Cranfield UNIVERSITY

SILSOE COLLEGE

Water Management

MSc Infrastructure Engineering (Community Water Supply option)

1997-98

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Fogwater Harvesting for Community Water Supply

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September 1, 1998

Abstract

Fogwater Harvesting has been demonstrated to be able to provide water for small rural communities in arid and semi-arid regions. Fog droplets coalesce on mesh screens and flow by gravity into a supply network. The technology is simple and can be maintained and managed by the users. The challenge is identifying suitable communities, environmental conditions and ensuring the system meets user demand sustainably. Following the First International Conference on Fog and Fog Collection (19-24 July 1998), a general project cycle for fogwater harvesting for domestic water supply is proposed and discussed. Methodologies and examples are reviewed and placed in an interdisciplinary project framework.

Acknowledgements

- Tammy and my parents
- Dr. Bob Schemenauer, Environment Canada
- Vilho ‘Snake’ Mtuleni, Desert Research Foundation of Namibia
- Tildenet Ltd. for their financial support

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List of Symbols and Abbreviations

d	day
FCU	Fog Collector Unit
O&M	Operation and Maintenance
p	person
PME	Participatory Monitoring and Evaluation
PRA	Participatory Rural Appraisal
PVC	Poly Vinyl Chloride
SFC	Standard Fog Collector

1. Introduction

1.1 Overview

Fogwater Harvesting is the collection of fog and cloud to augment water supplies for rural communities. Though an old idea[1], its successful implementation has only come about in the past ten years[2]. The environmental limitations mean that it does not have the widespread profile, understanding and credibility of other solutions. Nevertheless, in particular circumstances it is a viable, low-cost technology.

This paper proposes a scheme for assessing and planning the use of fogwater collection for community water supply. The opportunities and constraints of the technology are highlighted, then explored. Through the project process, each stage is examined and the practical implications discussed.

The emphasis throughout is on sustainability and its four main aspects: social/cultural/political, environmental, technical and economic. Only those factors directly relevant to fog collection are discussed. This introduces a bias towards technical and environmental aspects that are not representative of the process as a whole; an actual project will also need to consider broader issues, especially socio-economic. The overall water supply plan would be very similar to one for a spring-fed gravity water supply system. A participatory and capacity-building approach is also assumed.

1.2 Research Methodology

The information presented in this paper is a distillation and synthesis of material gathered by an extensive search of relevant and up-to-date material published in books, journals and on the internet. This is reinforced with information gained in discussion of the subject with leading authorities and workers in the field of fogwater harvesting. This discussion was aided considerably by the author's attendance at the First International Conference on Fog and Fog Collection in Vancouver, 19-24 July 1998. This exposed him to much of the latest thinking and results on the subject.

1.3 Technology Overview

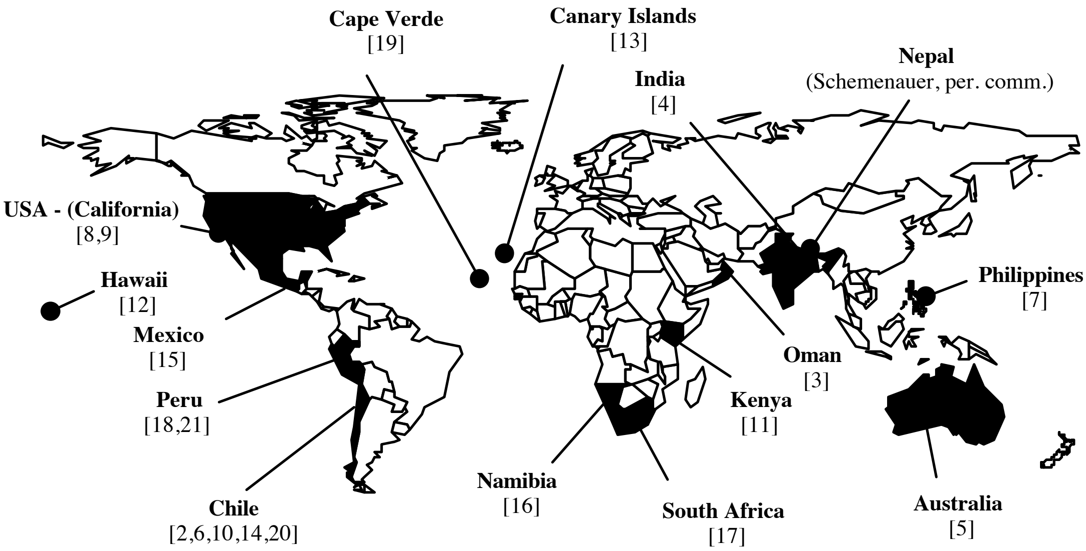
1.3.1 Basic Concepts

Collection of fog or cloud is achieved by the collision of suspended droplets on a mesh. The droplets coalesce on the mesh and run down into a collecting drain and then into a tank or distribution system. Fog collection can be thought of as an aerial spring; the piping and delivery system is no different from a standard spring-fed gravity water supply as outlined in standard texts[3].

