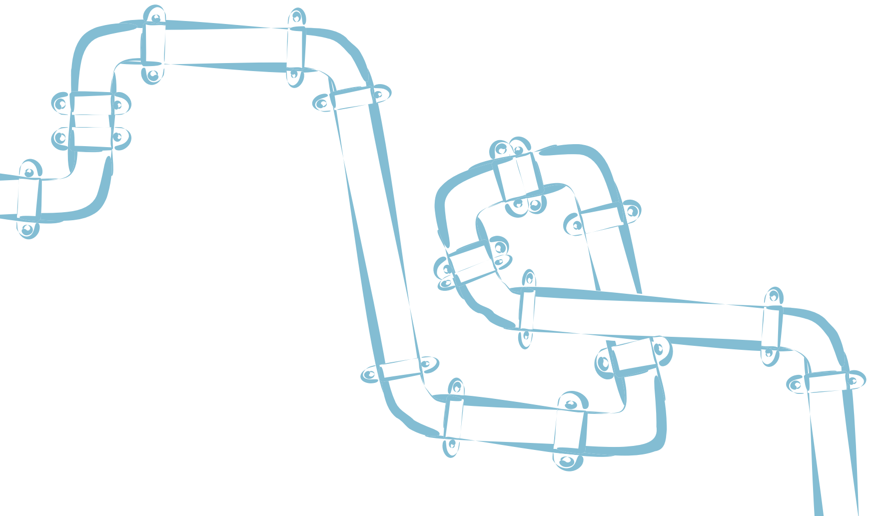
In addition to the agreement between SOPAC and UNEP a contract was signed between SOPAC and TCDT to implement the project. SOPAC was required to submit progress reports to UNEP every 6 months and TCDT was required to sumit quarterly progress reports to SOPAC. Administration of the project at the community level was facilitated by the VWDP extension workers through the local women's groups.

Project management on all levels was made more difficult by the fact that staff involved in the project from the three organisations operated in three different countries. Changeover of staff at TCDT and SOPAC also affected communication at times. Although reporting arrangements were clear, the project would have benefited from a better-defined mechanism for adjusting the implementation plans where needed.

2.3.3 Planning

The planning stage should include technical, socio-economic, environmental, health and institutional assessments and surveys to collect relevant information. Detailed social surveys, public meetings and interviews are some of the methods through which the community's goals and desires may be clearly ascertained. All of this information should be used for the detailed planning of the project including specific outputs, activities, workplans, budgets, timeframes and responsible parties.

It is vital that any community representative working with an external partner agency does represent the views of the whole community and is accountable to it. While community members may not be qualified to assess the technical merits of tank designs, they may have opinions or preferences based on experiences or cultural beliefs, which may strongly influence the popularity of a particular design within the community.



Needs assessment

Prior to construction of the rainwater harvesting systems, a social survey (including household questionnaires) was carried out in the community of ʻUtungake by SOPAC and TCDT. Technical surveys were also carried out which included water quality testing in existing tanks and a survey of roof areas to allow the appropriate sizing of new tanks. An example of the social questionnaire survey can be found in Appendix B.

For the household surveys an interpreter was used, as the SOPAC staff member was not able to speak the local language. The local interpreters from the VWDP community workers played a key role in the communication between the community and the external agencies. A full understanding of the survey by the local interpreter was therefore very important.

Based on this information the project outputs, activities, workplan, budget and timeframe were agreed upon by TCDT and SOPAC.

2.3.4 Economics and financing

Considerations and contributions

Taking economic considerations into account while implementing water supply projects is often difficult. There is usually an inverse relationship between the cost of water on one hand and the ability to pay on the other. While it becomes increasingly expensive to provide supplies to smaller and remoter settlements and communities, the economic opportunities for the communities, and ability to contribute financially, decrease at the same time.

Another important economic consideration that is sometimes overlooked is the time and energy involved in collecting water. Roof catchment systems for households reduce time and energy costs to near zero. For example, while the value of the time saved may be small in the case of poor rural communities, the benefits in terms of improved quality of life and livelihoods will often be dramatic as the time and energy previously devoted to collecting water can be used for other activities.

Project financing strategies will depend on the financial resources of the community. It is important to gain an understanding in the local context of whether systems are affordable and if people are willing to pay for them. If people are willing to pay but system costs are too high, some kind of funding mechanism is required. Many households could benefit substantially from a new or upgraded roof catchment system but simply cannot afford the costs. A clear indication is the number of households using inappropriate technology such as pots, pans, buckets, oil drums, and limited or no guttering.

Where affordability is an issue, incremental approaches have proven to be very successful. Installing smaller cheaper systems which can be added to in the future will allow more households to take advantage of rainwater harvesting in the short term. Householders who experience the benefits of small systems will be encouraged to add to their storage as they can afford it. The appropriateness of the design, size and cost of systems should be considered carefully in the local context.

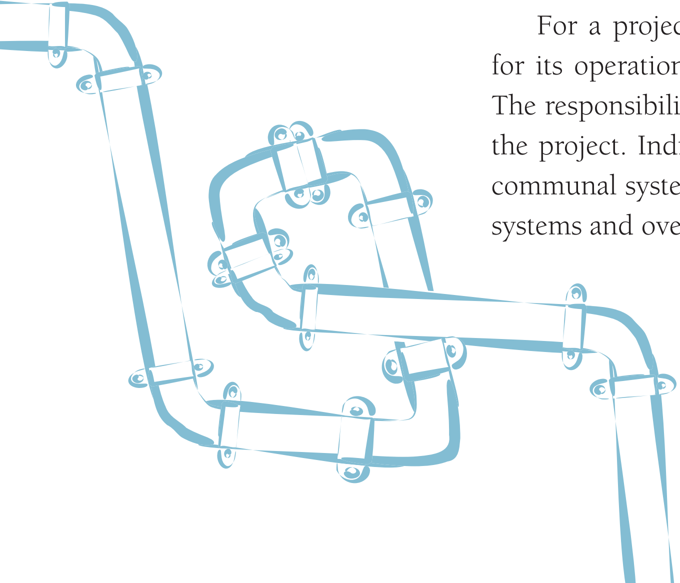
Where the ability of the community to contribute financially is limited, income-generating activities can be organised. Assistance in financing the systems can also be provided by establishing revolving funds or credit facilities. Subsidies from a donor or the government will be required where project beneficiaries are too poor to pay the full system costs. Where project beneficiaries are in a position to pay for the full cost of systems, they should be required to do so.

Although many households may have limited resources available when compared with the high costs of roof catchment systems, almost all households do have some resources at their disposal which could be invested in systems which include besides cash, labour capacity, local materials which can be used in construction (e.g. sand, stones and boulders) or livestock that can be sold to raise the necessary funds.

If loans and subsidies are provided they should be set at realistic levels. In many instances, subsidies are both appropriate and necessary in bringing rainwater harvesting systems within reach of the rural poor. However they should be used with care and a 100% subsidy is seldom appropriate.

By contributing towards a rainwater system, a householder not only signals a desire to acquire it but also secures some ownership of it. High levels of subsidy are normally unsustainable and limit the size of the population that can be reached. They also set an unsatisfactory precedent and may encourage dependency. Not using subsidies at all would pose the risk of depriving the rural poor of improved water supply, whereas many urban supplies are already subsidised.

For a project to be sustainable, the beneficiaries should be able to pay for its operation, maintenance, repair and ideally future replacement costs. The responsibilities for covering those costs should be clear to all partners in the project. Individual household systems require a different approach than communal systems where the setting up of a water committee to manage the systems and oversee the collection and expenditure of funds will be needed.



Financing and community contributions

Neither the community of ʻUtungake nor Matamaka possessed the financial resources to pay for the full cost of installing rainwater harvesting systems. Funding was provided by SIDA channelled through UNEP and SOPAC to TCDT to implement the project. The community contributions included the provision of a level area to locate the tank, part of the tank construction materials (sand and water), a suitable roof surface, fascia board, transport of all materials to site, food and lodging for contractors and some voluntary manual labour.

Usually TCDT rainwater harvesting projects also require a financial contribution of 100 Pa'anga* per household. However, during discussion with TCDT extension workers it was agreed not to ask for this contribution due to the timing of the project close to Christmas and the beginning of the school year.

One of the aspects that was not taken into account in the original project budget was the high level of inflation in Tonga. It is important when budgeting for a multi-year project to consider issues such as price fluctuations and how and when money is transferred to project partners.

During the course of the project in ʻUtungake, TCDT extension workers encouraged the collection of village funds to look after on-going operation and maintenance. Sub-committees of approximately 10 households collect and manage their own funds as appropriate. The effectiveness and efficiency of this institutional framework, continuing to collect money and making it available for maintenance and repair, will be proven over time.

(*Pa'anga is the Tongan currency 1 Pa'anga ≃ US$0.50)

Costs of rainwater harvesting systems

True system costs and how they compare to other technologies is complicated by the fact that the relative costs of different types of system vary from place to place, and the costs of most communal systems are subject to significant variations based on economies of scale. Nevertheless, some generalisations can be made about rainwater harvesting system costs:

- Initial per capita capital costs are relatively high compared with alternatives, such as simple groundwater systems or gravity-fed spring supplies;
- Recurrent (running) costs are low, especially compared with boreholes and piped schemes;
- Underground tanks are cheaper per cubic metre of storage than above-ground tanks; and
- Costs per cubic metre decrease as storage tanks become larger. This favours communal systems over private systems when compared purely in terms of cost.

When evaluating different types of rainwater harvesting systems, local factors such as availability of materials and labour, and ease of transport of goods to the installation site will have a significant influence on cost. Not only initial capital costs should be considered but maintenance and repair and replacement costs given different tank life expectancy scenarios. Some indicative costs for different tank types available in the Pacific and how they compare with the tanks built in the demonstration project in Tonga are included in Table 3.3 of Chapter 3.

Revolving fund schemes and income-generating activities

Establishing revolving fund schemes have sometimes been successful for the implementation of rainwater harvesting systems. Groups of households can agree to make small regular monthly contributions to a central fund. The amount raised each month should be sufficient to pay for at least one tank. If in each month one tank is constructed, a group of 12 households could each have a tank available after one year. Members of the group are also expected to provide labour and collect materials for construction.

Organising income-generating activities such as selling of handicrafts, providing catering services or selling produce from communal market gardens have been a more popular method of fundraising than the use of revolving funds.

Langafonua ‘a Fafine Tonga

(Nation Building by the Women of Tonga)

The Langafonua ‘a Fafine Tonga is a national non-profit, non-governmental organisation established in the 1950’s by the late Queen Salote Tupou III who believed it is necessary to both preserve and pass on the skills of traditional crafts and culture as well as promote the advancement, welfare, security and the development of all women in Tonga.

Langafonua addresses community development in various ways. One approach is through a scheme whereby people in communities produce handicrafts, mats, tapa, jewellery etc., which are sold from the Langafonua office. Enabling communities to generate income allows them to take control of their own development.

2.3.5 Training

Training should not be limited to simply transferring specific skills such as the construction techniques for a particular system. Instead, training should be part of a broader attempt to build capacity within the community to initiate, plan, implement and manage a whole range of development projects.

Training for rainwater harvesting systems should include the development of competence in some or all of the following areas:

- Survey and evaluation of potential sites;
- Simple design techniques and technology selection;
- Selection of suitable, locally available building materials;
- Operation, maintenance and repair of systems;
- Community participation and community management;
- Hygiene education;
- Project management and administration; and
- Project assessment and evaluation.

Training

Training was provided by SOPAC during the planning stage on the use of social and technical surveys and aspects of water quality with VWDP extension workers.

During a third field visit by SOPAC and UNEP a "training of trainers" workshop was carried out with VWDP community extension workers as well as additional participation by TCDT and local government representatives. As a result of the workshop a "Manual for Participatory Training in Rainwater Harvesting" was produced which is targeted for use by NGO's or others involved in rainwater harvesting projects.

Training was also provided in participatory evaluation for the VWDP extension workers in Vava'u during the final SOPAC visit. The extension workers then put the tools used in the training into practice by carrying out project evaluations in both 'Utungake and Matamaka.

2.3.6 Construction

Communities should be fully engaged in the construction phase, and while their voluntary labour provides a valuable input it is essential that they are not involved simply in the capacity of providers of free labour as is often the case.

On-the-job training can be an important component of grassroots capacity building and during the construction phase the community can be trained and gain skills that are useful in later phases of the project.

In the past, construction has often been viewed as a predominantly male occupation. While it is true that in some cultures heavy physical labour is predominantly undertaken by men, in many others women have traditionally been involved in construction. There is really no reason why women should not be involved in the construction phase, at the very least as team members.

The more familiar women are with the rainwater harvesting system at household or community level, the more able they will be to maintain and repair them, thus enhancing the role of women in the management of water.

Contracting out

The communities of 'Utungake and Matamaka were involved only to a limited degree in the construction phase as the civil works were sourced out to a local contractor in Vava'u. For a number of different reasons there were delays in the project and the use of a contractor was felt to be most expedient as well as ensuring good quality construction.

The contractor chosen by TCDT was experienced in the construction of rainwater harvesting tanks in Vava'u and had been involved in the EU-funded rehabilitation efforts for cyclone struck houses.

In 'Utungake the local youth group and parents & teachers association assisted with the construction of the two tanks in the school compound. Otherwise there was no planned effort to transfer construction skills to community members. Skill transfer takes time and where contractors are used, time is money, and capacity building will have low priority.

2.3.7 Operation, maintenance and repair

Regular inspection, cleaning, maintenance and occasional repairs are essential for the long-term success of any rainwater project. Manuals or guidelines can be provided during the implementation stage, and systems must be designed to encourage these practices.

Chapter 4 provides detailed information on operation and maintenance aspects for roof catchment systems.

Manual on operation and maintenance

The "Harvesting the Heavens: A Manual for Participatory Training in Rainwater Harvesting" – produced as part of the project – contains a number of participatory techniques, tools and activities based on best practices from a variety of sources. A section within the manual deals with operation and maintenance of systems using simple participatory techniques to transfer technical information across to training participants.

2.3.8 Evaluation, monitoring, improvement and replication

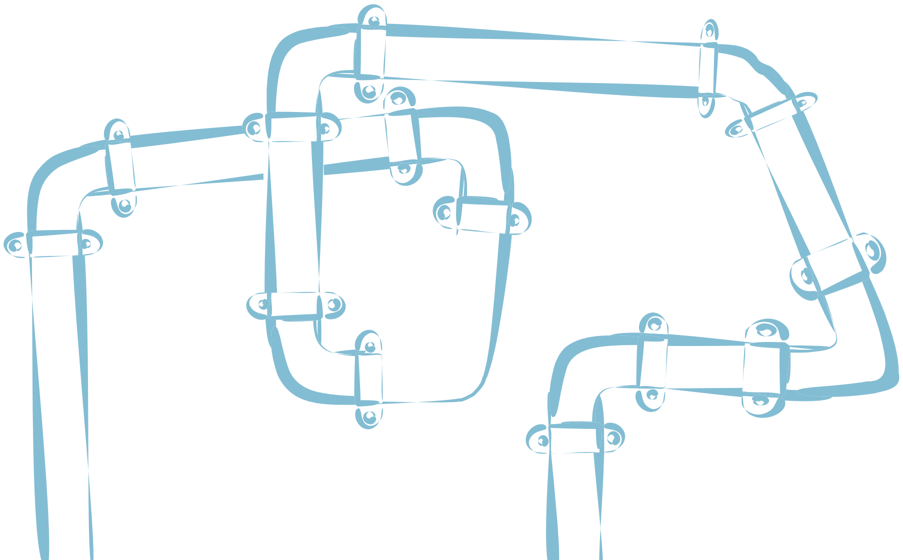
No project will ever be perfect and a thorough evaluation at the end of the implementation stage will produce a number of valuable lessons. In order that the community also learns, it is essential that it is fully involved in the evaluation exercise. After a comprehensive evaluation the community and external partners should be in a position to make improvements to any part of the project that is unsatisfactory. This ensures that future replication of the technology, both within the community and beyond, benefits from the lessons learned. Even after the evaluation, follow-up work and replication have taken place, monitoring the project is worthwhile through inspection of systems every few years to ensure the technology and its maintenance, repair, and overall project management continue to be sustainable.

Measures and features of successful projects

In order to effectively measure whether a project is successful or not, clear and realistic goals and objectives should be formulated. Measuring project success is then a matter of comparing the final outcomes with the goals and objectives.

A number of features common to successful projects are as follows:

- The projects started small and grew slowly allowing testing; development and modification of system design and implementation strategy based on constant re-evaluation;
- The communities needed improved water supply and indicated this as priority;
- The projects were planned, implemented and run predominantly with the input of local people; and
- The communities contributed with funds, labour and/or ideas.



Measuring project success

Measuring the success of any project involves first comparing the final outcomes with the original aims and objectives of the project to see if these were achieved.

For the Tonga project, the objectives were:

(a) To install rainwater harvesting systems in (i) one peri-urban community and (ii) one rural community in a Pacific small island country.

(b) To improve water availability in the rural and urban communities.

(c) To empower women to participate in water resources planning and decision-making.

(d) To promote rainwater harvesting by providing appropriate technologies and adoption of suitable policies.

Whether the first two objectives (a and b) were met by the project was relatively easy to verify through evaluation after completion of the project. The success in achieving the other two objectives (c and d) was more difficult to measure.

Social research techniques, such as participatory evaluation, can be useful in this regard. The participation of women (c) was assessed during the project evaluation but whether this has long-term effects in the community would require continued monitoring.

Regarding success in promoting rainwater harvesting (d), the best indication would be to assess whether application of rainwater harvesting systems had increased over time as well as how well schemes have been maintained.

Participatory evaluation

Participatory planning and development – involving users and communities in all stages of the development process – are now widely recognised as being critical to achieve sustained benefits. However, participatory data collection for monitoring and evaluation has not yet been widely applied and are often found not to be an integral part of the development process.

Field experiences and records of successful implementation of participatory evaluation that resulted from the UNDP-World Bank Water and Sanitation Programme provide some guidance in how to facilitate meaningful participation (Narayan-Parker, 1993; Srinivasan, 1990). The UNDP inter-regional programme for Promotion Of the Role of Women in Water and Environmental Sanitation Services (PROWWESS) developed a framework for planning and evaluation in partnership with people that has been used as a basis to introduce the concept of participatory evaluation to the project (i.e. the communities in Tonga, the VWDP extension workers and the project team).

Evaluation in ‘Utungake and Matamaka

A participatory project evaluation was carried out by VWDP extension workers in the villages of ‘Utungake and Matamaka. To prepare the evaluation a 2-day workshop was held to introduce participants to participatory evaluation principles and tools. During the workshop the participants reviewed the project from their perspective and prepared a list of questions to be asked in the communities around the key themes of construction materials, impact on the community, interaction of TCDT with the community and impact on individual families. The questions were posed through semi-structured interviews and the analysis of responses was carried out by the VWDP workers themselves. The evaluation by the community resulted in a list of 13 recommendations and this will be used by TCDT in future projects:

1. That TCDT support the extension workers of VWDP to motivate communities to work together to become less dependent on outside monetary aid;
2. That TCDT investigate lower cost designs of tanks;
3. That future projects involve the training of local people to be able to carry out construction work themselves;
4. For future projects the aim should be to help the whole community, however, where funds are limited it is possible to do projects that do not cover the whole community as the overall outcome is still positive;
5. That TCDT management investigate the issue of the missing cement and shortage of guttering in ‘Utungake with the contractor;
6. There should be regular visits to communities during the project and particularly during the construction phase;
7. For future projects the size and length of guttering and the size of downpipes should be designed to make full use of the roof area available. If the installation work is sub-contracted, these details should be specified in the contract;
8. Future projects should ask for a similar level of contributions from communities as in this project;
9. That TCDT continue to look for funding to increase the number of tanks in communities in order to allow other activities such as construction of improved sanitation facilities, improving agriculture and flower gardens and raising animals;
10. That the criteria for selecting households to participate be always considered with community consultation but the final decision should rest with TCDT;
11. That the criteria used for selection of households to participate in the project be applied consistently but that some flexibility be allowed for those that have difficulty meeting their commitments/deadlines;

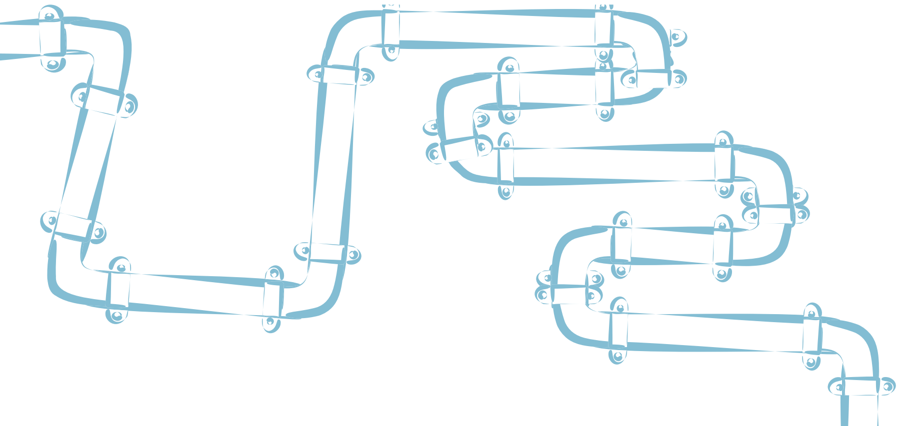
12. If the project is aiming to deliver tanks which differ from the standard size and materials the community should be consulted; and
13. In order to give clear and consistent messages to the communities about project activities, all communication should come through the local VWDP workers.

2.4 Obstacles

A wide variety of obstacles to project implementation exists. These can be identified at every level from the local community to external agencies. Such obstacles include:

- lack of willingness by individual community members to participate;
- pressure from funding partners to adopt a certain technology;
- unsustainable approach to implementation, e.g. hardware-oriented or top-down;
- opposition to a community-managed approach;
- lack of enthusiasm from politicians and policy makers;
- difficulties for engineers and government personnel in accepting and adapting to their new roles as facilitators in self-help initiatives;
- undermining of self-help programmes by government or donor-funded projects in the same vicinity offering free systems;
- conflicting priorities within the community and between the community and external agencies; and
- overlapping, conflicting or poorly-defined role for the government, and partner agencies.

In some cases resistance to a project may be overcome simply by engaging the community and raising awareness about the benefits and cost-effectiveness of the project while simultaneously allaying any concerns. Dialogue, the use of local media such as radio, newspapers, posters, and demonstration of systems at schools or other public buildings can all be used to change a community's perception of a project.



Lessons learned on implementing rainwater harvesting projects

Identification

- Apply selection criteria to identify project communities or areas (a decision matrix might help).
- Local communities should identify a real felt need for better water provision.
- Carefully identify partner organisations that can make the link to the communities including CBOs, NGOs, IGOs or other external agencies.

Project management and administration

- Apart from household initiatives, most projects involve a partnership between community members, government, donors and NGOs or CBOs. For this to succeed, the community must be fully involved in all aspects, including project planning, administration, management, financing, training, construction, operation, maintenance, repair, and evaluation.

Planning and design

- Clearly identify roles and responsibilities of the people and agencies involved.
- Develop clear lines of communication.
- Agree on a workplan with an achievable timeframe and provide regular updates.