The mesh is typically suspended 1.5m above the ground between two vertical posts. The size of the collector depends on topography and the intended use of the water. Details of collector design are covered in Section 4 and Appendix 10.4.

Figure 1-1 shows where recent and current fogwater harvesting studies have been conducted. The most extensive and long-term research has been conducted in Chile[1].

Figure 1-1 Recent Fog Collection Studies



In El-Tofo-Chungungo (Chile), 3,528 m^2 of collectors yield an average 10,580 ld^{-1}, providing the population of 350 with 30 $lp^{-1}d^{-1}$. Previously the village was supplied 14 $lp^{-1}d^{-1}$ by tanker[17].

1.3.2 Advantages

- Quick and simple design and construction. Installation requires little time or skill[22,23].
- Unpatentable technology[23] (except some mesh designs).
- Modular system that can grow in line with demand or available funds.
- Passive collection system requiring no energy input to operate[22].
- Cheap and easy to maintain and repair[22, 23]
- Low capital investment and other costs compared to conventional sources of potable water in mountainous and arid areas[22].
- Multiple uses of water for domestic, irrigation, livestock, reforestation[23].
- Potential to improve the quality of life for rural communities in remote desert and mountainous areas[15,22].
- Water quality is generally good[22] in non-industrial areas, though pH can often be low (Appendix 1).
- Renewable water source direct environmental impact likely to be beneficial[15,24]

1.3.3 Disadvantages

- Technology requires very specific climatological and topographic conditions. Yield is difficult to predict so a thorough pilot project is required in every case[22].
- Yield is very sensitive to changes in climate conditions (e.g. El Niño/La Niña) and so a back-up supply is required (such as improving the traditional source) [22, 23].
- Fog collection is unlikely to be of regional or national importance as a water supply. Emphasis is on the local level which requires full community participation[22].
- If the collectors are not close to the point of use then the cost of the pipeline can make the system uneconomic[22] and hydraulically difficult.

- Good access to the site is required for installation, maintenance and monitoring[23].
- Security of land tenure can cause problems where legal ownership is in dispute, highly fragmented or owned by an absentee landlord[23].
- In some regions water quality standards have not been met for chlorine, nitrate and some minerals[22].
- Vulnerability to vandalism[19].
- Possible secondary environmental degradation through increased human and livestock populations in fragile ecosystems[15,22].

1.3.4 Future Development Requirement

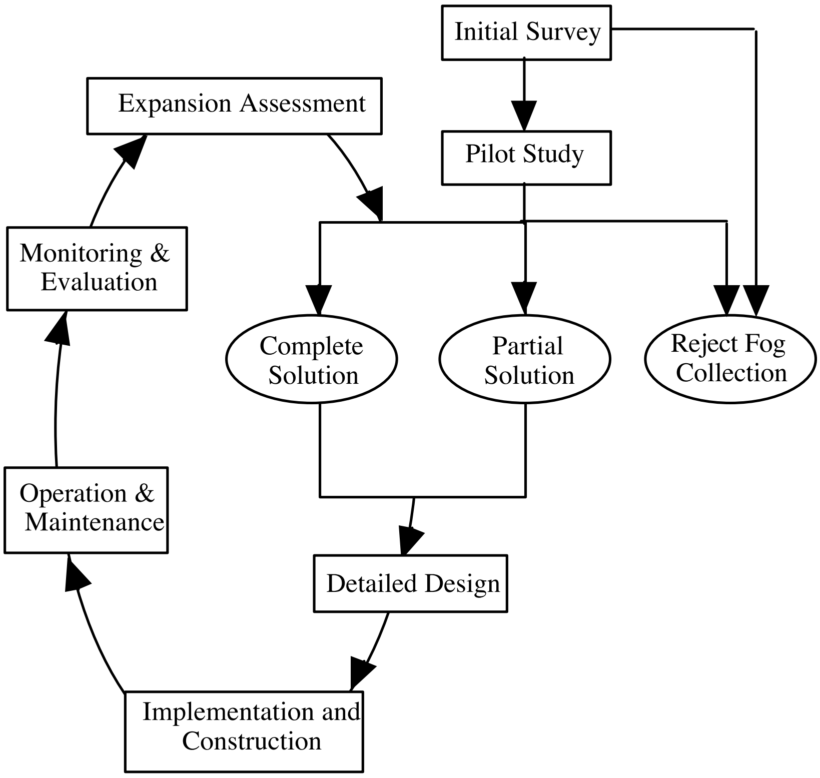
- More efficient meshes are needed to increase the l/m^2 yield to keep costs and space requirements down.
- Greater awareness of fog-harvesting technology is needed in the rural water supply sector and good understanding of its opportunities and constraints.
- Development of an easily accessible resource (journal, book or website) is needed on fogwater harvesting research and world-wide fog climatologies.
- More research is needed on the dynamics and chemistry of fog in order to optimise quality and yield.
- The key water quality parameters need to be identified.
- Expansion Assessment needs further investigation.

1.4 Proposed Project Structure

Figure 1-2 below outlines a proposed project process to aid those considering, planning or implementing fog collection for community water supply. It allows linkages between the different components to be seen and considered. Because there is a danger of this approach becoming too mechanistic, it should be flexible to requirements of the stakeholders[25].

These guidelines are aimed at water engineers familiar with designing and implementing small rural water supplies. A basic knowledge of sub-tropical meteorology is assumed: in particular, an understanding of general circulation and cloud and fog formation.

Figure 1-2 Fog Project Structure



2. Initial Survey

For fog-water harvesting to be successful, very special environmental and socio-economic conditions must exist. Because of the complexity of human-climate-topography interaction it is necessary to use the concept of Optimal Ignorance that forces us to ask:

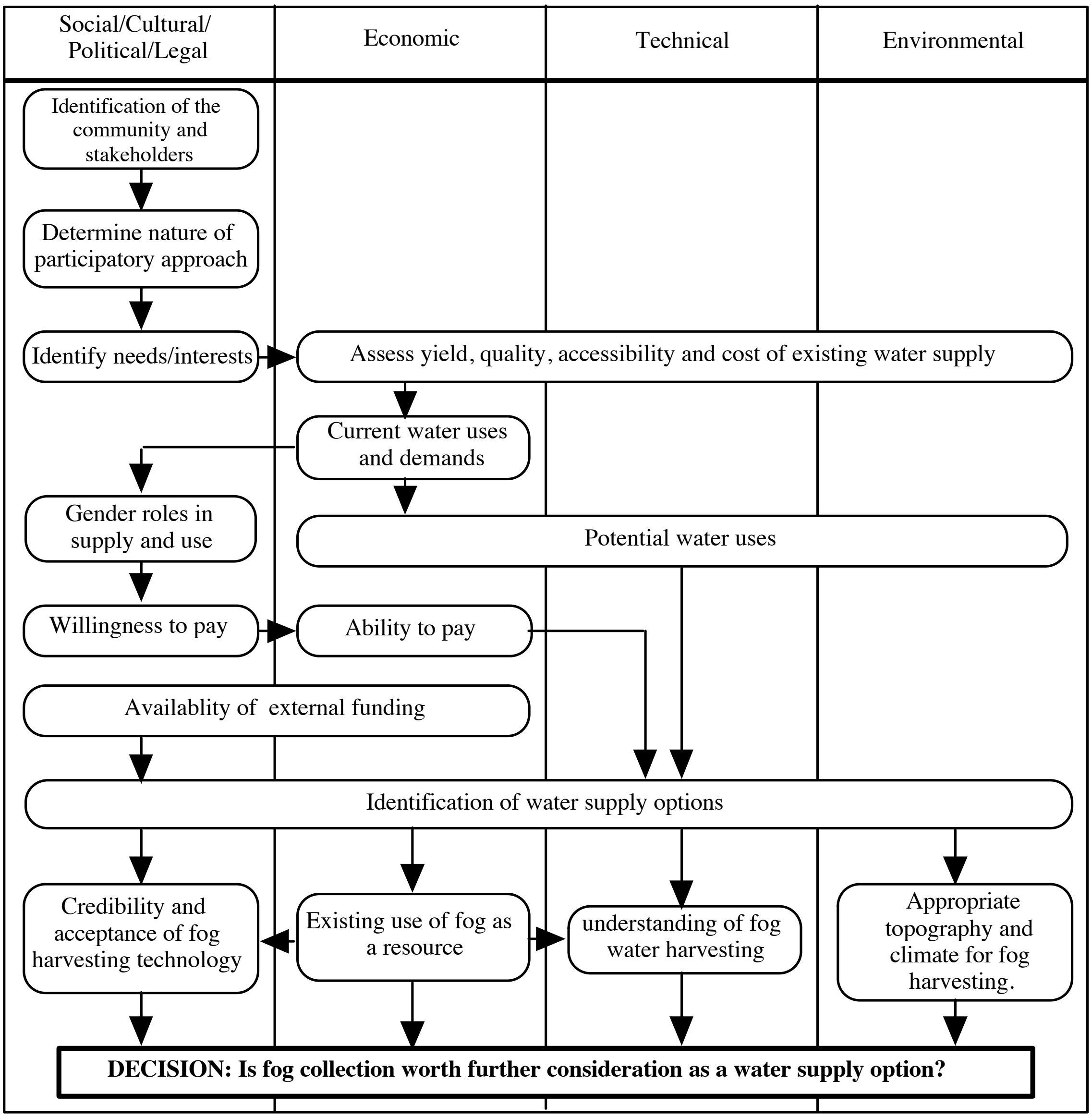
How much does the information cost? Who is going to process and use it? What benefits will accrue? Will the results be available in time? What can be left out? What simplifications can be introduced? What do we not need to know?[26]