Economics and financing

- Fully explore appropriate financing options.
- Donor and government agencies are encouraged to provide loans and subsidies set at realistic levels to bring rainwater harvesting systems within reach of the rural poor.
- High levels of subsidy are normally unsustainable and limit the size of the population that can be reached.

Training

- Provide training to communities or training of trainers in a variety of areas (e.g. community participation, operation and maintenance, survey and evaluation).
- Adopt participatory approaches in training.

Construction

- Encourage on-the-job training during construction and involve the community in the design of systems.
- Determine advantages and disadvantages of different system designs.

Operation, maintenance and repair

- Provide training and information/manuals on operation, maintenance and repair.

Evaluation, monitoring, improvement and replication

- Allow for evaluation within the project's duration and enforce improvements in the implementation.
- The replication of rainwater catchment systems technologies, both locally and globally, is ultimately the best measure of project success.

2.5 Sustainability

2.5.1 Community participation

To ensure the sustainability of any rainwater harvesting project it is essential that the community is fully engaged at every stage, including:

- identifying their most serious water-related problems and potential solutions;
- decision-making based on informed choices;
- sharing local knowledge and experience in designing the project;
- training for system construction and/or operation and maintenance;
- selection, siting and construction of the rainwater harvesting systems;
- developing financing mechanisms to ensure the project is sustained and costs are recovered; and
- evaluation of the project and redesigning when necessary.

Sustainability should be the principal criterion for evaluation of water projects or programmes.

Projects based on existing technologies and community-based institutions are far more likely to succeed and be sustained than those based on models imposed from outside.

The Village Women's Development Programme (VWDP)

TCDT's Village Women's Development Programme (VWDP) is a grassroots development programme, which works with women and communities. The VWDP supports activities which promote self-improvement, improvement of home/community environments, and which empower women (and through them, families and communities) to take control of, and be responsible for, their own development.

Approximately 270 women's groups in 60 outer island villages participate in the VWD Programme. Many activities are carried out with this outer-island network.

It was through VWDP that the project was "introduced" to the two village communities involved in the project, both of which had a very active network and took on the responsibility of coordinating the rainwater harvesting project for the village.

2.5.2 Ensuring the participation of women and men

It is important to recognise that communities are made up of people who will have different needs and priorities related to water supply. In particular, the roles and responsibilities of women and men within a community will generally be quite distinct, so the perspective and input of both these groups needs to be sought as part of any project. This would include such measures as:

- Disaggregating any data collected about the community to identify differences between women and men;
- Arranging project meetings so that it is possible for both women and men to attend. This may involve consideration of the time and place of meetings, how invitations are extended and communicated, seating arrangements and the facilitation of speaking out. Sometimes separate meetings with women and men may be necessary to enable full participation;
- Encouraging women as well as men to take on planning and decision making roles e.g. being part of committees; and
- Expanding traditional tasks by the teaching of new skills. For example, the simple regular maintenance tasks required for rainwater harvesting systems which in communities may be considered men's work, can also be taught to women.

2.5.3 Institutional and human resource development

For projects to be sustained and replicated it is essential that effective and supportive institutions exist. It is also important that the necessary local human resources are available to ensure the institutions continue to function effectively once any external agency assistance is withdrawn.

The failure of many water projects can be attributed to systematic deficiencies in the institutions responsible for policy-making, project design, and management. Therefore institutional strengthening and capacity building of human resources are key for the sustainability of any project. Institutional development refers to the organisation, management, financing, staffing, training, design, construction, operation and maintenance of water programmes.

Human resource development relates to the people that are needed to carry out these activities, and includes training, management and planning and supply of personnel.

Village-level water projects may succeed in the short term but the long-term sustainability of water management in general needs the support of institutions and commitment of the government through decision and policy makers. To ensure this support it is often necessary to explain and convince senior government and aid officials of the benefits of using appropriate technologies such as rainwater harvesting and the advantages of community-managed implementation strategies. Workshops, seminars, training courses and video presentations and the use of other media are all effective ways to reach and persuade key officials.

Rainwater harvesting video

In addition to the guidelines and manual, a demonstration video on Rainwater Harvesting was produced in collaboration with the Secretariat of the Pacific Community (SPC). The video encompasses the various stages of the project and is developed for Pacific island governments and communities, NGOs, donor agencies and international organisations to promote and demonstrate rainwater harvesting as a suitable option for domestic water supply.

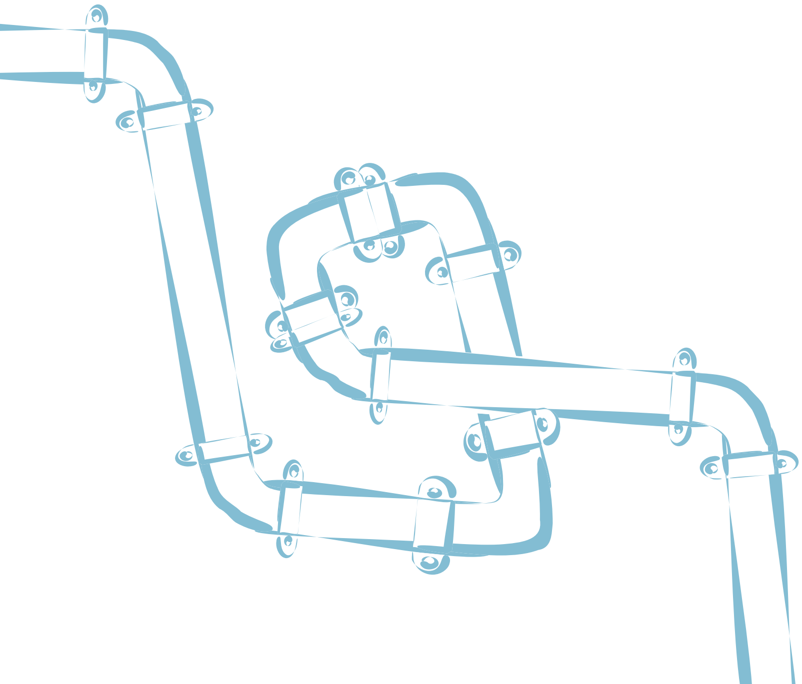
2.5.4 Responsibilities of project partners

The majority of water projects involve a partnership between individual community members and government, donors and/or NGOs, CBOs.

For such partnership to succeed it is essential that the community is fully involved. It is also very important that from the outset of any project, the various stakeholders have their specific roles and responsibilities clearly defined.

Role of communities and individuals

The success of any project that relies on a partnership between a community and an external partner agency depends on individual community members meeting their agreed obligations with respect to the project. These may include involvement in any public meetings relating to the project and establishing a water committee to manage its planning, implementation, operation and maintenance. The community may also provide agreed input of voluntary manual labour, local materials and money.



Fulfilling community obligations

The community contributions to the construction phase of the project were agreed during a field visit by TCDT prior to construction commencing. These included providing a level area to locate the tank, some materials and labour, a suitable roof surface, fascia board, transport of all materials to site, and food and lodging for contractors.

Initially the community was not informed on the quality of the sand required. An amount of sand sufficient to construct two tanks was already transported to the village before a problem with its quality was recognised.

Upon completion of the construction phase all homeowners that had met the requirements had been provided with a new tank (all but one homeowner fulfilled the original obligations).

In most cases the community as a whole stepped in to help individuals experiencing difficulties in meeting the obligations, as is common in Tonga. Interestingly, during the evaluation it was discovered that the men of the community felt that the homeowner who was not assisted could have been given more time. On the other hand, the women of the community felt that he had been given ample opportunity to ask for help and it was his own fault that he missed out.

Once the rainwater harvesting hardware is in place, it is normally the responsibility of the community or individual householders to ensure that proper operation, maintenance, and repairs are carried out. Many systems fail because the communities fail to meet their responsibilities. This is particularly common with respect to communally-shared facilities where often gutters and downpipes are not repaired and maintained and so become blocked or broken, reducing inflow into the tank. Tanks are also often neglected with leaking taps, cracks, broken screens and covers and no regular inspection and cleaning being carried out.

The failure of the community to maintain the systems properly often stems from the fact that clear responsibilities for addressing and paying for repairs were not allocated. Assuming these responsibilities is often more straightforward for individual households where they have a vested interest in maintaining the system. However, a common problem is that where a community is not sufficiently involved in a project it will expect the donor, NGO or government agency that installed the system to repair and maintain it.

Operation, maintenance and repair

Operation and maintenance of the rainwater systems were addressed through a "Training of Trainers" workshop held with community extension workers. This training also touched on issues with regards to reponsibilities associated with operation and maintenance. An outcome from the training was a manual for participatory training on rainwater harvesting, which uses simple participatory techniques to transfer information across to workshop participants. More information on operation, maintenance and repair can be found in Chapter 4.

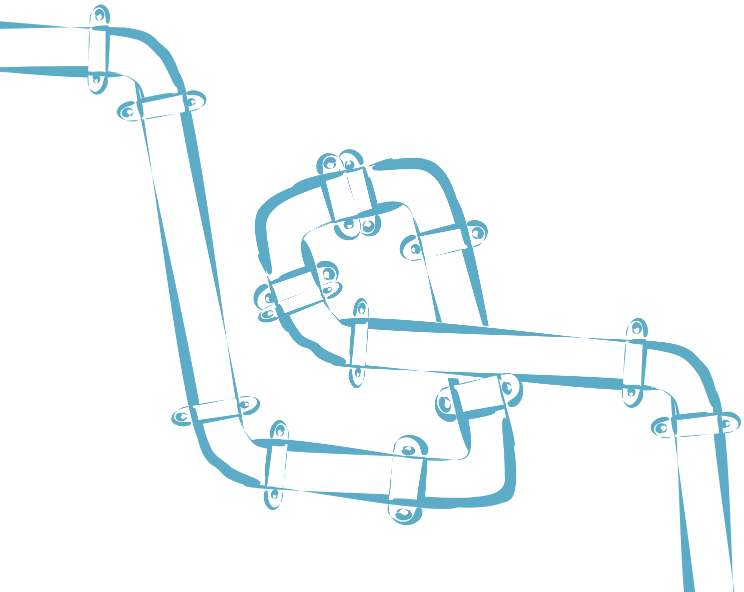
TCDT hopes to run training workshops in communities using the manual in the near future and are working on securing funds to do so. Ideally money would have been set aside in the original project to carry out this training.

Role of external agencies

From the community's point of view, government, donors, regional organisations and also NGOs are usually considered to be external agencies. To reduce the barriers created by such perceptions, representatives from these organisations should engage with the community, visiting frequently and giving support especially during the initial phase of any project.

Any external partner agency involved has a number of key responsibilities:

- Guarantee that the design being promoted is appropriate (i.e. safe, durable and cost-effective);
- Ensure obligations are met with respect to the project (written contracts are important); and
- Ensure all sectors of the community are involved in the project.



Parties to the project

External agencies that played key roles in this Rainwater Harvesting Project included:

- VWDP provided the linkages and coordination with the communities of 'Utungake and Matamaka;
- TCDT, as the local NGO counterpart, provided the operational inputs for the project including the identification of stakeholders and partners, liaison with women's groups, conducting field visits, developing design criteria and assessing the ability of the community to contribute to the implementation costs of the project.
- SOPAC, as Pacific regional executing partner, assumed the overall responsibility for the management of the demonstration project including the outsourcing of various tasks and assistance in the social and technical surveys, design and the operation and maintenance of rainwater tank systems;
- A stakeholder group which was made up of various government departments as advisors to the project;
- UNEP, as the implementing agency, provided advice, support and feedback on project implementation and experiences from the African demonstration project;
- SIDA was the funding agency for the demonstration project.

Role of the private sector

The private sector can play an important role in rainwater harvesting projects. Household and community construction of rainwater harvesting systems lends itself well to private sector involvement and the commercial marketing of tanks is sometimes encouraged as the most effective way of extending or replicating their use whilst continuing to assist poorer families.

Trained and experienced builders who have learned their skills on government or donor-funded projects can set up small-scale enterprises to service individuals in the community who can afford to buy rainwater harvesting systems. The emergence of dynamic private sector involvement in rainwater harvesting system implementation following a government- or donor-funded project is often a strong indication that the project has been successful.

Private sector involvement provides the opportunity for replication of designs introduced by the original project. If subsidies or other financing mechanisms are available the private sector should also be able to service the needs of poorer members of the community.

Contractor and design

A contract was awarded by TCDT to a local company for the construction of the rainwater tanks in ‘Utungake and Matamaka based on their substantial experience in tank building in Tonga. The contractor used a standard design that they were comfortable with from previous projects.

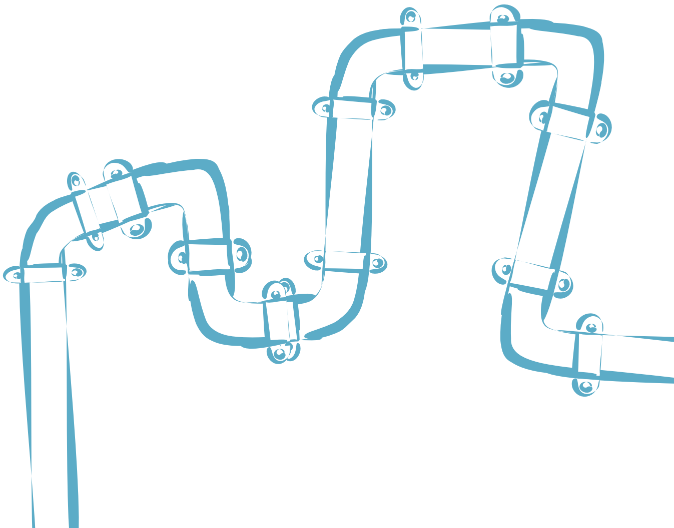
SOPAC provided technical advice on the tank dimensions based on the roof size inventory and the analyses of rainfall data. Suggestions were provided on tank sizes, material, first flush systems, screens, outlets, guttering etc. These were taken on board only to a limited extent.

The engagement of a contractor in the project allowed good quality construction in a tight time-frame but did not allow the flexibility to trial design improvements or include community involvement in the design choice.

2.5.4 Broader development benefits

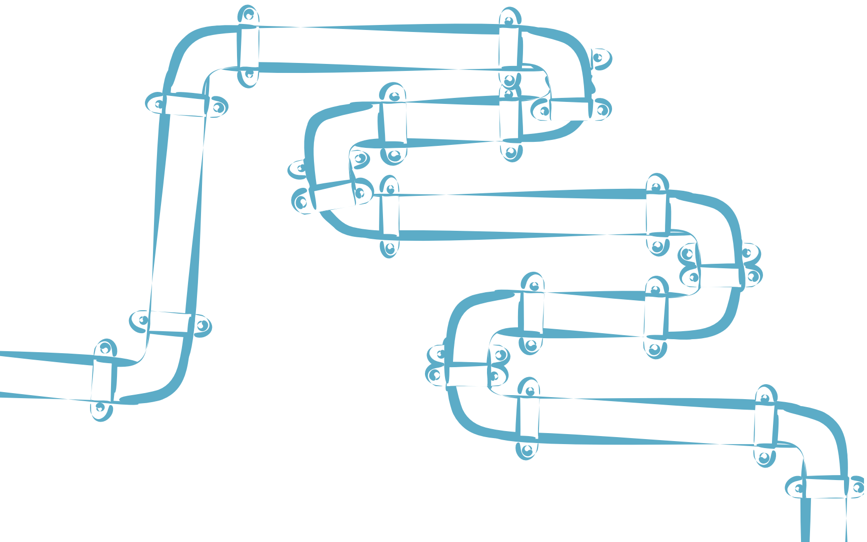
The extent to which individuals and the community at large will be prepared to commit time, labour, and money to a project will depend on their enthusiasm for the project. If the enthusiasm can be generated for a viable project, lack of skills in construction or project management need not necessarily be an obstacle to successful implementation if these can be addressed through adequate training initiatives. Indeed, most successful projects include a major element of capacity building within the community. This normally results in much broader development benefits than those resulting purely from the implementation of rainwater catchment systems hardware.

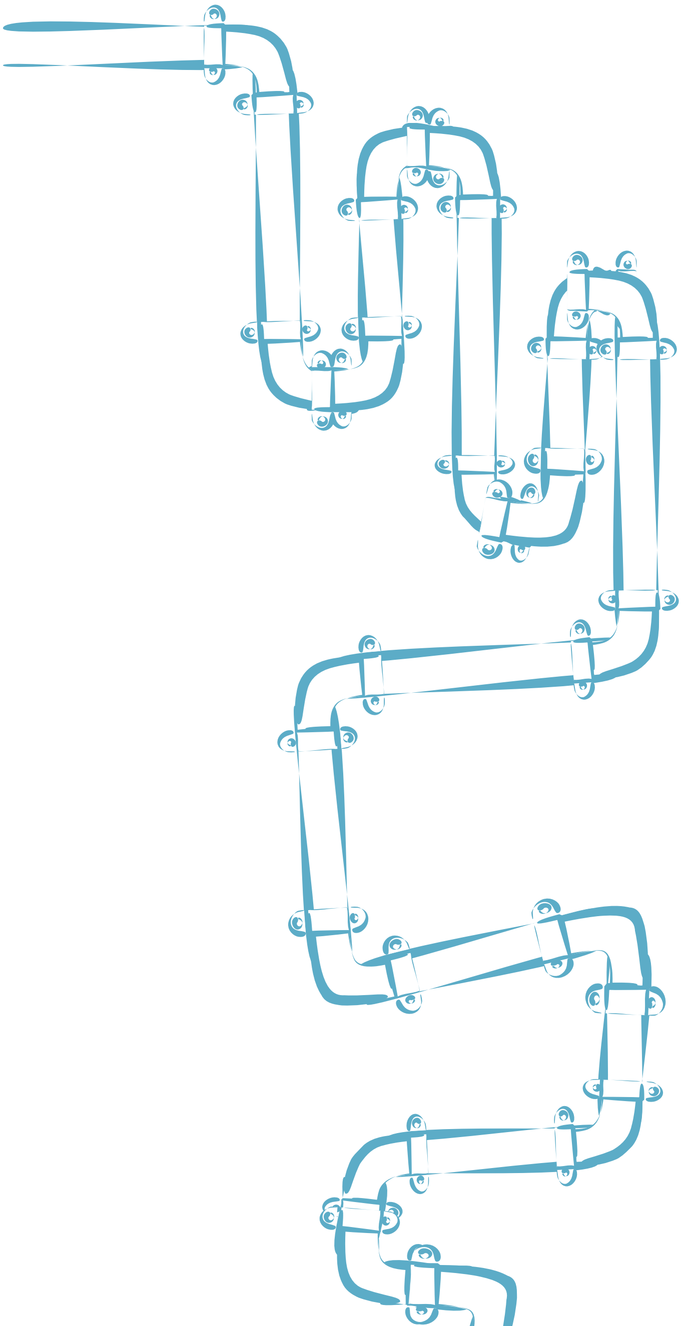
While it is common to scrutinize project beneficiaries to determine their capacity to engage in any project, it is less common to scrutinize the external partner agency’s capacity to succeed. Many projects fail because partner agencies lack experience, human resources, awareness or understanding of the needs of the local community. Any donor or community needs to be confident that any partner agencies involved with the project implementation have the capacity and the experience to succeed.



Lessons learned on sustainability

- When assessing the viability and sustainability of any rainwater harvesting project, it is important that all alternatives should first be investigated as well as the technical, social, economic and environmental feasibility of the project.
- Successful and sustainable rainwater harvesting projects can result in a broad range of benefits in addition to improved water supply. These include improved health, employment opportunities, development of new skills, and capacity in project planning, implementation, management, operation and maintenance. They can also result in a growing sense of self-esteem, self-confidence and self-reliance in the community.
- Communities should be encouraged to take ownership of rainwater harvesting projects by providing financial and in-kind contributions which need to be clearly defined before the start of the construction phase.
- Communities taking responsibility for ongoing operation and maintenance provide a good indicator of ownership and success of the project.

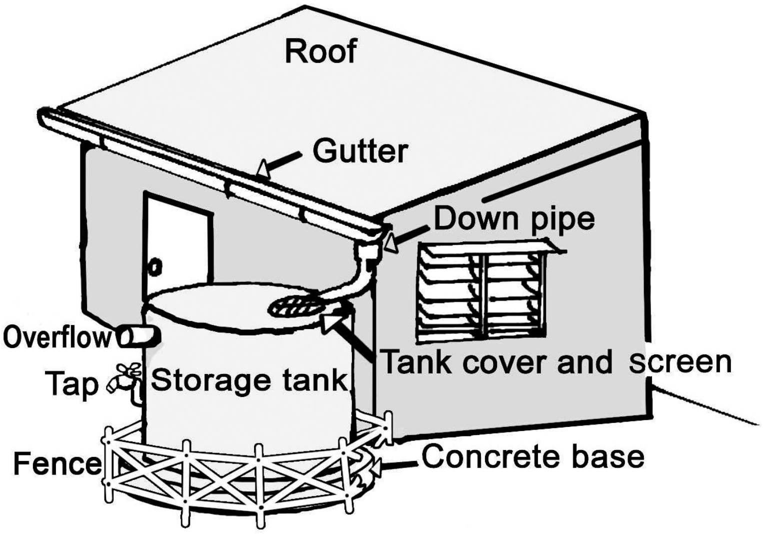




3 System components and design

Rainwater catchment systems consist of three major components: a catchment area (usually a roof); a delivery system (gutters, downpipe, filters and any first flush device); and a storage system (tank or reservoir).

Figure 3.1: *Simple rainwater collection system*

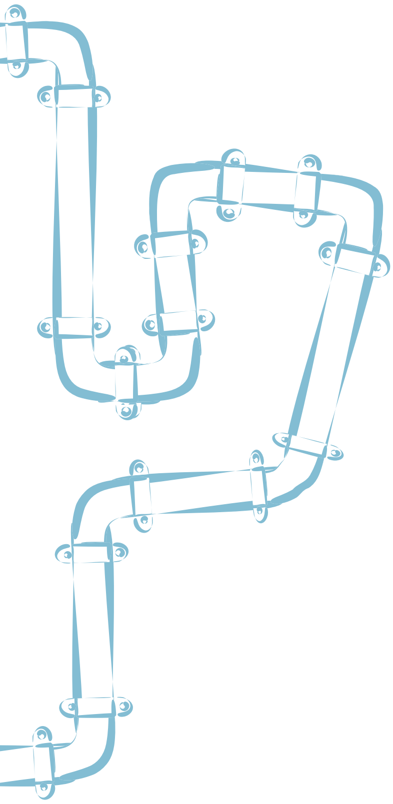


If projects are planned in areas where rainwater harvesting systems already exist, it is important to take time to visit and inspect the old systems. The owners or users of these systems should be asked for their opinion on the design. This process allows comparison of the different options available and could provide some useful lessons to avoid potential problems.

3.1 Roofs

Roofs can be 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 fibre reinforced cement tiles or sheets. 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 cement tile roofs.

Under normal circumstances, serious chemical contamination of rainwater from roofing materials is rare. However, in certain circumstances such as in areas of severe air pollution or where lead flashing, lead-based paints or other potentially toxic building materials have been used, chemical contamination of rainwater can pose a health threat (Gould & Nissen-Petersen, 1999). It is therefore recommended that:



- lead fittings are not used;
- metal roofs that are visibly corroded be repaired or replaced;
- paints are checked for suitability and where possible acrylic-based paints designed for exterior and roof use in the tropics are used;
- 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; and
- 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 basically banned. Generally speaking, existing systems with roofs containing asbestos can be considered safe to use but if new roofs have to be constructed it would be recommended to apply other materials.