Judging the information requirement and cost is important and difficult as climate is a highly variable phenomenon that is straightforward to measure but less easy to analyse meaningfully.

Fogwater harvesting should not be considered in isolation but as part of a suite of options to improve quality, quantity and security of water supplies for rural communities. Figure 2-1 is a proposed scheme of activities to be undertaken during the initial survey. Until the stage of 'Identification of water supply options', Figure 2-1 could refer to any small scale community water supply project.

The broad objectives are to assess need and demand, identify the resource available and options for development[27], including fogwater harvesting. These early stages are vital to the success of the project as a whole. Not only is information needed but also the build-up of trust and communication between the community, the project team and the other stakeholders[25].

Figure 2-1 Suggested Scheme of an Initial Survey



2.1 Credibility and acceptance of fogwater harvesting technology

It is likely that communities and government officials will be initially sceptical of fogwater harvesting as a viable water source[30]. This may be due to a number of inter-related reasons that need to be addressed and which all revolve around trust between the community, the government and the implementing agency.

2.2 Existing use of fog as resource

It is worth investigating whether rain, fog or dew collection technology has ever been used by the community or in the region. This will ease understanding, acceptance and the exploration for suitable sites. It may also help further the management and development of fogwater harvesting technology.

Successful examples include reforestation programmes in the Canary Islands based around using fogwater[1] and in the Cape Verde Islands where plastic sheeting channels fog-drip from trees into collectors[1,18]

2.3 Understanding fogwater harvesting technology

An advantage of fogwater harvesting is that it is reasonably straightforward to explain and demonstrate the technology. The system can allow local experimentation and development that should be encouraged with external technical and financial support, as recommended by the Farmer First philosophy[26]. Such joint research and development will lead to more whole-hearted acceptance of the technology.

2.4 Assessment of appropriate topography and climate

The principal areas of interest are typically in desert areas that receive fog, since they often lack conventional water sources. Islands and highland areas are also of interest as they often have limited groundwater potential but cloud and fog interception is common. Care must be taken because of the different types of fog [1] and its tendency to be highly variable both spatially and temporally[28,29].