3.2 Delivery systems

3.2.1 Gutters

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

Gutters should be constructed properly and must slope towards the tank. For long roofs, hanging V-shaped gutters with splash guards are useful for reducing any loss due to runoff over-shooting or under-cutting gutters (Gould & Nissen-Petersen, 1999).

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.

A guide to the gutter widths required for a given roof area and minimum downpipe sizes are given in Table 3.1 (adapted from Still & Thomas, 2003 and Davis & Lambert, 2002).

Table 3.1: *Guide to sizing of gutters and downpipes for rainwater harvesting systems in tropical regions*

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

3.2.2 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 on the inlet of the tank. Without screens, leaves and other material may enter tanks and provide food and nutrients for micro-organisms to multiply. In the absence of such nutrients, bacteria eventually (within 2-20 days) die off from starvation.

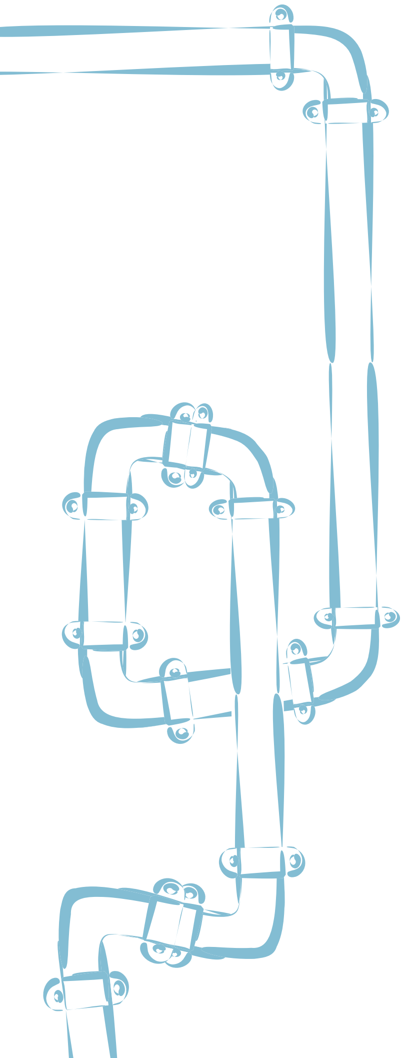
A filter or screen should be durable, easy to clean and replace, and should not block. It is essential that there are no gaps in the storage tank inlets where mosquitoes can enter or exit. Coarse filtration screens (made of stainless steel or synthetic mesh) are the simplest, most inexpensive and widely 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. They also effectively remove bacteria (Faisst & Fujioka, 1994). The devices usually used are gravel, sand or fine filter screens (e.g. Macomber, 2001). However, in a tropical rain shower, water flow rates off a roof may be very high (> 1.5 l/s) 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.

3.2.3 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 of 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 thermotolerant coliform 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 thermotolerant coliforms in the runoff from a building located close to a bus depot in Australia. Field studies in Uganda showed unacceptable turbidity after 2 mm of rain had fallen although thermotolerant 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 & Fujioka, 1994).

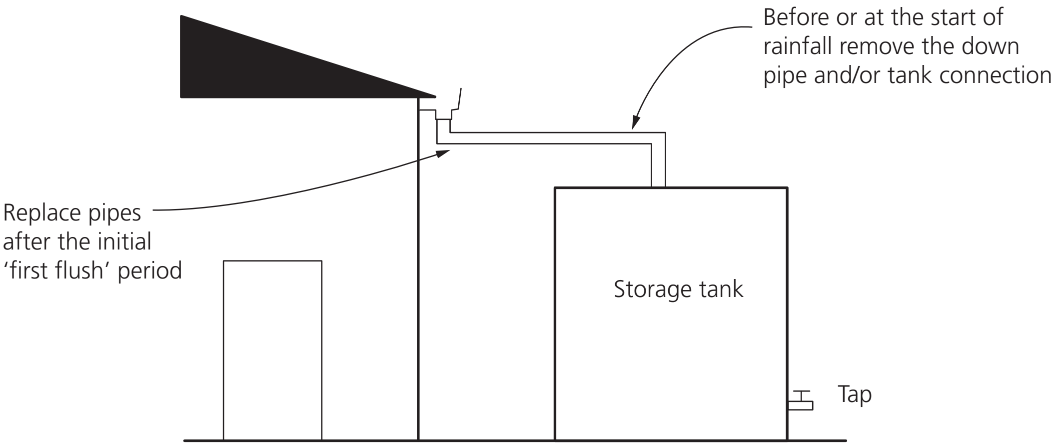
Numerous designs and references to various first-flush diverters, sediment traps and filters can be found in publications dealing with roof catchment systems. The main types of system include various types of sediment traps and sedimentation devices which sit on the tank (Michaelides, 1987), different types of tipping bucket mechanisms (UNEP/IETC, 1998; Mollison, 1992), and different manual diversion devices. In the field however, the reality is that most of these are rarely used. Those most likely to be found operating effectively are ones that are very simple to operate and maintain. Many of the more sophisticated and cumbersome examples need regular inspection and maintenance in order to function properly. Without attention, many systems will get blocked and may even pollute the water in the tank (Vadhanavikkit, *et al.*, 1984).

For Pacific Island Countries we recommend choosing a system that has minimum cost, few moving or metal parts, and little maintenance requirements. For this reason only two simple systems are outlined below:

Manual method

This is a simple manually-operated arrangement, whereby the downpipe 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 that somebody capable of removing the downpipe needs to be always present during the initial stages of rainfall events. On volcanic islands it is also advised to follow these procedures if ash has fallen on the roof.

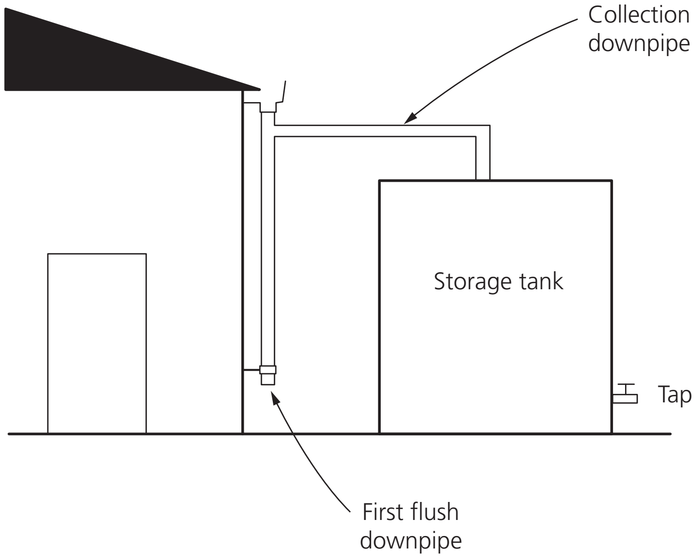
Figure 3.2: *Manual first-flush method*



Semi-automatic method

A simple first-flush system that is not reliant on someone being present at the beginning of rainfall is known as the 'downpipe first-flush device'. In this system, a separate vertical pipe is fixed to the downpipe 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 downpipe' where it is retained. When this downpipe becomes full, water flows down the 'collection downpipe' 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).

Figure 3.3: *Semi-automatic method: Simple downpipe first-flush device*



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 criterion is that the device should divert the first 0.5 mm of the rainfall. To calculate the volume of water to be diverted, multiply the length and width of the collection surface (in metres) by 0.5 (mm).

Required volume of diverted water (l) = house length (m) x house width (m) x 0.5 (mm)

For example, a house which is 5 m long by 8 m wide would need to divert at least 20 L of water. This is the amount the simple downpipe 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 x pipe radius^2 (mm) x 0.001)

For the example above (5 m by 8 m house size, diverting 0.5 mm rain), a first-flush downpipe of 150 mm diameter (75 mm radius) would need to be at least 1.1 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.

3.3 Storage tanks

For rainwater catchment systems, the storage tank is usually the most expensive part, so the design and construction needs due attention. As well as having the appropriate volume with respect to the catchment area, rainfall conditions and demand, it should have a functional, durable and cost-effective design.

Field experience has shown that an ideal universal tank design does not exist. Local materials, skills and costs, personal preferences and other external factors are important to take into consideration. Nevertheless, there are a number of key requirements common to all effective tank designs (Gould & Nissen-Petersen, 1999):

- Functional and water-tight design;
- Solid, secure cover to keep out insects, dirt and sunshine;
- Screened inlet filter;
- Screened overflow pipe;
- A manhole (and ideally a ladder) to allow access for cleaning;
- An extraction system that does not contaminate the water (e.g. tap, pump);
- Soakaway to prevent spilt water forming puddles near the tank; and
- A maximum height of 2 m to prevent high water pressures (unless additional reinforcement is used in walls and foundations).

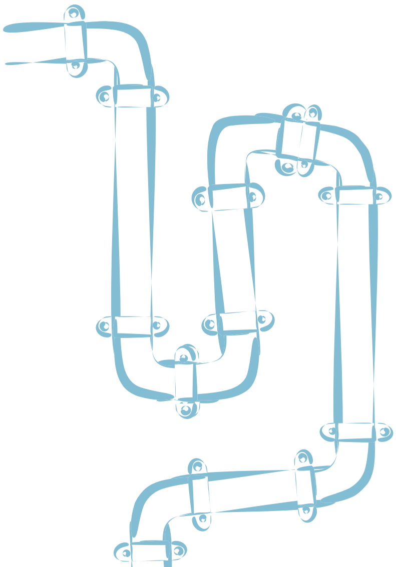
3.3.1 Above-ground or underground

Building a storage tank under the ground is a popular method of cost reduction in tank building. Foundation problems are avoided completely as the tank is immersed in the supporting soil and so very large tanks for communal use can be constructed with relative ease.

Where stable soils are present which can reliably take the force of the stored water, any cement or render is needed only as a sealant. Several tanks have been made in West Uganda using a 25 mm layer of mortar applied directly to the soil with few reported problems after 5 years service. In Ethiopia, a number of tanks have been made using a similar technique with a soil-cement, further reducing the requirement for imported material.

Failure of underground tanks can be a problem, leaks are difficult to locate and equally difficult to repair. The major causes of failure are tree roots and a rising water table which causes empty tanks to “float” out of the ground or simply collapse under the strain of the outside water.

Tanks lining the ground with plastics have been tried since the 1970s often with little success, however some designs demonstrate that the method can be used with care. The usual failure modes of these tanks are tree roots as with other underground tanks and vermin intrusion. The tanks are, however immune to flotation as they simply flex out of the way. Reports of termites attacking underground plastic sheet tanks are common, however there are



equally as many reports of termites living under the plastic and not damaging it.

A summary of the advantages and disadvantages of underground and above-ground storage is shown in Table 3.2. Overall, about 80% of users express a preference for above-ground tanks despite a cost penalty of 50%. (DTU, 2004)

Table 3.2: *Advantages and disadvantages of above-ground and underground storage*

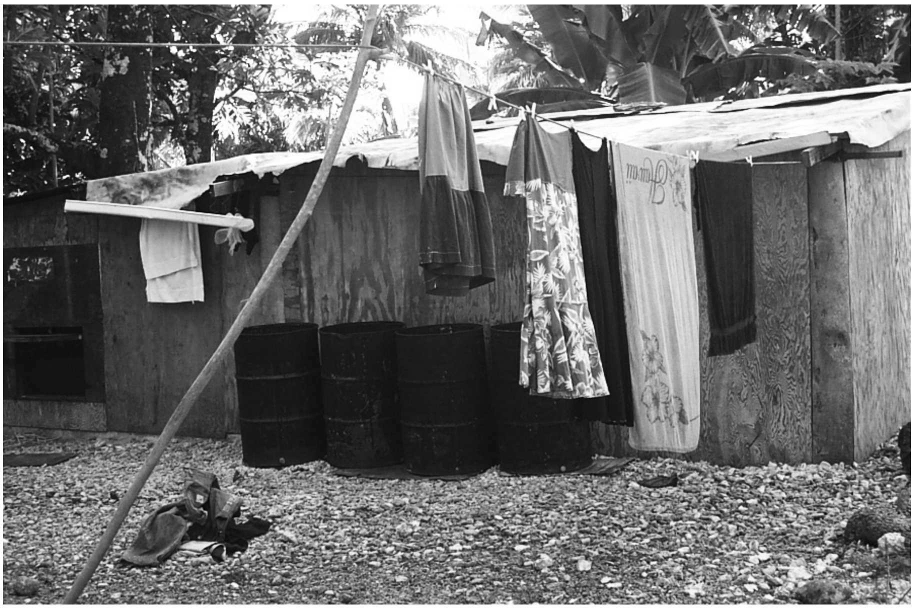
	Advantages	**Disadvantages**
Above-ground	💧 Allows for easy inspection for cracks or leakage 💧 Water extraction can be by gravity with extraction by tap 💧 Can be raised above-ground level to increase water pressure	💧 Requires space 💧 Generally more expensive 💧 More easily damaged 💧 Prone to attack from weather 💧 Failure can be dangerous
Underground	💧 Surrounding ground gives support allowing lower wall thickness and thus lower costs 💧 More difficult to empty by leaving tap on 💧 Require little or no space above-ground 💧 Unobtrusive 💧 Water is cooler 💧 Some users prefer it because "it's like a well"	💧 Water extraction is more problematic – often requiring a pump, a long pipe to a downhill location or steps 💧 Leaks or failures are difficult to detect 💧 Possible contamination of the tank from groundwater or floodwaters 💧 The structure can be damaged by tree roots or rising groundwater 💧 If tank is left uncovered children (and careless adults) can fall in possibly drowning 💧 If tank is left uncovered animals can fall in contaminating the water 💧 Heavy vehicles driving over a cistern can also cause damage 💧 Cannot be easily drained for cleaning

3.3.2 Tank materials

Although other types of storage vessels are used for rainwater collection, a large tank is usually required for storing sufficient quantities of water for a household. The different types of materials used to construct tanks include ferrocement, bricks and blocks, concrete, metal, plastic, wood and fibreglass. Ferrocement tanks have been used successfully for over a century in the Pacific 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 these also provide good water quality.

Open topped vessels such as buckets and drums are not recommended for collection of rainwater for drinking purposes as contaminants may easily enter into them. It is important that the storage vessel itself does not introduce contamination into the water. For this reason the use of old oil or chemical drums is not recommended, as these may contain substances harmful to human health.

Inappropriate collection *of rainwater using oil drums.*
Majuro, Marshall Islands



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 clear fibreglass tanks are not recommended for use in Pacific Island Countries. In hot climates water stored in thinner walled plastic or metal tanks will tend to heat up, particularly if the tanks are not shaded, and for this reason some consumers express a preference for thicker walled ferrocement or concrete tanks.

Whichever material is chosen, in order to ensure that tanks are durable, good quality, clean construction materials must be used. Poor selection of materials, poor mixing and poor workmanship are all common causes of problems in completed water tanks. A solid foundation is also essential for aboveground rainwater tanks.

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. Ferrocement tanks have sometimes been promoted as a technique requiring only limited skills. In fact, considerable skills are required, both for the correct installation of the reinforcement and in mixing the plaster. The ever-increasing costs of weld mesh, chicken mesh and galvanized wire have also meant that, in many places, ferrocement tanks now cost much more than some alternatives, such as water tanks built with bricks and blocks. On the positive side, cracks in ferrocement tanks can be repaired fairly easily and leaks can be sealed by coating the interior of a tank with sealants and bonding agents. (Gould & Nissen-Petersen, 1999).

Brick and block tanks

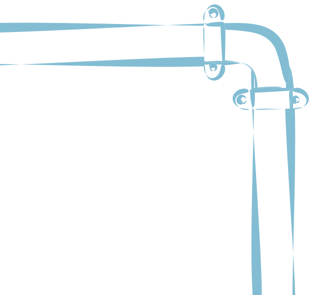
A wide range of brick and block tank designs have been developed, and construction methods are described by several authors including Hasse (1989), Vadhanavikkit et al. (1984) and Nissen-Petersen (1998). These tanks use local building materials and adapt skills which already exist in the construction of homes so they can be very low cost. Unfortunately, many brick and block tanks have cracked due to one or more of the following reasons: insufficient reinforcement, poor plastering, or using a square rather than a circular design. Another drawback in a rural setting is the problem of transportation on rural roads, which usually contributes to blocks getting broken (Gould & Nissen-Petersen, 1999).

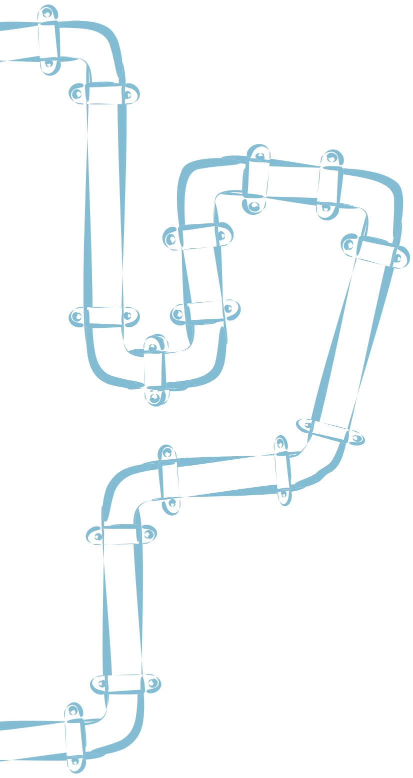
Reinforced-concrete tanks

Well-constructed concrete tanks are extremely durable and can be built to any size. The main drawback with conventional reinforced tank designs is that they are expensive. While conventional reinforced-concrete construction techniques may often be inappropriate in developing countries due to their high cost, in areas where aggregate is abundant, it may be worthwhile adapting it into a more affordable method (Gould & Nissen-Petersen, 1999).

Metal tanks

Corrugated galvanised-steel tanks have been popular, usually pre-fabricated they are quick to install and, being lightweight, relatively easy to transport. Although they are still used widely around the world, their success rate has been somewhat mixed. Three factors influence their durability: the quality and thickness of the metal used; the level of protection provided for the tank, e.g. protective paint; and the quality of construction and level of exposure to saline or acidic water and atmospheric moisture. Life expectancy of these





tanks can vary from less than 2 to more than 20 years. Clearly, the tanks are not appropriate in coastal environments or in any situation where saline or 'aggressive' acidic water will be mixed with any stored rainwater. Some newer polymer coated tanks specifically developed for water storage are available in some areas and can be very cost competitive. In the Pacific these tanks come with a 10 year guarantee against corrosion to perforation provided they are installed more than 500 m from the sea.

Probably the most common type of rainwater tank in the world is the recycled 200 litre oil drum which is generally available and affordable in even the poorest communities. Issues with contamination from the original contents as well as from the environment (not having taps or covers) make them less than ideal, however, their use does indicate a desire and real felt need to utilise rainwater, and is a good precursor for any rainwater tank implementation project (Gould & Nissen-Petersen, 1999).

Plastic tanks

Moulded plastic tanks have become popular in recent years, they are easily installed and corrosion is not an issue. Due to improved processes to stabilize plastic against deterioration resulting from exposure to UV light, these tanks are much more durable than they used to be. They are, however, relatively expensive and their durability beyond 10-15 years is still unknown. Because plastics are light and flexible, they can be easily transported, even on very bad roads. To prevent plastic tanks being blown away by strong winds when empty, they must be properly secured (Gould & Nissen-Petersen, 1999).

Other tank types

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 tanks constructed on site and due to light penetration may develop problems with algal or bacterial growth in tropical climates.

Rainwater tanks have also been made of various other materials including wood, bamboo, fibre-reinforced cement and natural-fibre polymer resins. None of these are recommended for widespread replication. Wood tanks are not very common as they tend to be expensive, but are found in parts of the Pacific as well as in New Zealand and Australia. Some manufacturers claim very long life expectancies of 80 years or more if an ongoing maintenance programme is adhered to. Cement tanks using bamboo, sisal fibre and basketwork 'reinforcement' were enthusiastically promoted during the early 1980s, but failed to stand the test of time. Termites, bacteria and fungi attacked any exposed 'reinforcement' leading to cracks and even bursting. The construction of these tanks, has now, with a few minor exceptions, been generally discontinued. While widespread replication of any particular tank design depends ultimately on an effective awareness raising and promotion strategy, ultimately, a good tank design will sell itself, and a bad design will always fail as knowledge of its poor performance spreads (Gould & Nissen-Petersen, 1999).

Table 3.3: *Comparison of different storage tank types*

Tank type	Indicative price*	Capacity	Life expectancy	Notes
Ferrocement (Demonstration project Tonga)	$2,500 FJD for 11 m^3	Up to 150 m^3 but typically less than 12 m^3	If well built with good quality materials and maintained, can be 50+ years	Tank built on-site Larger sizes needs welded mesh or bars and roof supports Minimum 8 days for installation
Ferrocement (Contractor Fiji)	$2,000 FJD for 11 m^3			
Concrete	$5,000 FJD for 10 m^3	No upper limit. More reinforcement and expansion joints will be required for larger sizes Pre-cast up to 35m^3	If well built with good quality materials and maintained can be 50+ years	Can be pre-fabricated or cast on site
Corrugated galvanised steel	$900 FJD for 10 m^3	Up to 10 m^3	Can be less than 2 years in corrosive environments but typically 5-8 years Well maintained painted tanks can reach 20 years but this is not typical	Corrosion can be a problem Galvanised tanks should be painted inside and out to prolong life and are not suitable for coastal areas
Polymer-coated steel	$1,300 FJD for 10 m^3	Up to 10 m^3	Tanks designed for rainwater storage have 10-20 year manufacturers warranties depending on location	
Plastic/HDPE	$2,500 FJD for 10 m^3	Up to 25 m^3	15-25 years Limited experience past 15 years but some manufacturers now provide 25 year warranty	No joints, lightweight, non-toxic food grade PE

Fibreglass	$2,700 FJD for 10 m^3	Typically less than 20 m^3	Minimum 25 years claimed by manufacturers	Complete with inlet, outlet and overflow connections
Brick and blockwork	$2,000 FJD for 10 m^3	Up to 6 m^3 If reinforced up to 175 m^3	Variable depending on design and local conditions and materials. Some designs have failed within 2 years while others have lasted more than 20 years	Constructed on site usually utilising local skills and materials Uses more cement than equivalent sized ferrocement tanks
Wood	$4,400 FJD for 11 m^3 (excluding freight ex-NZ)	Up to 100 m^3	Manufacturer claims 80 years for the tank and 25 years for the liner	Constructed on site, can use local labour under supervision Concrete ring-beam foundation required

* These prices are ballpark estimates for Fiji in 2004. 1 FJD ≃ USD 0.60. Costs for pre-fabricated tanks do not include transport to site or cost of any foundation requirements. Prices will vary greatly with time and location and cost estimates for individual projects should always be calculated based on local conditions.

3.3.3 Tank covers

The roofs of water tanks play a crucial role with respect to both the quality and quantity of the stored water. The tank roof has two very important functions. First, it prevents water loss by evaporation which can be substantial in tropical regions. Secondly, it reduces the risk of contamination. Rainwater tanks should be completely covered with a solid material. A covered manhole should be provided to allow access for cleaning. The more protected stored water is from contamination, the better quality and safer it will be.

3.3.4 Tank outlets

Abstraction of water from the tank should be via a tap or pump. Water abstraction with a lowered bucket is not recommended as this increases the risk of contamination. If a tap is used it should be protected from animals, which may drink from it or brush against it, leading to subsequent water contamination. Taps or draw-off pipes should be at least 5 cm above the tank floor (more, if debris accumulation rates are high). This allows any debris entering the tank to settle on the bottom, where, provided it remains undisturbed should not adversely affect water quality. A tank floor sloping towards an additional washout tap installed in the base of a tank, makes emptying and cleaning easier. The area under the tap should be concreted and drained to a soak-away pit so that water does not pool providing a site for mosquito breeding.

3.3.5 Tank overflows

Additional 'dead storage' will be created at the top of a water tank if the bottom of the overflow pipe is not placed at the maximum water level of the tank. For flat-roofed reinforced concrete tanks, the overflow pipe should be concreted into the base of the tank roof to avoid dead storage. In domes being used for storage, the overflow can either be placed at the level of the inlet for guttering, which determines the maximum water level, or the gutter inlet can also be used as the overflow. In any case, the overflow should be situated vertically over the tap stand to allow water overflowing to be drained to the soak-away pit without eroding the base of the tank.

3.4 Determining storage tank size

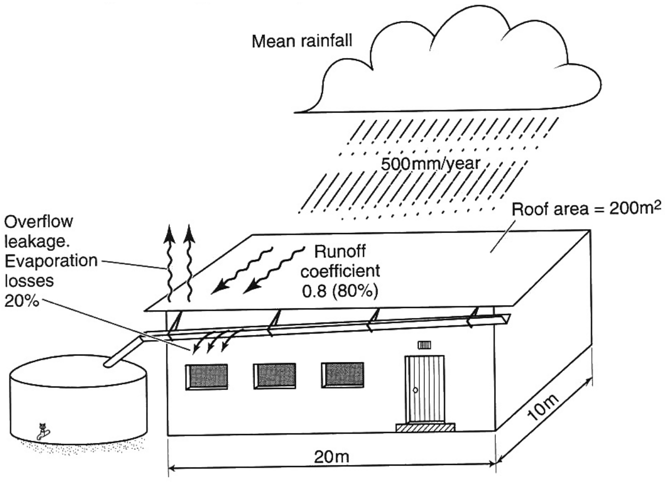
The following section details methods for determining storage tank size under ideal circumstances. One of the most important factors however in choosing a tank size will be affordability, so the volume of storage calculated should be seen as an amount to aim for rather than as a capacity required for the success of a rainwater harvesting scheme. It is important to remember that even moderate amounts of storage will provide benefits for households and several smaller tanks that can be installed incrementally may be a more suitable approach than one large tank.

3.4.1 Supply and demand

Rainwater supply

Although rainfall is abundant in the Pacific, its distribution in both time and space is erratic. Developing rainwater catchment systems that meet any given requirement depends therefore on a careful design. The maximum yield of rainwater runoff from any system is dependent upon two variables: the rainfall amount and the size of the catchment area. In practice, the total yield will also be determined by the collection efficiency (runoff coefficient) and storage capacity of the system.

Figure 3.4: *Calculating potential rainwater supply by estimating runoff (Gould & Nissen-Petersen, 1999)*



$S = R \times A \times Cr$

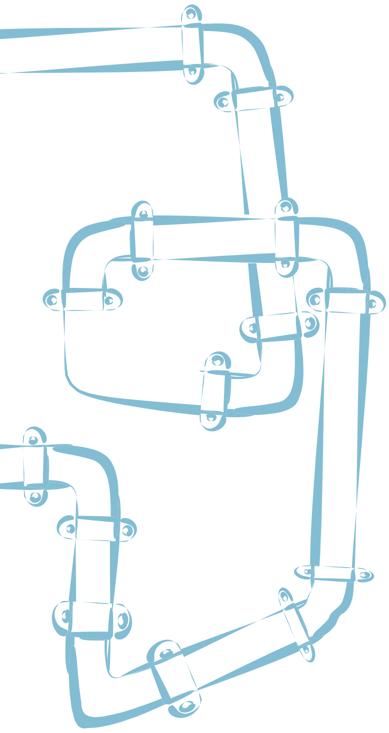
Where:
S = mean rainwater supply in litres (l)
R = mean annual rainfall in millimetres (mm)
A = catchment area in square meters (m^2)
Cr = runoff coefficient (volume of runoff/volume of rainwater)

Table 3.4: *Roof material with runoff coefficient*

Roof material	Runoff coefficient
Sheet metal	0.8 – 0.85
Cement tile	0.62 – 0.69
Clay tile (machine made)	0.30 – 0.39
Clay tile (hand made)	0.24 – 0.31

Household demand

Estimating household annual water demand, may at first seem straightforward i.e. multiplying average daily water use per person by the number of household members by 365 days. However, in reality, actual daily water use may vary considerably. In households, adults would use greater quantities of water as compared to young children, and water use will vary with the season, more water being used in the hottest or driest times. The number of family members staying at home may also vary at different times of the year if some members work or study away.



The best estimates of household water demand will come from detailed surveys of many households where mean per capita consumption can be calculated on the basis of hundreds of responses. Even with great care and attention to detail, estimates of water demand can be far off the mark. Often, this is because they measure actual consumption and not demand itself. If water shortages exist or access to water supplies are restricted by distance or cost, people may use less water than they would like. If an improved water supply such as a rainwater tank is provided, water consumption may increase. It is therefore worthwhile asking householders if they are satisfied with their current quantity of water supply.

Where demand estimates are being used as the basis for designing rainwater systems, they should be treated with great caution, especially if the rainwater systems are the major or only source of supply. As a general rule of thumb, it is appropriate to 'over-design' systems to provide at least 20 per cent more than the estimated demand. It is far more preferable to over-design than to under-design the system and risk periods when the tank is empty.

In reality, however, people will use rainwater more sparingly when water levels in household tanks get low. This informal rationing process is very important as it can significantly reduce the likelihood of the tank becoming completely empty and reduce the duration of any such system failures, when they occur (Gould & Nissen-Petersen, 1999).

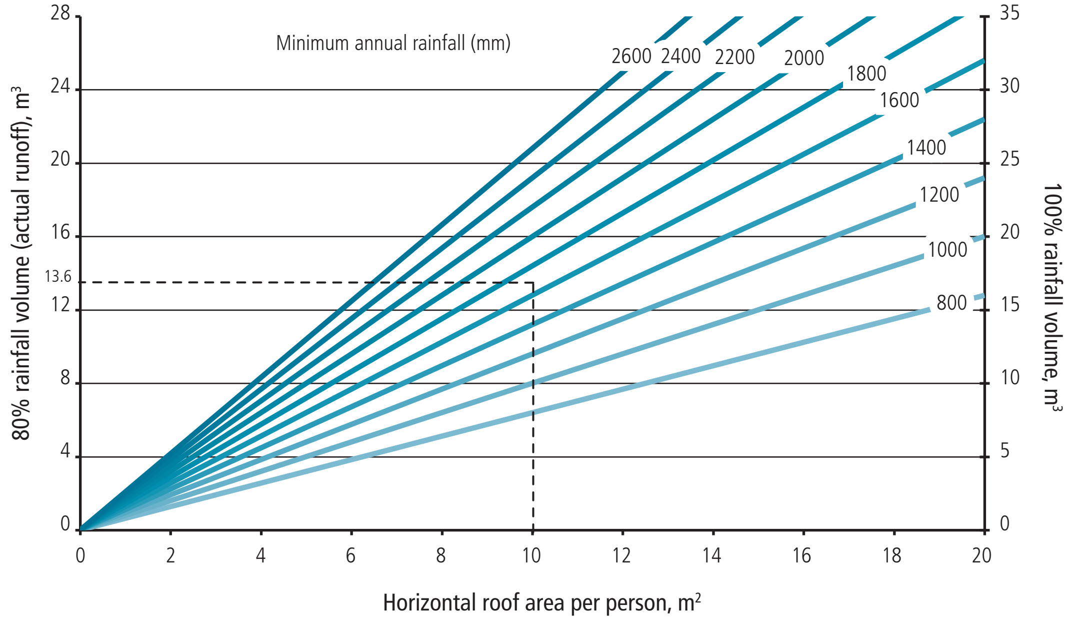
Can supply meet demand?

Before embarking upon any detailed calculations, it is a good idea to gauge the annual rainwater availability for a given location and catchment area and check if this can meet the estimated annual demand. These calculations are easily performed manually but another simple and straightforward method uses the diagram shown in the box below.

Supply vs demand for Vava'u

The rainfall data for Vava'u showed that over the past 56 years, the annual rainfall was greater than 1,700 mm 90% of the time, so this is a good value to take as the minimum annual rainfall. If we assume that there is a roof area of 10 m^2 per person available (equivalent to a family of 6 sharing a house with a 60 m^2 roof) and that 80% of the rainfall will be captured (a runoff coefficient of 0.8), then reading off the graph, the amount of rainfall available per person is 13.6 m^3 per year. The equivalent of 37 litres per person per day.

Set of curves for determining rainfall availability



3.4.2 Calculation methods

Once initial estimates have been made of annual supply and demand and it has been established that a rainwater supply scheme is feasible, it is then necessary to determine the amount of storage required. There are a number of different methods of varying complexity used to calculate the minimum amount of storage necessary. All methods require assumptions about rainfall, water demand patterns, average catchment areas and runoff coefficients and as a result, there is not always a great deal to be gained by performing a more detailed analysis over a simpler method. However, where large numbers of tanks are being implemented in any project or programme, detailed analysis will often be worth undertaking as economies of scale become apparent.

Use of rainfall data

The amount of rainfall data available will vary according to the location. Reliable rainfall data for a period of at least 10 years (longer in drought-prone areas) is ideally required to get an accurate estimate of the potential rainwater supply from a given catchment. Monthly, weekly or daily data may be available. The worked examples given here use monthly data but the same methods can be used with decadal (10-day periods), weekly or daily rainfall data for a more accurate assessment, especially for climates with year round rainfall.

Dry period demand method

This is the simplest approach used to calculate rough estimates of tank size or in the absence of any rainfall data.

The tank is designed to accommodate the necessary water demand throughout the longest dry period. If rainfall data is available it can be examined to find the longest average time periods without significant rainfall. If no data is available and a distinct dry season is known to exist, this period can be used in the calculation.

For example, if the daily household water demand is 100 litres and the dry season lasts for 120 days, a tank with a capacity of at least 12,000 litres would be required.

In the absence of any concrete data it is important to also make some crude estimate of the available roof runoff during the wet season to ensure there is sufficient rainwater to fill the tank.

Simple tabular method

In this method monthly data over a one year period is used. When several years of data are available, it is safest to use the rainfall pattern for the worst year, that is the year with the lowest total annual rainfall or with the longest dry period. Average figures should not be used. To find the minimum tank volume required a table is constructed as shown in Table 3.5.

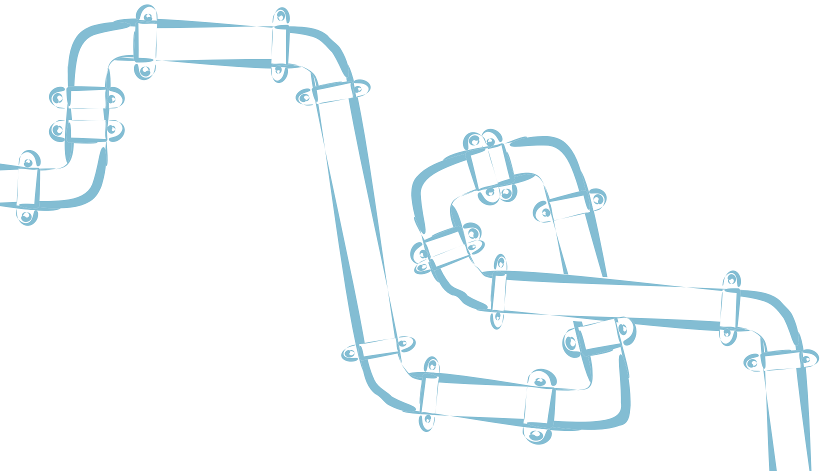


Table 3.5: *Calculation of storage tank size using the simple tabular method*

A Month	B Volume captured in month	C Cumulative volume captured	D Volume demanded in month	E Cumulative demand	F Total amount stored C – E	G Deficit / surplus for month B – D
November	300 (a)	300 (b=a)	250 (d)	250 (e=d)	50	50
December	500 (c)	800 (b+c)	250 (f)	500 (e+f)	300	250
…	…	…	…	…	…	…
October	100	3,700	250	3,000	700	–150
Total	3,700					700

A. If there is a distinct dry season the table should begin at the first wet month after the dry season where supply exceeds demand, i.e. the tank is filling.

B. The volume captured in a month in litres is calculated by multiplying the available roof area equipped with gutters (A, m^2) by an appropriate runoff coefficient based on the type of roof surface (Cr) and the monthly rainfall (R, mm):

Volume Captured = R x A x Cr

C. The monthly volumes captured are cumulatively added through the year in column C.

D. Generally the monthly demand is calculated based on an estimate of the daily usage per person (U) and the number of people who will be using water from the tank (N). The actual number of days in a month can be used or an acceptable approximation is to assume all months are of equal length (365 ÷ 12 = 30.4 days).

Volume demanded in month = U x N x 30.4

If water is rationed during drier months the usage figure can be altered for these months.

E. The monthly volumes demanded are cumulatively added through the year in column E.

F. The total amount stored is calculated by subtracting the value in column E from the value in column C.

G. Column G is not strictly necessary but helps to illustrate what is happening each month during the year. It is calculated by subtracting the value in column D from the value in column B.

The storage volume required is found by examining column F in the table. If no water is allowed to overflow the tank, the storage volume required will be equal to the highest value in column F. The absolute minimum storage volume is found by taking this highest value and subtracting the amount left in storage at the end of the year. A full worked example using the data from Vava'u is shown in Appendix C.

If when constructing the table, 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.

The actual tank capacity will need to be greater than the minimum storage volume calculated in order to allow for the 'dead storage' space below the outlet and air space above the overflow to the tank.

Graphical method

The minimum tank volume can also be found graphically using the cumulative supply and demand figures as calculated in the simple tabular method. The basic steps to follow are:

1. Plot a graph of cumulative roof-runoff graph against time (the supply line).
2. Add a dotted line showing cumulative water use (the water demand line).
3. Find the greatest difference between the supply line and the demand line, this is the storage volume required.

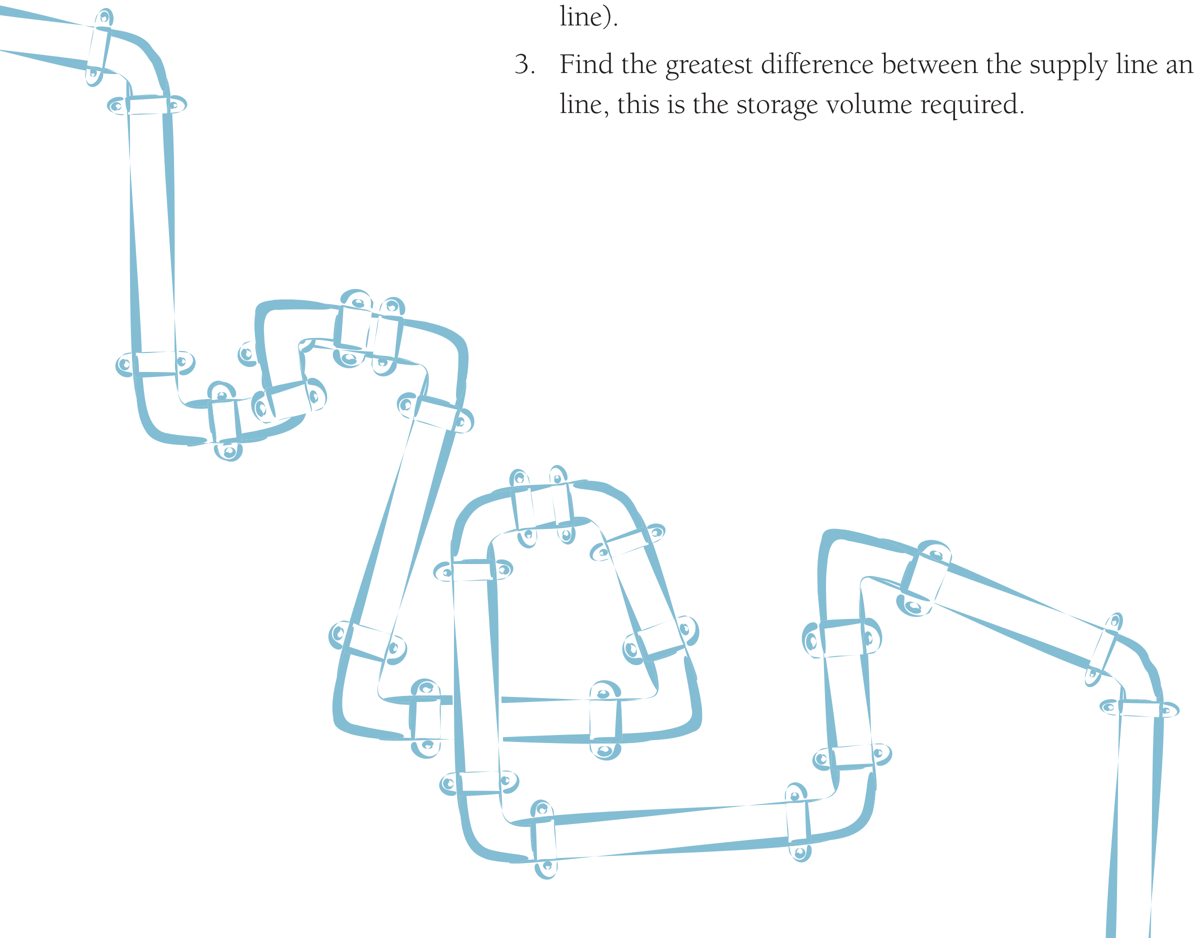
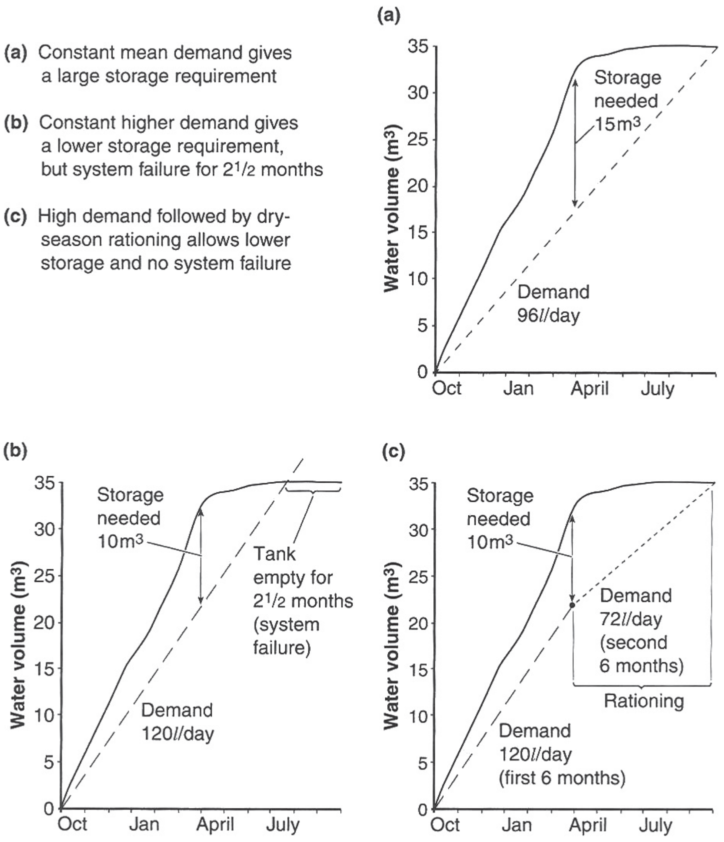


Figure 3.5: *Cumulative supply graph for 12 months illustrating the effect on storage of three different demand scenarios (Gould & Nissen-Petersen, 1999)*



Mass curve analysis

Mass curve analysis is an extension of the simple tabular method where data over longer time periods can be examined. This method is only really practical using a computer spreadsheet package. The same type of table is constructed as for the simple tabular method. An extra column (H) is added showing the difference between the maximum and minimum amounts stored (taken from column F) during a cycle. A cycle is considered to be a period of time from when a tank first starts filling after a dry period, until the end of the next dry period. A worked example is shown in Appendix C.

Dimensionless constant analysis

Mass curve analysis of different demand scenarios can be used to create a dimensionless constant graph plotting the storage required (as a percentage of supply) against demand (also as a percentage of supply). This graph can then be used for the rapid analysis of individual systems, its only restriction being that it can only be used for the region where the rainfall data is applicable. A worked example is shown in Appendix C. A useful example of this approach is in a booklet developed by the Water and Environmental Research Institute of the Western Pacific University of Guam (WERI) which contains tables and graphs to help consumers choose appropriately-sized rainwater catchment and storage systems in Saipan (Heitz, Habana & Raza, 2001).

Computer-based models

A number of simple computer-based models have been developed to assist in rainwater harvesting system design calculations. One such example which can be freely downloaded from the internet is *SimTanka*, a model produced by the Ajit Foundation in India. The programme simulates the performance of rainwater harvesting systems and can be used to determine tank volume requirements or the fraction of water demand that can be reliably supplied from existing systems. A sample output from the *SimTanka* model is shown in Appendix C.

3.4.3 System reliability

No matter which method is used for calculating storage tank volume, some analysis of the system reliability should also be carried out with an understanding of the level of reliability required. As the storage tank is usually the most expensive item in a rainwater harvesting scheme, the designer should bear in mind how the rainwater supply will be used. If rainwater is being used to supplement another source, providing storage against infrequent long dry periods would not be warranted whereas if rainwater is the only source available a greater storage volume will be required.

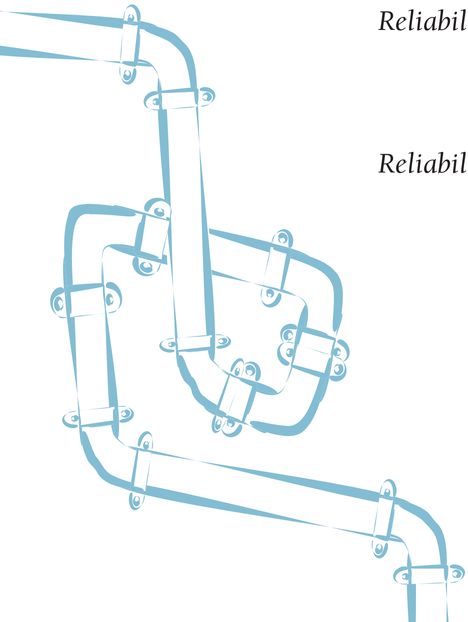
The percentage reliability is calculated by looking at the number of times the volume in the storage tank would fall below zero when using a particular sized tank. This is termed a failure.

Reliability % = (1 – (total number of failures/total number of time periods)) x 100

For example, if failures were recorded during 2 months of a 36 month period the reliability would be:

Reliability = (1 - (2/36)) x 100 = 94.4%

Analysis of the reliability is included in the worked examples in Appendix C.



Reliability

Calculations were made of the reliability of the rainwater storage systems in Vava'u. These were based on a system designed for a household consisting of 6 to 7 persons consuming an average amount of water of 40 l/p/d with application of a 50% rationing factor in the dry season using the rainfall data from 1947 to 2003, a typical roof area of 70 m^2 and a runoff coefficient of 0.9.

From the analysis a storage tank with a volume of 11,000 litres (as was the size of the standard tank constructed in Vava'u) would have run out of water for only a little above 3% of the time between 1947 and 2003. The longest consecutive period without water in the tank would have been 6 months during the drought of 1992.

3.5 Pressurised water supply systems

Rainwater harvesting storage tanks or reservoirs can be equipped with a pressurised supply system providing water directly to household connections for kitchen, shower and bathroom.

There are generally two ways to pressurise a water supply system: 1) through pump pressure and 2) by creation of a head. Each of these options combined with a renewable energy source are discussed below, with their specific advantages and disadvantages.

3.5.1 Pressurised system

A regular stand-alone pressurised system is composed of a pump, a pressure tank, 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 (or 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, 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.

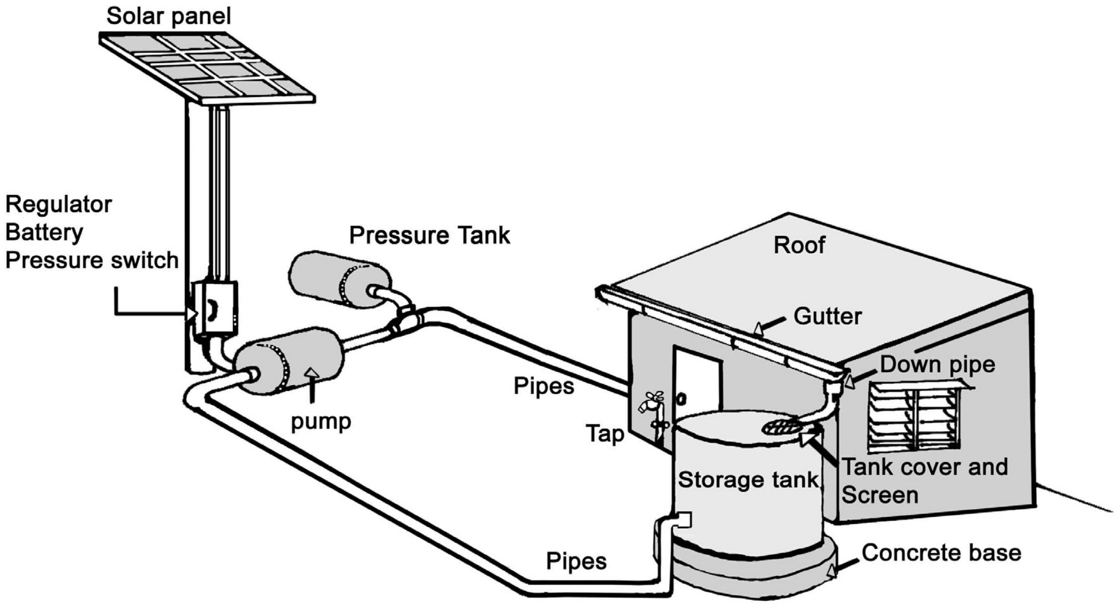
The electricity for this system can be supplied by a photo-voltaic (PV) system with solar panels or by a small wind turbine. The renewable energy system will need a battery however, to cover the periods when electricity is required, but when there is no direct energy source available. This would cover the periods with a PV system when there are clouds or at night, or with a wind turbine when there is no wind.

The electrical storage in the form of a battery that is required in this system increases both the complexity and the maintenance costs. Another disadvantage is that upon opening two or more taps, the water pressure will drop as the pressure and flow of the pump are limited.

Maintenance in such systems is required for the check valve, pump and battery storage. PV arrays need no special maintenance apart from a regular clean. Wind turbines require yearly maintenance on all moving parts. An advantage of PV over wind is that it is easier to install, however site specifics such as solar insolation and average wind speed are more important factors.

Indicative costs for such a system range from US $1,000 to 2,000 depending on the volume and flow required.

Figure 3.6: *Application of stand-alone pressurised system*



3.5.2 Head pressure system

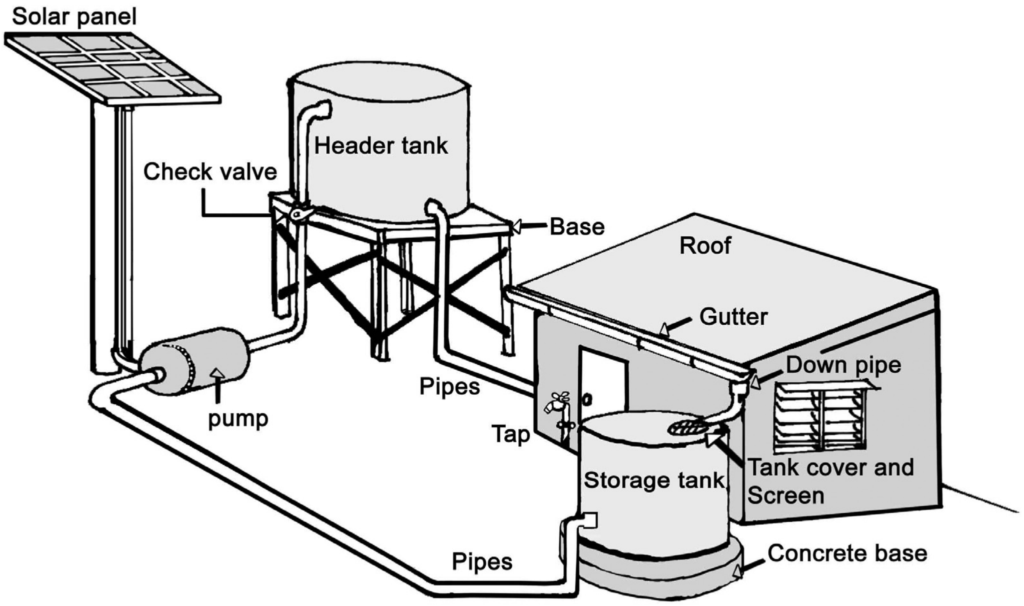
Another option to create pressure in a water supply system is to pump the water from the rainwater tank into another storage tank, 2-3 meters aboveground level. This creates a natural head for the water supply system that allows water flow through gravity. With this system, sufficiently large piping is necessary to reduce pressure loss in the supply system.

The renewable energy system that pumps the water to the higher tank does not require storage, as the "potential energy" will be stored through the elevated storage tank. The power of the pump system need not be large; it just pumps the water from the collection tank to the storage tank next to, or even onto the roof of the house. The pump needs to be switched off when the upper tank is full, to avoid spillage. It also needs to be switched off when the lower tank is empty, to avoid it from running dry.

The system does require a careful resource assessment of the wind or the solar energy potential in the particular area, to ensure sufficient water will be pumped to the storage tank. 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.

An advantage is the maintained pressure at two or more opened taps. A disadvantage is the requirement of a large second tank as well as, in some cases, the need to build a (cyclone-proof) structure for it.

Figure 3.7: *Application of head pressure system*



3.5.3 Combined pressurised rainwater systems

If a number of households with roof catchments are close together, a combined reticulation system might be constructed. The set up would be the same as described above in the head-pressure system. Because of economies of scale, the cost per household decreases significantly.

The challenge with these types of systems in the Pacific is to organise a sustainable management component so that the system is properly maintained. Also, social agreements on the use of the water in scarce times are necessary.

3.5.4 Application of renewable energy

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, as compared to diesel systems. It will depend on the monthly and yearly average wind speed and the monthly and yearly annual insolation whether solar or wind systems are more cost-effective. This requires a careful analysis, as the seasonal and spatial variations of both water demand and natural resource fluctuations have to be considered.

The resource availability data must be matched with the demand for the power as a function of time. For solar PV systems, this will be based on the insolation data throughout the year, with the lowest resource month (i.e. most cloudy) as a reference. If the water availability requirements are also dependent on the time of year, these two graphs will have to be matched properly. A similar exercise is required when applying a wind turbine system. In the Pacific, these are areas away from the equator, however they will still be very site-specific.

3.5.5 Pros and cons of pressurised water systems

Below is a general overview of the pros and cons of the two types of pressurised water systems. The overall column shows the applicability of the pressurisation type for the Pacific.

Table 3.6: *Pros and cons of pressurised water systems*

Type	Affordability	Vulnerability*	Maintenance	Overall
Pump Pressurised	– –	+	–	+
Head Pressurised	–	–	+	++

* earthquakes or cyclones

3.5.6 Cost of applying renewable energy pumping systems

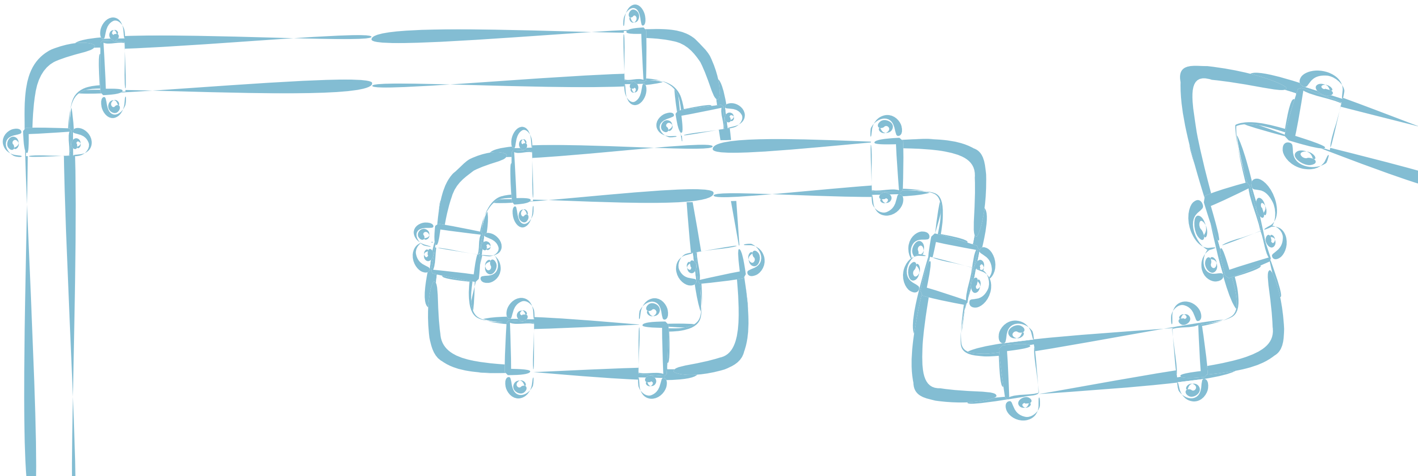
A small renewable energy system to pressurise water will be in the range of US $1,000. Slightly less for a simple head pressurised system, slightly more for a small pump pressurised system. In the case where a combined system is organised for more than 10 households, the combined system costs might come down as low as US $500 per household (reserve 5% maintenance per annum for a system without batteries, 10% per annum for a system with batteries).

Design in the Tonga demonstration project

The design used in Vava'u consisted of cylindrical ferrocement tanks with a volume of 3,000 gallons (approx. 11,000 l), a diameter of 3 m (radius 1.5 m) and a height of 2 m. Plastic U-shaped gutters were installed without first-flush systems. Screens and fences were included in some cases but not all. Lockable swivel-taps were installed at the bottom of the tanks above a concrete gravel-filled drainage basin.

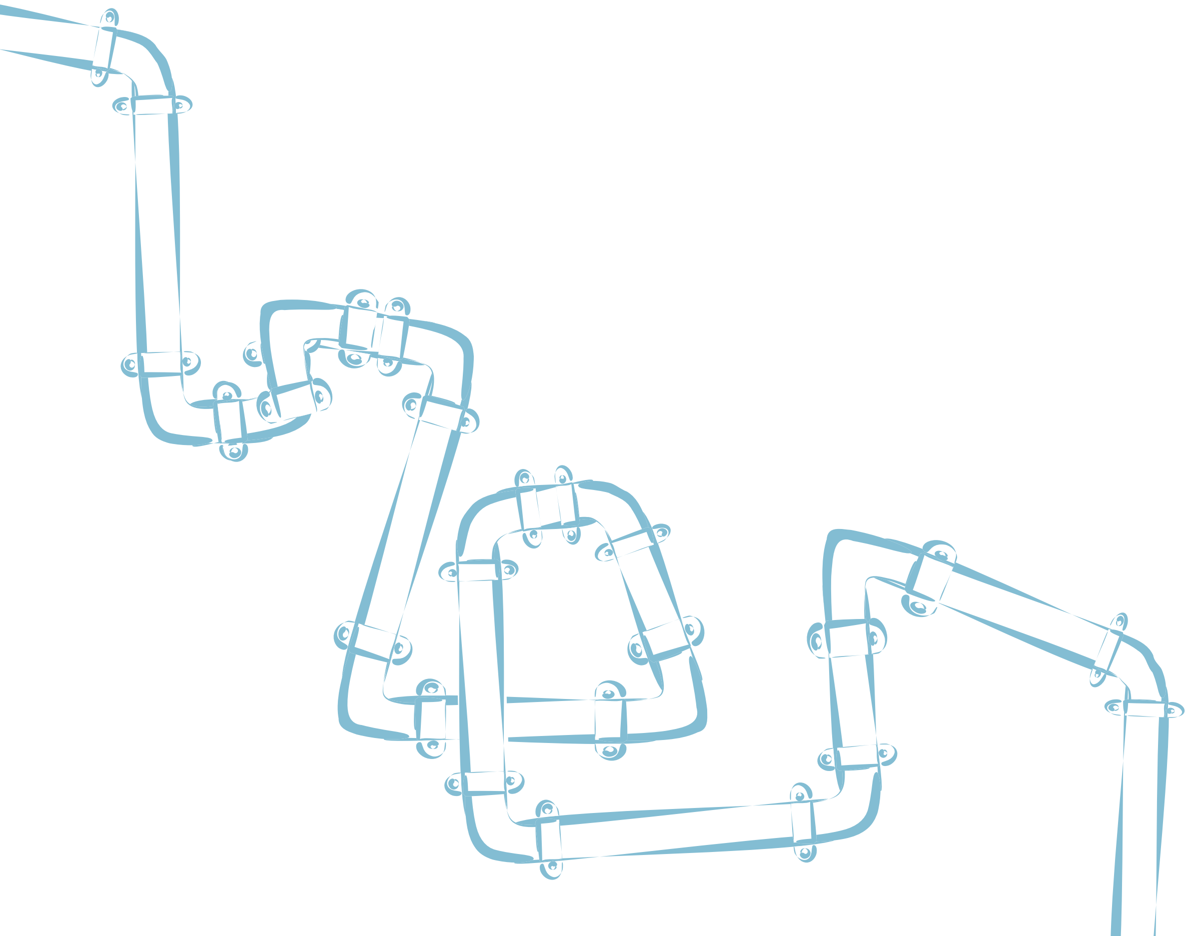
Recommendations for future improvements for this design include:

- Further analysis of rainfall and household demand to estimate the optimum tank size for each family or household;
- Installation of simple first-flush devices;
- Installation of screens and fences at all tanks;
- Better access to tap points;
- Full guttering at all houses; and
- Increase sizing of downpipes.



Lessons learned on system components and design

- Select tank material based on comparison of price, durability, availability and community's preferences.
- To ensure that tanks are durable; good-quality, clean, construction materials, which meet the required specifications, must be used.
- A solid foundation is essential for surface rainwater tanks and this can also double up as the tank floor. A 13-15 cm reinforced-concrete slab cast in two layers on the same day is normally sufficient.
- Tank walls can be constructed in several ways, including using bricks, blocks or concrete poured in situ, and ferrocement.
- Proper construction of gutters is essential and these must slope evenly towards the tank.
- Apply simple first-flush systems such as the manual or semi-automatic methods.
- Ensure the installation of an access manhole, screen, overflow and also a fence when required.



4 Operation and maintenance

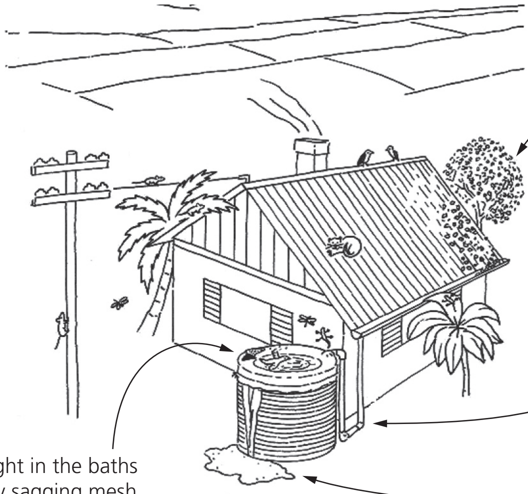
The operation and maintenance tasks required for rainwater harvesting systems serve two purposes: to maintain good drinking water quality by protecting water from contamination; and to keep the system in good working order.

4.1 Contaminants in rainwater harvesting systems

Clean rainwater can become contaminated:

- as it passes through the atmosphere;
- as it flows over the catchment surface;
- while it is being stored or during collection from storage;
- in the home; and
- during maintenance.

Figure 4.1: *Water pollution hazards for rainwater catchment systems (Macomber, 2001)*



Trees and shrubs that touch or overhang the roof and gutters can cause several problems. Plant debris can block gutters and downspouts so water can't get to the tank. Decomposting organic materials provide nutrients for microorganisms and can taint the water so that its colour and taste become unappealing. Plants also host insects, birds and other animals whose wastes and corpses contaminate your water supply. Rats in particular are a potential source of disease and they are adept at getting onto roofs via branches and utility wires.

Downspouts that are not properly designed hold water between rains. This water is not affected by water purification treatments applied to the tank, and it stagnates while waiting for the next rain to flush it into the water supply.

Birds delight in the baths formed by sagging mesh tank covers or blocked gutters. Many insects, particularly mosquitoes, find these pools perfect for breeding. Holes in the cover allow critters direct access to your stored water. Rodents and larger animals such as chickens and cats have fallen through holes in tank covers and drowned.

Uncontrolled tank overflow can undermine a tank's foundations, resulting in eventual tank collapse. This runoff needs to be directed to avoid causing problems on your property or neighbours.

4.1.1 Contamination from the atmosphere

Rainwater is generally a very pure form of water. However, pollutants in the air can be absorbed by raindrops and in industrialized urban areas this can render rainwater unfit to drink. This is unlikely to be a problem in most rural and island locations where the levels of contamination of natural rainfall are very low.

4.1.2 Contamination from the catchment

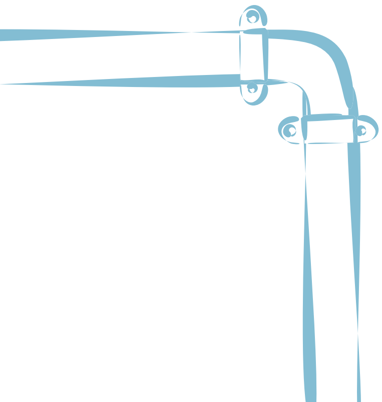
Bacteria of faecal origin may cause human diarrhoea and other life-threatening diseases (e.g. typhoid fever). As most faecal pollution from man and animals occurs at or below ground level, water collected from raised roof catchments is likely to be of better bacteriological quality than that collected from ground-level catchments. However, wind-blown dust particles, birds, reptiles and other animals can carry human faecal pathogens from ground level onto roof catchments. Animals can also deposit their own faeces on such surfaces and other contaminants such as dust and leaves can be deposited on roofs by wind, birds, animals and children. With the wrong type of surfaces, such as roof sheets painted with toxic paints, chemical contamination can take place. Water from thatched roofs is often discoloured and has an objectionable taste and/or smell.

4.1.3 Contamination during storage

If storage tanks are provided with a good quality cover, all openings are screened and water is withdrawn using a tap or pump, the opportunities for water to become contaminated during storage are severely limited. In fact rainwater quality usually improves with storage as bacteria and pathogens gradually die off and particles settle to the bottom of the tank.

4.1.4 Contamination in the home

Usually water collected from the storage tank is stored for short periods in small containers in the home. If rainwater, or indeed any source of water, is being promoted to provide good quality drinking water, it is important that the consumers understand the ways in which diseases are transmitted. Trained communicators with an understanding of the behaviour of the community can assist in creating awareness on how to avoid contamination of domestic water storage vessels. In homes, storage containers should be placed out of the reach of small children and animals and the containers should be kept covered or sealed. Containers themselves need to be clean and when water is drawn from them it needs to be done in a hygienic manner.



4.1.5 Contamination during maintenance

When performing maintenance tasks such as de-silting or cleaning the tank, cleaning screens, catchment surfaces and sediment traps it is possible that the system gets contaminated. If people enter tanks for cleaning they can introduce faecal matter carried on their feet so they should be encouraged to wash with soap before entering the tank. The equipment itself used for cleaning the tank needs to be clean. For example if a brush previously used for sweeping around the house is used in a tank it will be a source of contamination. It is advisable to monitor rainwater catchment schemes over time and to give advice and training concerning proper maintenance procedures. Disinfection of the tank with chlorine after maintenance is recommended and is further explained in section 4.4.1.

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

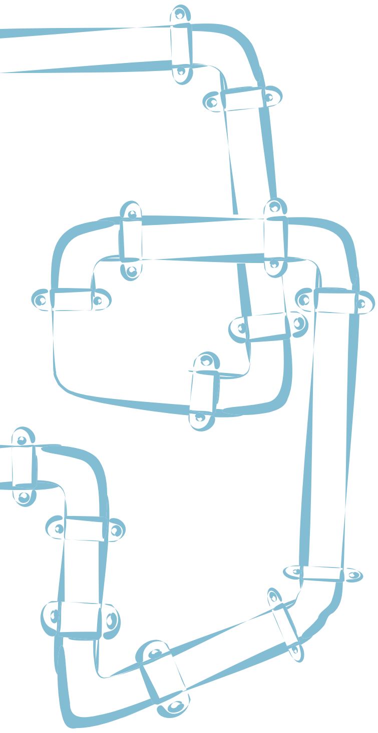
Table 4.1: *Contaminants found in rainwater collection systems*

Contaminant	Source	Risk of entering rainwater
Dust and ash	Surrounding dirt and vegetation, volcanic activity	*Moderate*: Can be minimised 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 minimised by use of a first-flush device and good roof and tank maintenance.
Heavy metals	Dust, particularly in urban and industrialised 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 sea-spray)	Sea-spray, 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	Mosquitoes laying eggs in guttering and/or tank	*Moderate*: If tank inlet is screened and there are no gaps, risks can be minimised.

4.2 Protecting collected rainwater from contamination

Good system design and proper operation and maintenance will protect water against contamination. This includes:

- Using an appropriate roofing material which is kept clear of any moss, lichen or other vegetation. A clean brush can be used to sweep roofs and gutters near to the end of the dry season and at other times as necessary;
- Removing branches from overhanging trees to prevent leaf debris falling on the catchment area. Branches also provide sanctuary for birds and access to the roof for rodents and other animals;
- Keeping gutters clear. If gutters sag or leak they need to be repaired. Sagging gutter systems will hold water providing breeding sites for mosquitoes. Leaking gutters will waste valuable water;
- Mosquito mesh should cover all openings to tanks to prevent any insects, frogs, toads, snakes, small mammals or birds entering the tank. The mesh needs to be inspected and cleaned periodically to ensure that it still excludes insects;
- Installing a coarse filter and/or first-flush device to prevent dirt and debris entering the tank. These devices need to be inspected and cleaned/drained periodically;
- Installing taps or draw-off pipes above the tank floor to avoid entraining any settled material;
- Covering tanks and excluding light to prevent the growth of algae and micro-organisms;
- Cleaning and disinfecting tanks annually if possible. A tank floor sloping towards a sump and washout pipe can greatly aid tank cleaning;
- Monitoring of tanks for leaks and repairing when necessary. Householders should monitor the level in their water tank to regulate usage but this should also help to detect leaks through the base of the tank;
- Not mixing water from other sources with that in the tank;
- Hygienic water handling practices in households; and
- Training householders in proper operation and maintenance of their systems.



4.3 Maintenance and repair tasks

The necessary maintenance and repair tasks for a given rainwater harvesting project are often obvious to designers and promoters but are usually not so obvious to the users. It is essential to include education and training in operation and maintenance as part of any rainwater harvesting project. Constructing a matrix such as that shown in Table 4.2 is a useful tool to identify the required tasks and equipment in relation to all components of the system.

Table 4.2: *Example of a maintenance and repair matrix*

THE MATRIX Maintenance and repair of rainwater harvesting systems				
PARTS	**ONGOING MAINTENANCE AND REPAIRS**	**HOW OFTEN?**	**MATERIALS**	**TOOLS**
Roof	Wash off roof with water when dust/dirt accumulates diverting runoff away from tank inlet	Check monthly and especially after a long period of dry weather or cyclone or heavy wind	Roofing iron Paint Water	Hand saw Nails Hammer Brush
	Trim and cut trees around tank	When required		
	Replace rusted roofing	When required		
	Fix holes for maximum runoff	When required		
	Paint if rust is present using lead-free paint	When required		
Gutters	Clean and wash out bird droppings, leaves etc. with water	Check monthly and especially after a long period of dry weather or cyclone or heavy wind	Water Guttering Gutter hanger Gutter fittings	Brush Screwdriver Screws Hammer Nails Level
	Check and repair gutters	When required		
	Add more guttering to increase water collected	When possible		
	Ensure guttering is slanted to ensure steady flow and avoid pooling of water, collection of dirt, debris, etc.	When required		
Tank	Clean	Once a year	Water Disinfectant Cement Sand Gravel Proper lid	Brush Shovel Wheelbarrow Saw Trowel
	Repair leaks	When required		
	Disinfect	When required		
	Cut nearby tree roots	When required		
	Ensure lid is sturdy and secure to prevent animals and children from falling in	When required		

THE MATRIX
Maintenance and repair of rainwater harvesting systems

PARTS	ONGOING MAINTENANCE AND REPAIRS	HOW OFTEN?	MATERIALS	TOOLS
Tap	Fix leaking taps. If new taps are needed brass taps are stronger	When required	♦ Tap ♦ Washer ♦ Plumbing tape ♦ Glue ♦ Rubber ♦ Stones/gravel	♦ Spanner ♦ Wrench ♦ Pliers ♦ Screwdriver
	Sponge out excess water to ensure it does not pool or collect	When required		
	Place stones or gravel on bottom of collection area to help drainage	When required		
Downpipe	Repair holes and replace if screen is damaged	When required	♦ Stainless steel wire mesh ♦ Twine ♦ PVC pipe ♦ Glue	♦ Pliers ♦ Tin snips
	Ensure there are no gaps where mosquitoes can enter or exit	When required		
	Repair leaks at elbows	When required		
Overflow	Securely fasten mosquito screen over the end of the overflow pipe/valve	When required	♦ Wire mesh ♦ Twine	♦ Pliers ♦ Tin snips
	Ensure there are no gaps where mosquitoes can enter or exit	When required		
	Repair screen if damaged.	When required		
Fence	Ensure fence is high and strong enough around tank and collection area to keep out pigs, dogs and small children	When required	♦ Fencing wire ♦ Poles	♦ Nails ♦ Hammer ♦ Digging hoe
	Repair any gaps or damage to fence	When required		
First Flush Devices	Remove downpipe from tank inlet to divert water. Securely replace the downpipe after first flush	Before starting to collect water, and especially after a long period of dry weather, a cyclone or heavy wind	♦ PVC pipe ♦ Pipe fittings	♦ Pipe wrench

It is recommended that tanks are cleaned on an annual basis, particularly if a large amount of debris has entered the tank or a sanitary survey (Appendix D) indicates a risk. Cleaning will help restore good water quality. To clean a tank, first most of the water can be drained and transferred to another rainwater storage or temporary tank. A bottle of household bleach can be added to the remaining water in the tank. The tank bottom and sides should be 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. Proper hand and eye protection should be worn when handling chlorine bleach solutions. Step by step instructions on tank cleaning and disinfection are included in Appendix E.

4.4 Water treatment

There are several different types of household water treatment systems available including sediment filters, activated carbon filters, ceramic candle filters, reverse osmosis purifiers, distillation and ultra-violet disinfection units. All of these systems will add cost and complexity, which, in the context of rainwater harvesting schemes in Pacific Island Countries is rarely warranted. Rainwater harvesting systems that are well constructed, operated and maintained will provide good quality drinking water without the need for further treatment.

4.4.1 Chlorine disinfection

Where rainwater harvesting systems are not well constructed or maintained, disinfection is required to safeguard human health. Adding small quantities of chlorine to the water tank is the cheapest and most effective means of disinfection which is recommended 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; and
4. An animal, or faecal material has entered a tank.

Chlorine can be added in various forms such as common household bleach (unscented and not coloured e.g. Janola). Instructions for disinfecting a rainwater storage tank using household bleach are detailed in Appendix E.

4.4.2 Disinfection by boiling

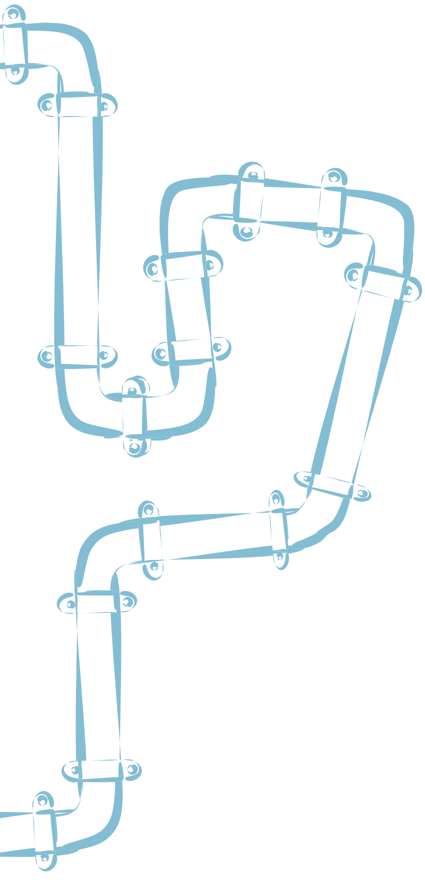
If the taste of chlorine is found to be unacceptable, boiling of water for at least 5 minutes before drinking is a suitable alternative to provide safe drinking water. Boiling is not always a practical option as it requires energy which may be a problem where fuel is scarce or expensive.

4.4.3 Other Disinfection Methods

Solar disinfection, distillation and ultra-violet systems as well as various chlorine substitutes are other options for disinfection. None of these systems currently has widespread application in the Pacific region.

4.5 Testing of water quality

Ideally, water quality testing should be regularly carried out by a relevant in-country agency, such as the Ministry of Health. Results should be compared with national drinking water standards (where they exist) or against WHO water quality guidelines (shown in Appendix F). Testing of water quality can guide when tanks need to be cleaned or disinfected.



Unfortunately, water quality testing in the Pacific Islands is not often performed on rainwater harvesting tanks as the use of these systems are often considered the responsibility of the individual householder. Where testing is not performed, communities could request relevant government agencies to begin conducting regular testing. Simple water quality testing equipment could also be supplied to communities so they can self-test their water.

If water quality testing is possible, the main focus should be on microbiological testing using tests such as thermotolerant coliform count (also known as faecal coliform count), Escherichia coli (E. coli) count, or the simple H_2S test. World Health Organization guidelines (WHO 2004) state that indicators of faecal pollution, E. coli or thermotolerant coliforms should not be detectable per 100 ml of sample. However, Fujioka (1994) stated that a more realistic standard may be 10 thermotolerant coliforms/100ml where a sanitary survey (Appendix D) 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 2004).

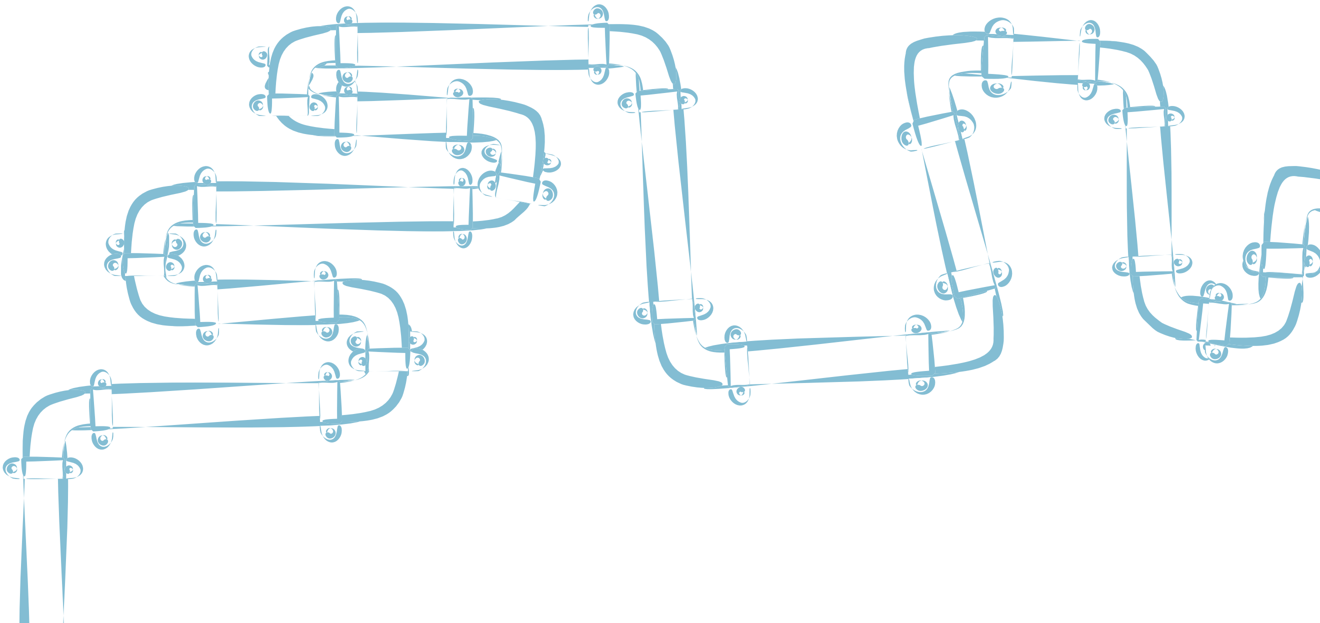
The H_2S test has been shown to correlate well with thermotolerant coliform levels in rainwater tanks (Faisst & Fujioka 1994). The results of most comparative studies suggest that the H_2S test detects faecally-contaminated water with about the same frequency and magnitude as traditional test methods such as Most Probable Number (MPN) and membrane-filtration methods (Sobsey & Pfaender 2002). More information on the H_2S test can be found in Appendix G.

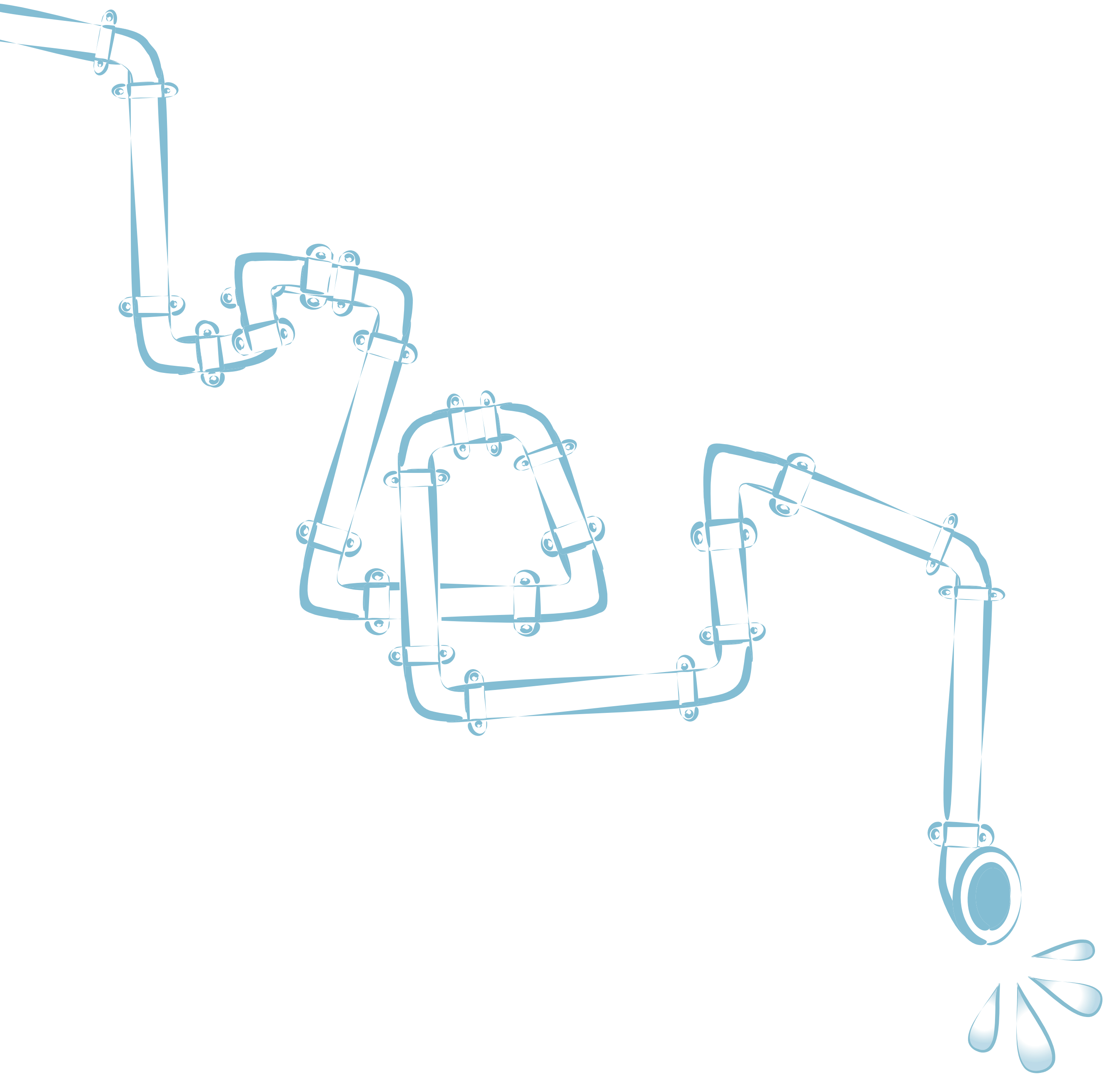
The physical parameters pH and turbidity should also be measured and compared to WHO guidelines. Rain is considered acidic when the pH is less than 5.6, and levels below this may cause corrosion of metal roofs and fittings. Heavy metals (e.g. lead, copper, cadmium, zinc) should also be monitored periodically,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

Given the current lack of testing for tank rainwater it is imperative that households are provided with sufficient education and awareness (workshops, printed material) on maintaining their tanks. This should be an integral part of any rainwater harvesting project. An example of a printed public awareness brochure used in Tonga is shown in Appendix H.

Lessons learned on operation & maintenance

- Rainwater harvesting systems that are well constructed, operated and maintained will provide good quality drinking water without the need for further treatment.
- Regular inspections of the system helps to maintain the water quality.
- Integrate water quality testing in follow-up activities.
- A matrix can help to identify the necessary tasks to maintain and repair rainwater harvesting systems.
- Training of Trainers for extension workers and adoption of participatory approaches are useful to transfer skills to communities.
- Awareness should be raised on the relation between water, hygiene and health.
- Perform simple absent-present tests like the H_2S test and use results to raise awareness in the community.
- Funding mechanisms for ongoing maintenance and repairs should be identified as part of rainwater harvesting projects.





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Appendices

Appendix A

Decision matrix for the demonstration of rainwater harvesting

In order to create transparency in the site selection process, especially as a number of SOPAC member countries formally requested to host the project, a decision matrix was used to evaluate the suitability of each of the six prospective countries.

Criteria for selection

Several broad areas were highlighted for consideration and a decision matrix developed with selected criteria used in order to select the site for the project.

Table A1: *Decision matrix for project site selection*

Yes, high, good	**1**
No, low, bad	**0**

Unless otherwise indicated.

	Practical implementation considerations	**Data**	**Score**	**Weighting**	**Final**
1	Existing rural power supply (yes or no)			1	
2	Distance between rural and urban sites (less than 300km)			3	
3	Availability/frequency of transport (boat: less than once a month) (air: yes or no)			 3 3	
4	Presence of NGO partners on the ground (yes or no)			4	
5	Cost of 4 trips to site (less than $8,000 FJD)			4	
6	Strength of in country contacts (high or low)			3	
	Technical considerations				
7	Availability of data (good or bad)			2	
8	Pre-existing catchment surface available (yes or no)			3	
9	Skilled labour available (yes or no)			2	
	Economic considerations				
10	GDP/capita (less than USD $2,000)			2	
11	Community willing to contribute financially (yes or no)			4	
12	Value of time and energy involved in collecting water (high or low)			2	
13	Benefits from improved health from cleaner water (high or low)			3	

	Social considerations	Data	Score	Weighting	Final
14	Benefits to women (high or low)			3	
15	Convenience/level of satisfaction with existing supply (high or low)			2	
16	Existence/strength of women/community groups (high or low)			4	
17	Demand/felt-need for improved water services (yes or no)			4	
18	Willingness of community to become fully involved; time, money, skills, management (high or low)			4	
19	Positive history of communal cooperation/projects (yes or no)			2	
20	Preferred sweet/soft tasting water (yes or no)			1	
21	Conducive political climate (yes or no)			2	
22	Water supply high on community's development priorities (yes or no)			3	
	Health considerations				
23	Existence of sanitation facilities (yes or no)			2	
24	High instances of diarrhoea (yes or no)			2	
25	Perceived problems with water quality (yes or no)			2	
26	Perceived problems with water quantity (yes or no)			2	
	Environmental considerations				
27	Vulnerability of existing supply to contamination (high or low)			3	
28	Vulnerability to ENSO events (high or low)			3	
29	Amount and pattern of rainfall (rainfall greater than 2,000 mm/y)			2	
30	Limited aggregate resources for construction material (yes or no)			1	
	Other considerations				
31	Promotes rainwater harvesting (yes or no)			4	
32	Support of government and policy makers (high or low)			2	
	Total				

Appendix B

Social surveys

Questionnaire survey

The survey was held using a random distribution of households in ‘Utungake. A team of two people went from house to house asking questions from a pre-developed sheet. A dialogue was to be developed in which the interviewee was comfortable. The interview was conducted in Tongan and translated in English for recording.

Questionnaire key

A: Roles and responsibilities

1. Who is responsible for collecting water?
2. Who is responsible for managing water supply?
3. Who looks after sick people in the household?
4. Who takes care of the maintenance or repairs?

B: Water quality

1. Do you have problems with pollution of the water and water quality vary over time? If so, when? How?
2. Do you think the water smells or tastes bad? How?
3. What causes the pollution of the water supply?
4. What do you prefer rainwater – rainwater or groundwater? Why?
5. What do you do to improve the water quality?

C: Awareness

1. Is there any education or awareness programme that you know of? If yes, by whom and what?

D: Operation, maintenance and management

1. Does your water supply breakdown sometimes. If so, how often?
2. Can you ask for assistance? (Y/N) How?
3. Who do you think should be paying for the maintenance and repairs?
4. Do you think improvements can be made to the water supply system? If so, what and how?
5. Are you prepared to pay for an improved system? (Y/N) How? (in-kind, $)

6. Has the community been involved in the implementation of earlier water supply and sanitation projects?

E: Land

1. Is your land registered or not?

F: General

1. Do you think that the issues/needs of the community were sufficiently analysed/researched before the project started?
2. Has there been sufficient involvement of the community in the decision-making in this project?
3. How were the women involved in the project so far, and how did that differ from the roles of the men in the project.

Appendix C

Storage volume calculations – worked examples

Storage volume calculations using the simple tabular method

Monthly rainfall data for Vava'u was available from 1947 until mid 2003. During this period annual rainfall averaged 2,200 mm and ranged from 1,183 mm in 1998 to 3,286 mm in the year 2000. As there has been quite a large range over recent years, it was considered safer to use the pattern for the driest year, 1998 in the storage volume calculation. This rainfall data is shown in Table A2.

Supply

Table A2: *Vava'u monthly rainfall data for 1998 (mm)*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1998	148	100	212	52	30	100	60	32	14	7	157	271	1,183

The volume captured from the roof each month was then calculated using an available roof area of 70 m^2 and a runoff coefficient of 0.9 assuming a corrugated iron roof with a good guttering system.

Volume Captured (litres) = Rainfall (mm) x Area Roof (m^2) x Runoff coefficient

So for January, Volume captured = 148 x 70 x 0.9 = 9,324 litres

Table A3: *Possible household monthly water supply volumes for Vava'u in 1998*

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1998 Rainfall (mm)	148	100	212	52	30	100	60	32	14	7	157	271	1,183
Litres captured	9,324	6,300	13,356	3,276	1,890	6,300	3,780	2,016	882	441	9,891	17,073	74,529

Demand

A first estimate of demand was calculated using an average of 6.5 people per household and a usage of 40 litres/person/day.

Total yearly demand = 6.5 x 40 x 365 = 94,900 litres

This value is in excess of the total litres captured for the year so it would not be possible to meet this demand. It was then assumed that water would be rationed for six months of the year from May to October at 20 litres/person/day. Assuming all months are of equal length (30.4 days) the monthly demands were calculated as follows:

Monthly demand (Nov. to Apr.) = 6.5 x 40 x 30.4 = 7,904 litres

Monthly demand (May. to Oct.) = 6.5 x 20 x 30.4 = 3,952 litres

Using the volume captured and demand figures, Table A4 can be completed to determine the minimum storage volume.

Table A4: *Calculation of minimum storage volume for Vava'u using the simple tabular method (volumes are in litres)*

A Month	B Volume captured in month	C Cumulative volume captured	D Volume demanded in month	E Cumulative demand	F Total amount stored C – E	G Deficit/ surplus for month B – D
November	9,891	9,891	7,904	7,904	1,987	1,987
December	17,073	26,964	7,904	15,808	11,156	9,169
January	9,324	36,288	7,904	23,712	12,576	1,420
February	6,300	42,588	7,904	31,616	10,972	–1,604
March	13,356	55,944	7,904	39,520	16,424	5,452
April	3,276	59,220	7,904	47,424	11,796	–4,628
May	1,890	61,110	3,952	51,376	9,734	–2,062
June	6,300	67,410	3,952	55,328	12,082	2,348
July	3,780	71,190	3,952	59,280	11,910	–172
August	2,016	73,206	3,952	63,232	9,974	–1,936
September	882	74,088	3,952	67,184	6,904	–3,070
October	441	74,529	3,952	71,136	3,393	–3,511
Total	74,529					3,393

The minimum storage required is then the maximum value in column F, 16,424 litres minus the surplus water left at the end of the year, 3,393 litres.

Minimum storage tank volume = 16,424 – 3,393 = 13,031 litres.

Some points to note about the data:

- The total of all the values in column B should equal the final value in column C.
- The total of all the values in column G should equal the final value in column F. This is the amount of water left over in the tank at the end of the year.

- If the cumulative volume captured is not greater than the cumulative demand, the household will run out of water at some time during the year and demand figures may need to be adjusted.

If we were to use the minimum storage volume, we can check the effect including columns which show the overflow from the tank (I) and the total amount actually stored (J).

Table A5: *Calculation of the effect of using the minimum storage volume for Vava'u using the simple tabular method (volumes are in litres)*

A Mth	B Volume captured in month	C Cum. volume captured	D Volume demand in month	E Cum. demand	F Total amount stored if no overflow C – E	G Deficit/ surplus for month B – D	I Over flow F – J	J Amount actually stored (max. 13,031)
Nov	9,891	9,891	7,904	7,904	1,987	1,987	0	1,987
Dec	17,073	26,964	7,904	15,808	11,156	9,169	0	11,156
Jan	9,324	36,288	7,904	23,712	12,576	1,420	0	12,576
Feb	6,300	42,588	7,904	31,616	10,972	–1,604	0	10,972
Mar	13,356	55,944	7,904	39,520	16,424	5,452	3,393	13,031
Apr	3,276	59,220	7,904	47,424	11,796	–4,628	0	8,403
May	1,890	61,110	3,952	51,376	9,734	–2,062	0	6,341
Jun	6,300	67,410	3,952	55,328	12,082	2,348	0	8,689
Jul	3,780	71,190	3,952	59,280	11,910	–172	0	8,517
Aug	2,016	73,206	3,952	63,232	9,974	–1,936	0	6,581
Sep	882	74,088	3,952	67,184	6,904	–3,070	0	3,511
Oct	441	74,529	3,952	71,136	3,393	–3,511	0	0
Tot.	74,529					3,393		

The amount in column J is equal to the figure in column F until the value of F exceeds the maximum capacity of the tank.

In this case the calculation shows the system is 100% reliable for this year, however at the end of October there is zero volume in the tank. This is risky as it assumes that rainfall goes exactly to plan which is unlikely!! This method also assumes that rainfall and demand are spread evenly over each day of the month which, in reality, is not the case.

Some other years with rain patterns with significant deviations from the norm were checked with tank volumes of 16,424 and 13,031 litres. It is important to note that if the "safer" figure of 16,424 litres had been used for design purposes the scheme would not have failed in any year.

Table A6: *Check of reliability using two tank sizes and rainfall figures from years with low or unusual rainfall patterns*

Year	Reason chosen	Tank size 16,424 l	Tank size 13,031 l
1992	Significantly lower than average rainfall figures for 9 of 12 months	Sufficient storage	Fail
1983	5 consecutive months with < 55 mm rainfall	Sufficient storage	Fail
1969	3 of 4 consecutive months with ≤15 mm rainfall	Sufficient storage	Sufficient storage
1953	2nd lowest total rainfall 1,283 mm	Sufficient storage	Sufficient storage
1952	3rd lowest total rainfall 1,444 mm	Sufficient storage	Sufficient storage

Mass curve analysis

A sample cycle is shown in table A7. Here the supply exceeds the demand for the first 3 months building up a maximum volume in storage of 500 litres. This is followed by a period of 3 months where the demand exceeds supply and the water in storage is drawn upon lowering the volume in the tank to a minimum of 190 litres. The volume of storage required to provide the household with water during the dry period is then the difference between these two numbers (i.e. 500 – 190 = 310 litres).

Over the period examined, the largest difference calculated in column H should be taken as the tank storage volume.

Table A7: *Sample calculation of minimum storage volume using mass curve analysis*

A Month	B Volume captured in month	C Cumulative volume captured	D Volume demanded in month	E Cumulative demand	F Total amount stored C – E	G Deficit/ surplus for month B —D	H Difference between max & min amount stored during a cycle
1	300	300	250	250	50	50	–
2	500	800	250	500	300	250	–
3	450	1,250	250	750	500 (a)	200	310 (a-b)
4	240	1,490	250	1,000	490	–10	–
5	150	1,640	250	1,250	390	–100	–
6	50	1,690	250	1,500	190 (b)	–200	–
7	300	1,990	250	1,750	240	50	–
…	…				…	…	
N	…				50,000		

Using the data from Vava'u Table A8 was constructed

Table A8: *Calculation of minimum storage volume for Vava'u using mass curve analysis (volumes are in litres)*

A Month	Rainfall	B Volume captured in month	C Cumulative volume captured	D Volume demanded in month	E Cumulative demand	F Total amount stored C – E	G Deficit/ surplus for month B – D	H Difference between max & min amount stored during a cycle
1	316	19,908	19,908	7,904	7,904	12,004	12,004	1,415
2	103	6,489	26,397	7,904	15,808	10,589	–1,415	
3	657	41,391	67,788	7,904	23,712	44,076	33,487	4,439
4	55	3,465	71,253	7,904	31,616	39,637	–4,439	
5	161	10,143	81,396	3,952	35,568	45,828	6,191	
6	287	18,081	99,477	3,952	39,520	59,957	14,129	
7	134	8,442	107,919	3,952	43,472	64,447	4,490	
8	73	4,599	112,518	3,952	47,424	65,094	647	
9	90	5,670	118,188	3,952	51,376	66,812	1,718	
10	172	10,836	129,024	3,952	55,328	73,696	6,884	3,809
11	65	4,095	133,119	7,904	63,232	69,887	–3,809	
12	312	19,656	152,775	7,904	71,136	81,639	11,752	
532	184	11,592	6,216,840	7,904	3,161,600	3,055,240	3,688	
533	167	10,521	6,227,361	3,952	3,165,552	3,061,809	6,569	
534	143	9,009	6,236,370	3,952	3,169,504	3,066,866	5,057	1,684
535	36	2,268	6,238,638	3,952	3,173,456	3,065,182	–1,684	
536	80	5,040	6,243,678	3,952	3,177,408	3,066,270	1,088	18,478
537	33	2,079	6,245,757	3,952	3,181,360	3,064,397	–1,873	
538	24	1,512	6,247,269	3,952	3,185,312	3,061,957	–2,440	

A Month	Rainfall	B Volume captured in month	C Cumulative volume captured	D Volume demanded in month	E Cumulative demand	F Total amount stored C – E	G Deficit/ surplus for month B – D	H Difference between max & min amount stored during a cycle
539	107	6,741	6,254,010	7,904	3,193,216	3,060,794	–1,163	
540	66	4,158	6,258,168	7,904	3,201,120	3,057,048	–3,746	
541	49	3,087	6,261,255	7,904	3,209,024	3,052,231	–4,817	
542	55	3,465	6,264,720	7,904	3,216,928	3,047,792	–4,439	
610	183	11,529	6,974,919	3,952	3,612,128	3,362,791	7,577	3,998
611	62	3,906	6,978,825	7,904	3,620,032	3,358,793	–3,998	
612	153	9,639	6,988,464	7,904	3,627,936	3,360,528	1,735	
613	148	9,324	6,997,788	7,904	3,635,840	3,361,948	1,420	1,604
614	100	6,300	7,004,088	7,904	3,643,744	3,360,344	–1,604	
615	212	13,356	7,017,444	7,904	3,651,648	3,365,796	5,452	6,690
616	52	3,276	7,020,720	7,904	3,659,552	3,361,168	–4,628	
617	30	1,890	7,022,610	3,952	3,663,504	3,359,106	–2,062	
618	100	6,300	7,028,910	3,952	3,667,456	3,361,454	2,348	8,689
619	60	3,780	7,032,690	3,952	3,671,408	3,361,282	–172	
620	32	2,016	7,034,706	3,952	3,675,360	3,359,346	–1,936	
621	14	882	7,035,588	3,952	3,679,312	3,356,276	–3,070	
622	7	441	7,036,029	3,952	3,683,264	3,352,765	–3,511	

The largest value in column H was found to be 18,478 litres which would be the minimum storage tank volume required if we were aiming for 100% reliability. In fact the reliability can be checked by including columns which show the overflow from the tank (I) and the total amount actually stored (J) as shown in the example using the simple tabular method. It is then a matter of counting the negative values or “failures” in column J. Table A9 shows part of the calculation.

Table A9: *Check of reliability using the minimum storage volume calculated with mass curve analysis (volumes are in litres)*

A – Mth	Rainfall	B – Volume captured in month	C – Cum. volume captured	D – Volume demand in month	E – Cum. demand	F – Total amount stored (no overflow) C – E	G – Deficit/ Surplus for month B – D	I – Over flow	J – Amount actually stored (max. 18478)	K –Storage OK/ Fail
530	201	12,663	6,181,308	7,904	3,145,792	3,035,516	4,759	4,759	18,478	OK
531	380	23,940	6,205,248	7,904	3,153,696	3,051,552	16,036	16,036	18,478	OK
532	184	11,592	6,216,840	7,904	3,161,600	3,055,240	3,688	3,688	18,478	OK
533	167	10,521	6,227,361	3,952	3,165,552	3,061,809	6,569	6,569	18,478	OK
534	143	9,009	6,236,370	3,952	3,169,504	3,066,866	5,057	5,057	18,478	OK
535	36	2,268	6,238,638	3,952	3,173,456	3,065,182	–1,684	0	16,794	OK
536	80	5,040	6,243,678	3,952	3,177,408	3,066,270	1,088	0	17,882	OK
537	33	2,079	6,245,757	3,952	3,181,360	3,064,397	–1,873	0	16,009	OK
538	24	1,512	6,247,269	3,952	3,185,312	3,061,957	–2,440	0	13,569	OK
539	107	6,741	6,254,010	7,904	3,193,216	3,060,794	–1,163	0	12,406	OK
540	66	4,158	6,258,168	7,904	3,201,120	3,057,048	–3,746	0	8,660	OK
541	49	3,087	6,261,255	7,904	3,209,024	3,052,231	–4,817	0	3,843	OK
542	55	3,465	6,264,720	7,904	3,216,928	3,047,792	–4,439	0	–596	Fail
543	165	10,395	6,275,115	7,904	3,224,832	3,050,283	2,491	0	1,895	OK

Using the tank volume of 18,478 only one failure was found during 624 months or a reliability of 99.8%.

Reliability = (1 – 1/624) x 100 = 99.8 %

If the tank volume was increased to 19,074 (18,478 + 596) reliability would have been 100%. As a comparison a tank volume of 15,000 litres gave 6 failures for a reliability of 99.0%. A volume of 11,000 litres gave 20 failures for a reliability of 96.8%. In the latter case there was one period where no water would have been available for 6 months consecutively and 2 periods of 4 months. Depending on the scheme a decision would have to be made as to whether this is an acceptable failure rate or not.

Dimensionless constant analysis

To construct the dimensionless constant graph:

1. Calculate the storage volume required using mass curve analysis when the demand is 10, 30, 50, 70 and 90% of the total annual supply
2. Take the storage volume calculated in each case, divide by the total annual supply and multiply by 100 to give the storage required as a percentage of supply.
3. Plot this data with storage required as % of supply on the y-axis and demand as % on the x-axis.

For a given annual supply and user demand, the demand as a % of supply can be calculated for a range of roof areas. The supply as a % of demand can then be read off the dimensionless constant graph and the corresponding tank volumes calculated. This then allows a series of curves to be constructed showing Tank Size vs Roof Area for different water-demand scenarios. An example using the data from Vava'u is shown below.

Average annual rainfall – 2185 mm

Average roof area – 70 m^2

Runoff coefficient – 0.9

Average number of people per household – 6.5

Table A10: *Calculation of points required to construct a dimensionless constant graph*

Demand as % of supply	10	30	50	70	90
Storage required (m^3)	0.96	6.93	22.1	40.3	58.6
Storage as % of supply	0.70	5.06	16.1	29.4	42.8
Demand (m^3)	13.7	41.1	68.5	95.9	123.3
Demand l/p/d	5.8	17.3	28.9	40.4	52.0

Annual average supply = 2,185 mm x 70 m^2 x 0.9 = 137 m^3

Taking the first column as an example, if demand is 10% of supply:

Demand (m^3) = 0.1 x 137 = 13.7 m^3

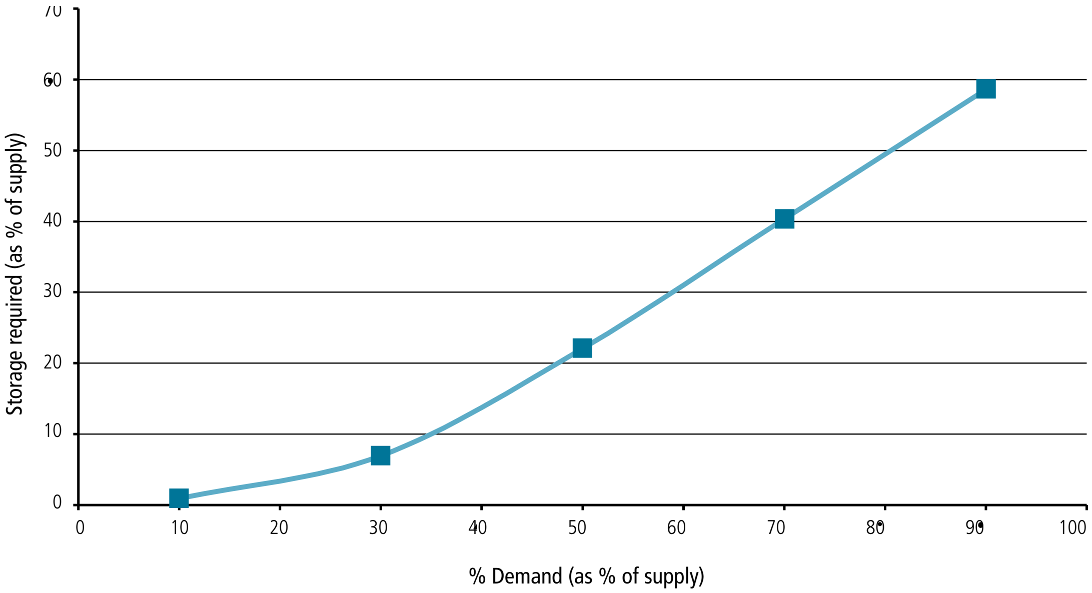
Demand (l/p/d) = 13.7 x 1,000 / 6.5 / 365 = 5.8 l/p/d

Using mass curve analysis for the calculated demand, the storage requirement in m^3 can be determined. (See the previous section for a worked example demonstrating mass curve analysis).

Storage as % of supply = 0.96 / 137 x 100 = 0.70 %

Once this process has been repeated for 30, 50, 70 and 90% demand, the dimensionless constant graph can be plotted as shown in Figure A1.

Figure A1: *Dimensionless constant graph constructed from Vava'u monthly rainfall data*



For a given user demand, storage tank volume can then be calculated using the dimensionless constant graph based on a number of different roof areas as shown in Table A11.

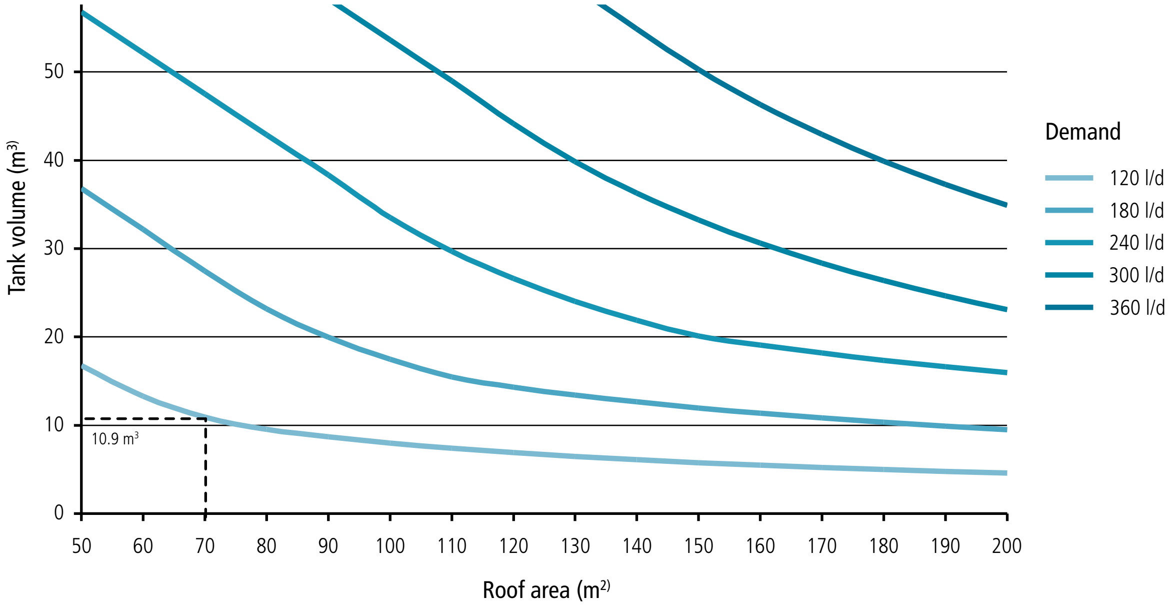
Table A11: *Sample calculation of storage tank volume using the dimensionless constant graph*

Annual supply	2,185 mm
User demand	30 l/p/d
No. in household	6 p

Roof area (m^2)	Runoff coefficient	Avg annual supply (m^3) A	Demand for year (m^3) B	Demand (%) B/A x 100	Storage (%) (from graph)	Roof area (m^2)
50	0.9	98.3	65.7	66.8	37.4	50
60	0.9	118.0	65.7	55.7	27.3	60
70	0.9	137.7	65.7	47.7	19.9	70
80	0.9	157.3	65.7	41.8	14.7	80
90	0.9	177.0	65.7	37.1	11.3	90
100	0.9	196.7	65.7	33.4	8.9	100
110	0.9	216.3	65.7	30.4	7.2	110
120	0.9	236.0	65.7	27.8	6.1	120
130	0.9	255.6	65.7	25.7	5.2	130
140	0.9	275.3	65.7	23.9	4.6	140
150	0.9	295.0	65.7	22.3	4.1	150
160	0.9	314.6	65.7	20.9	3.6	160
170	0.9	334.3	65.7	19.7	3.2	170
180	0.9	354.0	65.7	18.6	2.9	180
190	0.9	373.6	65.7	17.6	2.7	190
200	0.9	393.3	65.7	16.7	2.4	200

These calculations can then be used to construct a series of graphs relating roof area and tank size for easy reference as shown in Figure A2.

Figure A2: *Roof area vs tank size for different demand scenarios constructed from Vava'u monthly rainfall data*



For example, for a household with 6 people, a demand of 20 l/p/d (total 120 l/d) and a roof area of 70 m^2, the tank volume required would be 10.9 m^3.

SimTanka model

The SimTanka model can be downloaded from the website address http://homepage.mac.com/vsvyas/science.html#simtanka.

The SimTanka model requires at least 15 years of monthly rainfall data. The user then must specify the desired reliability and the water demand. The model offers three options for reliability:

Extremely reliable – monthly demand is met 95% of the time.

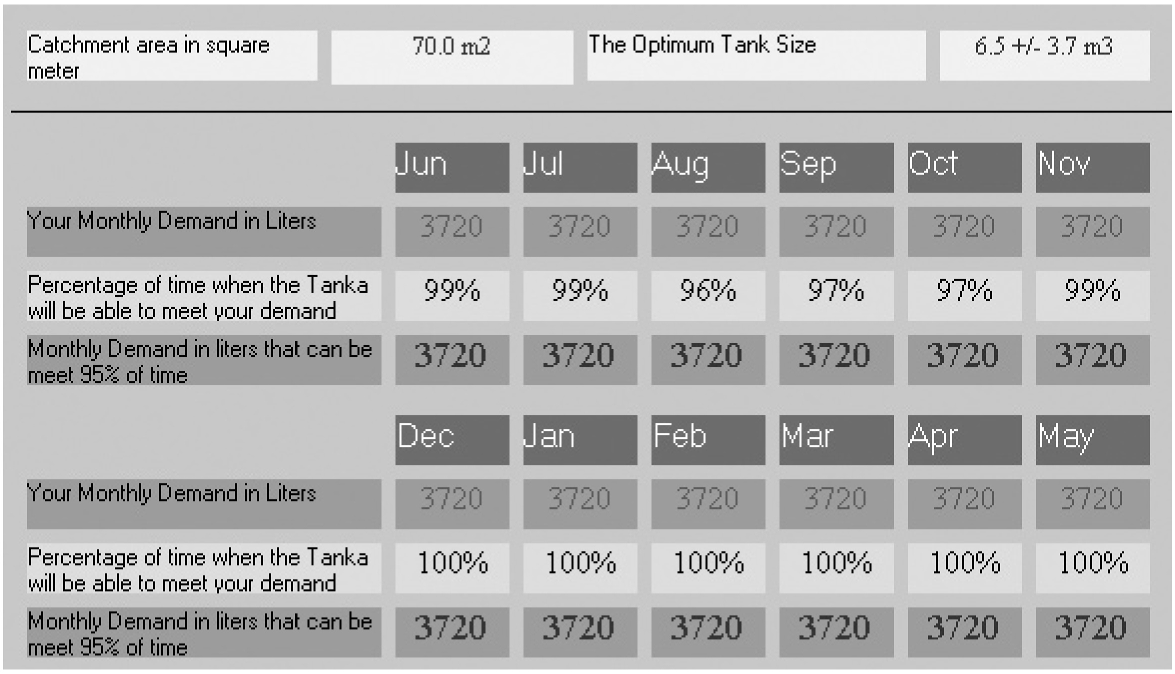
Reliable – monthly demand is met 85% of the time.

Tolerable – monthly demand is met 75% of the time.

The user can specify either the roof area, or the tank size. If neither is known the model will calculate a value for both. The type of catchment surface must also be specified, several options are given.

Some sample results are shown below using the data in Vava'u from 1947 to 2002. A catchment area of 70 m^2 was used with a runoff coefficient of 0.8 and a household of 6 people. Three scenarios were run, a demand of 20 l/p/d and 95% reliability and demands of 30 l/p/d with 95% and 75% reliability.

Figure A3: *SimTanka model output using 70 m² catchment with demand of 20 l/p/d and 95% reliability*

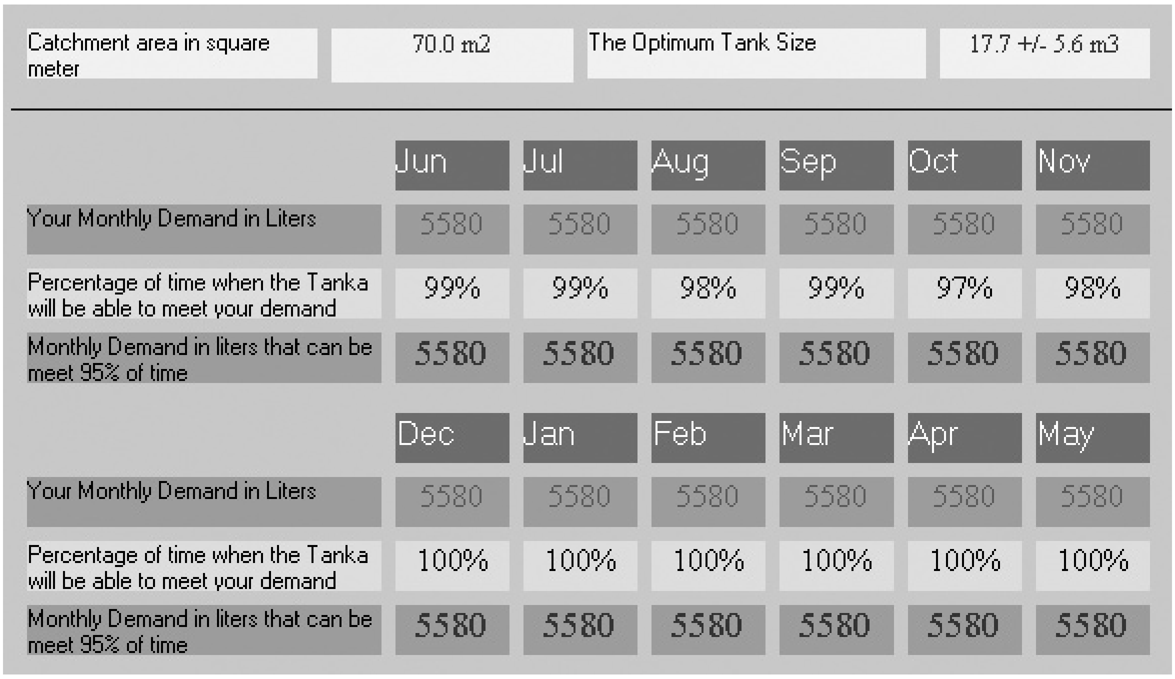


Catchment area in square meter	70.0 m2	The Optimum Tank Size	6.5 +/- 3.7 m3

	Jun	Jul	Aug	Sep	Oct	Nov
Your Monthly Demand in Liters	3720	3720	3720	3720	3720	3720
Percentage of time when the Tanka will be able to meet your demand	99%	99%	96%	97%	97%	99%
Monthly Demand in liters that can be meet 95% of time	3720	3720	3720	3720	3720	3720

	Dec	Jan	Feb	Mar	Apr	May
Your Monthly Demand in Liters	3720	3720	3720	3720	3720	3720
Percentage of time when the Tanka will be able to meet your demand	100%	100%	100%	100%	100%	100%
Monthly Demand in liters that can be meet 95% of time	3720	3720	3720	3720	3720	3720

Figure A4: *SimTanka model output using 70 m² catchment with demand of 30 l/p/d and 95% reliability*



Catchment area in square meter	70.0 m2	The Optimum Tank Size	17.7 +/- 5.6 m3

	Jun	Jul	Aug	Sep	Oct	Nov
Your Monthly Demand in Liters	5580	5580	5580	5580	5580	5580
Percentage of time when the Tanka will be able to meet your demand	99%	99%	98%	99%	97%	98%
Monthly Demand in liters that can be meet 95% of time	5580	5580	5580	5580	5580	5580

	Dec	Jan	Feb	Mar	Apr	May
Your Monthly Demand in Liters	5580	5580	5580	5580	5580	5580
Percentage of time when the Tanka will be able to meet your demand	100%	100%	100%	100%	100%	100%
Monthly Demand in liters that can be meet 95% of time	5580	5580	5580	5580	5580	5580

Figure A5: *SimTanka model output using 70 m^2 catchment with demand of 30 l/p/d and 75% reliability*

Catchment area in square meter	70.0 m2	The Optimum Tank Size	12.1 +/- 5.6 m3

	Jun	Jul	Aug	Sep	Oct	Nov
Your Monthly Demand in Liters	5580	5580	5580	5580	5580	5580
Percentage of time when the Tanka will be able to meet your demand	99%	98%	96%	96%	93%	96%
Monthly Demand in liters that can be meet 75% of time	5580	5580	5580	5580	5580	5580

	Dec	Jan	Feb	Mar	Apr	May
Your Monthly Demand in Liters	5580	5580	5580	5580	5580	5580
Percentage of time when the Tanka will be able to meet your demand	96%	100%	100%	100%	100%	100%
Monthly Demand in liters that can be meet 75% of time	5580	5580	5580	5580	5580	5580

Appendix D

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	

OTHER INFORMATION:

1. Type GUTTERING: vinyl ☐ PVC ☐ metal ☐ other [describe]: ________________________
2. Type TANK: fibreglass ☐ poured concrete ☐ ferrocement ☐ PVC ☐
   galvanised 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: ___________

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

Appendix E

Tank cleaning and chlorine disinfection using household bleach

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.

Remember to clean your water tank once a year

You will need:

- Liquid chlorine/bleach (such as Dash or Janola) or chlorine tablets. If household bleach is used it should be unscented and not coloured.
- Bucket
- Brush
- Eye and hand protection (glasses, rubber gloves)
- A helper to watch the person inside the tank

Cleaning procedure

1. Drain any water in the tank to the level at the tap. Transfer water to a clean, contaminant-free storage or temporary vessel. If tanks are cleaned during a rainy period any lost water will soon be replaced.
2. Add 1 bottle of bleach or X number of chlorine tablets to the remaining water in the tank. The ratio of bleach to water should be around 1 part bleach to 50 parts water.
3. Climb inside the tank. Using a brush thoroughly scrub the bottom and sides of the tank. Make sure that ventilation is adequate for the person inside the tank and that a helper is watching.
4. Remove the water and bleach solution remaining below the tap with a bucket.
5. Refill the tank with water.
6. Leave the water to settle overnight before use.

Tank disinfection

You should disinfect your tank only when one or more of the following situations are present:

- People are getting sick from drinking the water with sore stomachs and diarrhoea;

- Animal or human waste, including bird droppings have entered the tank;
- After tank repairs or maintenance where people have entered the tank;
- The water has been tested and there is a known bacterial contamination.

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 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.

Remember to wear proper hand and eye protection when preparing and handling chlorine solutions to avoid burning skin and damaging eyes.

The amount of bleach to add, based on a 4% active ingredient, is shown in the table below relative to the amount of water in the tank.

Table A12: *Bleach amounts per volume of water*

Volume of water in tank (litres)	Amount of bleach to add (ml, with 4% active ingredient)
1,000	125
2,000	250
3,000	375
4,000	500
5,000	625
6,000	750
7,000	875
8,000	1,000
9,000	1,125
10,000	1,250
11,000	1,375
12,000	1,500

For example, an 8,000 litre tank that is half full contains approximately 4,000 litres of water, so 500 ml of bleach would be added.

If the available bleach has a different level of active ingredient, the amount to add will have to be adjusted accordingly. For example, using bleach with 8% active ingredient would halve the amount of bleach listed in the above table for a particular water volume.

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 the chlorine residual can be tested 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.

Appendix F

World Health Organization water quality guidelines

Selected WHO guidelines (2004) relevant to water quality of rainwater systems are presented below. Critical values for some parameters are given in order to protect human health. The 2004 edition of the WHO Guidelines for Drinking-water Quality no longer includes guideline values for parameters unrelated to human health. However, information is included on acceptability aspects for consumers and this is also presented below for selected parameters.

Table A13: *Selected WHO guideline values for drinking water that are human health significant*

Parameter	Guideline value
E. coli or thermotolerant coliform bacteria (previously known as faecal coliforms)*	Not detectable in a 100 ml sample
Cadmium	0.003 mg/l
Copper	2 mg/l (staining of laundry and sanitary ware may occur below guideline value)
Fluoride	1.5 mg/l
Lead	0.01 mg/l

*E. coli is the more precise indicator for faceal pollution and is the recommended test for verification of microbial quality. The count of thermotolerant coliform bacteria is an acceptable alternative

Table A14: *Drinking water quality consumer acceptability aspects*

Parameter	Guideline information
Aluminium	The presence of aluminium at concentrations in excess of 0.1-0.2 mg/l often leads to consumer complaints as a result of deposition of aluminium hydroxide floc in distribution systems and the exacerbation of discolouration of water by iron.
Chloride	High concentrations of chloride give a salty taste to water and beverages. Taste thresholds are in the range of 200-300 mg/l.
Iron	At levels above 0.3 mg/l iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 mg/l.
pH	pH has no direct impact on consumers but for effective disinfection and control of corrosion in distribution systems it should be in the range 6.5-8.
Sodium	The average taste threshold for sodium is about 200 mg/l.
Sulphate	Sulphate can cause noticeable taste and very high levels might cause a laxative effect in unaccustomed consumers. It is generally considered that taste impairment is minimal at levels below 250 mg/l.
Turbidity	The appearance of water with a turbidity less than 5 NTU is usually acceptable to consumers. Where water is disinfected ideally turbidity should be below 0.1 NTU.
Total dissolved solids (TDS)	The palatability of water with a TDS level less than 600 mg/l is generally considered to be good. Drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l.
Zinc	Zinc imparts an undesirable astringent taste to water at concentrations of about 4 mg/l. In excess of 3-5 mg/l water may appear opalescent and develop a greasy film on boiling.

Appendix G

H_2S test for water quality

The H_2S (hydrogen sulphide) test was originally developed over 20 years ago, to detect in a volume of water, the production of H_2S by enteric bacteria associated with faecal contamination. The contamination is detected by formation of a black precipitate from the reaction of the H_2S with iron in the medium. This relatively simple, low-cost test has been studied, modified in various ways, tested and used to some extent in many parts of the world as an indicator of faecal contamination of drinking water. A method for preparing and conducting the test is detailed as follows.

Preparation of H_2S test containers

1. Any type of glass bottle or tube with a volume of between 20 ml to 200 ml, which has a heat resistant cap/lid, can be used. The bottles or tubes are first cleaned and calibrated to indicate a 10 ml, 20 ml or 100 ml volume, or any volume in-between – depending upon their size. Calibration is done with a graduated cylinder or other measuring device. A glass marking pencil, permanent ink pen or tape can be used to mark the desired volume.
2. The medium used in the test is prepared from the following chemicals, which are dissolved into distilled or dechlorinated tap water while stirring.

Table A15: *H_2S media preparation*

Bacteriological peptone	40 g
Dipotassium hydrogen phosphate	3 g
Ferric ammonium citrate	1.5 g
Sodium thiosulphate	2 g
Teepol (a liquid detergent, any detergent may be used)	2.0 ml
Water (distilled or boiled tap water)	100 ml

3. If not immediately used, the media can be sterilized and stored in a refrigerator until ready for use.
4. Taking tissue paper, filter paper, non-toxic paper towelling, absorbent pads used for membrane filtration, or any other type of absorbent material (coasters used in bars work well if no black ink is used), place a measured quantity of media onto the paper so that a pad or paper strip for a 10 ml test sample contains 0.5 ml of media, a 50 ml sample will use 1 ml of media and a 100 ml sample will require 2.5 ml of media (a pipette graduated at 0.1 ml intervals may be necessary for this). Alternatively, paper strips can be cut to a size that has absorbed 0.5 ml of media. If the sample to be tested is 10 ml, use one strip; if 50 ml, use two strips; and if 100 ml, use five strips.

   The next step is to dry the strips in an oven at about 55°C. These reagent-impregnated strips can be stored dry (in an envelope or preferably a zip-locked bag) for several months – until ready for use. It is always advisable if the health authority supplies prepared strips to the community.
5. When ready to conduct the test, a strip or strips are introduced into the appropriate (clean) sample bottle, loosely capped and sterilised. This can be done with an autoclave or a simple pressure cooker for 15 minutes at 115°C. It can also be done by steam (in a rice steamer) for about 30 minutes, or in a hot air oven at about 120°C for 60 minutes. The tubes or bottles are then allowed to cool and the caps or lids tightly sealed. The tubes or bottles should be stored in a dark place until ready for use.

Sampling procedure:

1. At the time of sampling, label each container with a sample number. Also record the date, time and location of collection on the container with a glass marking pencil or permanent ink pen.
2. Flame the mouth of the tap nearest to the tank and let the water run freely for at least 30 seconds. Place the opened H_2S sample collection bottle under the tap and collect the pre-calibrated amount being careful not to contaminate the cap. It should be noted however that samples should not be collected from taps that are leaking and flaming the tap is not necessary if you are testing the quality of the water as it is actually consumed.
3. Each day of sampling, a control is collected. This is a sample that is known to be uncontaminated, such as boiled water, commercially bottled water, or water treated with chlorine. The control sample is used as a benchmark to compare colour change in the test samples and to ensure that the sample bottles have been properly sterilised prior to use.

Note: There will be slight change in the colour of the sample to a pale yellow or light brown due to the colour of the reagent, which is normal.

Reading and interpreting results

1. After sampling, place all test samples in a dark place and incubate at room temperature for a total of three days. Every 12-18 hours examine the samples for changes in colour. The date and time of each observation is recorded on the report form and the observations are recorded as follows: (–) = no change; (+) = slight change, the paper strip or water has turned grey; (++) = the paper strip is partially black; (+++) = the strip and the water sample itself are noticeably black.
2. As noted above, a colour change indicates the presence of bacteria of faecal origin. The speed of the reaction will determine the density of organisms present; i.e. the quicker the reaction the higher the number of faecal organisms present. This can also be interpreted in terms of a risk factor. For example, no colour change until day three indicates a lesser risk than a (+++) change within 12 hours.
3. Positive results would indicate that the water is contaminated and results of sanitary survey should be considered to determine the source of contaminant. For example, if the tank inlet is not screened and the results of the H_2S test are positive on the first day, the users should disinfect the water as outlined in Appendix E and the tank inlet should be screened.

Table A6: *H_2S water quality test report form*

Water Quality Testing Report Form											
Address											
Location of source (describe)						Results[2]					
						Day 1		Day 2		Day 3	
						Date:		Date:		Date:	
Sample number	Type of water source	Date of sample collection	Time of sample collection	Location	Remarks[1]	Time	Time	Time	Time	Time	Time
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
Notes[3]:											

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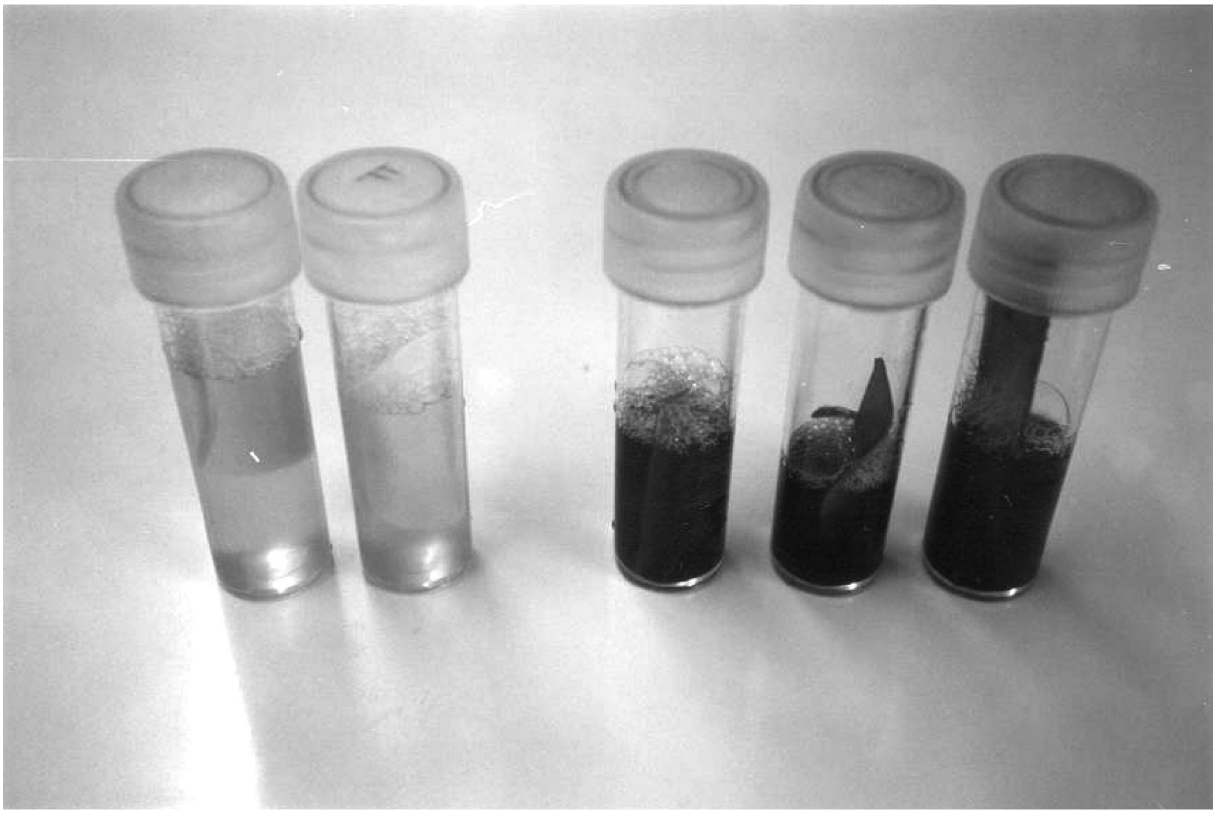
[1] Indicate under "remarks" if the water is turbid, coloured, or contains settled solids or material in suspension. Also note any problem at the sampling site like a leaking tap, area unclean or littered, drainage problems etc.

[2] Results: (–) indicates a negative; (+) grey colour, a reaction has started; (++) the reagent pad is now partially black; (+++) the reagent pad and the water is now black.

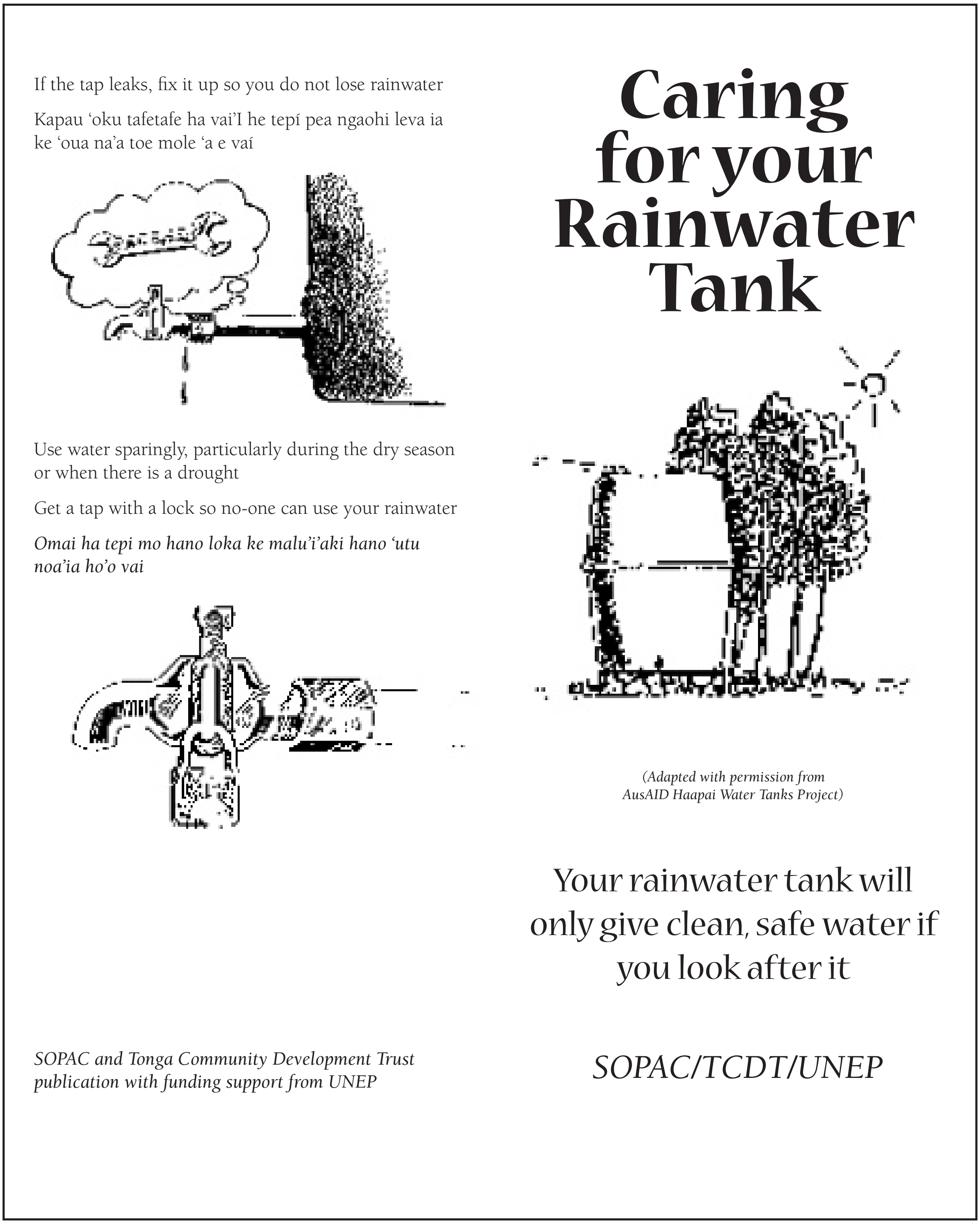
[3] Indicate the distance between the water source and any other sources of pollution, like a compost pit, septic tank or leach field etc.

Figure A6: *H_2S test samples. The three tubes on the right are showing positive for faecal contamination*



Appendix H

Public awareness brochure – caring for your rainwater tank



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

SOPAC and Tonga Community Development Trust publication with funding support from UNEP

Caring for your Rainwater Tank

(Adapted with permission from AusAID Haapai Water Tanks Project)

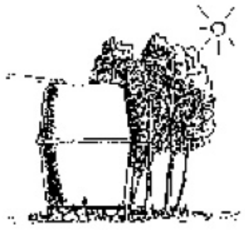
Your rainwater tank will only give clean, safe water if you look after it

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.

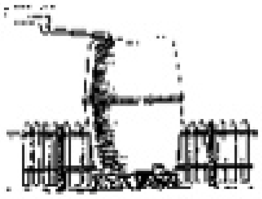
Plant shady bushes near your tank to help keep the water cool in the tank

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

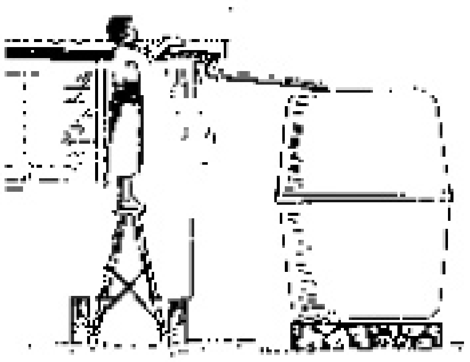


Regularly clean away the leaves from the top of your tank

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

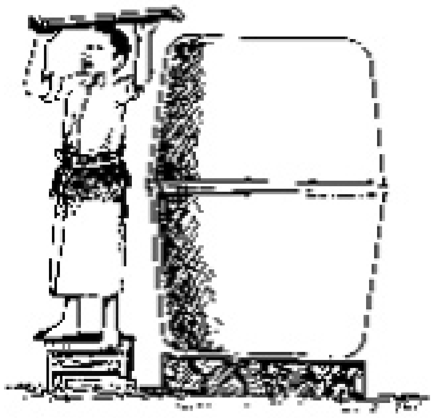


Make sure that you buy some extra guttering so that the whole roof will give rainwater to your tank

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



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