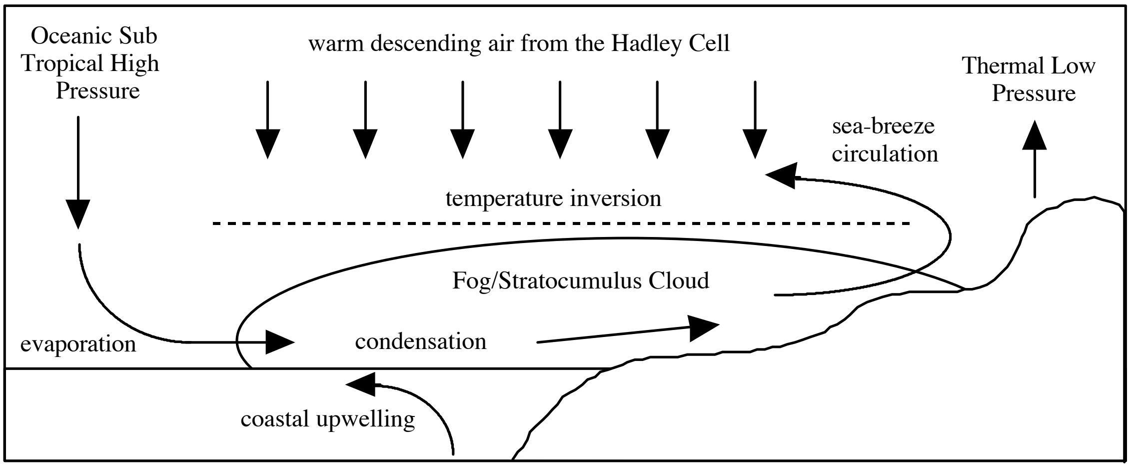
2.4.1 Indicators

2.4.1.1 Global wind patterns

Conditions for fogwater harvesting are best where there are persistent winds from one direction to transport low-level cloud and advective fog[22,30]. Figure 2-2 shows the east-west cross section of an idealised case for a west coast, such as Chile-Peru[31,32], California[9] or Namibia[33,]. This is a very simplistic explanation; fog in these desert areas can be caused by much more complex atmospheric and oceanic interactions that are not properly understood[33,34]. In the Namib, this coastal fog gives only moderate yield and has lower wind speeds than the so-called 'high fog' which is in fact cloud intercepted further inland[33].

The key factor is the temperature inversion caused by the subsiding subtropical air that prevents vertical development of the cloud that would produce rain[35]. Instead the cloud and fog moves inland until ground heating causes the moisture to evaporate.

Figure 2-2 West Coast Advection Fog



2.4.1.2 Mountain Range

The topographic relief must intercept the cloud. With low-level coastal fog this can be isolated hills or dunes[22]. For higher cloud, larger mountains are needed, such as the Andes in Chile and Peru. In this latter case the cloud can be pre-existing or orographically induced. Orographic cloud is most clearly seen on islands, such as Hawaii[7], St. Helena[36] or Cape Verde[20].

2.4.1.3 Distance to the coastline

Marine cloud and fog decks generally dissipate further inland due to evaporation. It is often therefore desirable to have collectors located within 5km of the coast and usually not more than 25km[30]. This distance must be balanced against topography in relation to the cloud deck. Observations and experiments are needed to determine the optimum location.

In high elevation areas where cloud is intercepted or induced by the topography, the distance to the coast is irrelevant[22].

2.4.1.4 Rainfall Seasonality

Fogwater harvesting is not restricted to hyper-arid areas. There is potential application in highland tropical areas, such the Chiapas of Mexico[15] or the Philippines[8]. The rainfall in these areas, though generally very high, is often very seasonal and there may be application for fog collection as a dry-season water supply. In the Cape Verde Islands, the dominant Trade Winds bring moist air that produces no rain, but the short monsoon season brings 600-1000mm at high elevations[20].

2.4.2 Information Sources

2.4.2.1 National or regional weather bureaus and airports

Weather bureaus are likely to be the best source of information and experience on general fog occurrence and behaviour[22], though are not good for identifying specific sites[32]. Many take an interest in fog as a hazard and a pollutant transport vector, but some have active research on its use as a resource[18]. Airports may be a good source because of their measurements and interest in fog as a navigation hazard.

2.4.2.2 Secondary sources (journals, maps, remote sensing, internet, etc.)

Before going on-site it is worthwhile investigating whether any other fog collection studies or projects have been conducted in the area. Important information and professional contacts can be gained in this manner and will save much time and resources.

Large fog banks can be seen on satellite imagery. However, on grey-scale Meteosat images (visible and infra-red) of Namibia it has been found to be very difficult to differentiate fog from stratocumulus cloud. It has also been difficult to locate ground stations and there is a poor match between satellite and ground temperatures[37]. However, technology and understanding are improving and the more sophisticated NOAA - AVHRR satellite instrumentation has been used successfully for spatial analysis of fog in Europe[38].

Secondary information and topographic maps can often give important clues. For example, the western coast of Australia, though under a sub-tropical high pressure, has no topographic features equivalent to the Andes or the Southern African Escarpment. It also lacks a strong, cold eastern boundary current. Thus we might expect poor fog potential, and measurements support this[5].

2.4.2.3 Observations and measurements by project staff

If a fog event does occur during the Initial Survey then it is an important opportunity to:

- Identify its type[1].
- Measure the wind speed and direction during the event.
- Estimate the elevation at which it occurs.
- Identify topographic features where it occurs.

Though a positive sign, such a single event should not be considered too significant but it may influence the decision to pursue a Pilot Study.

2.4.2.4 Local people

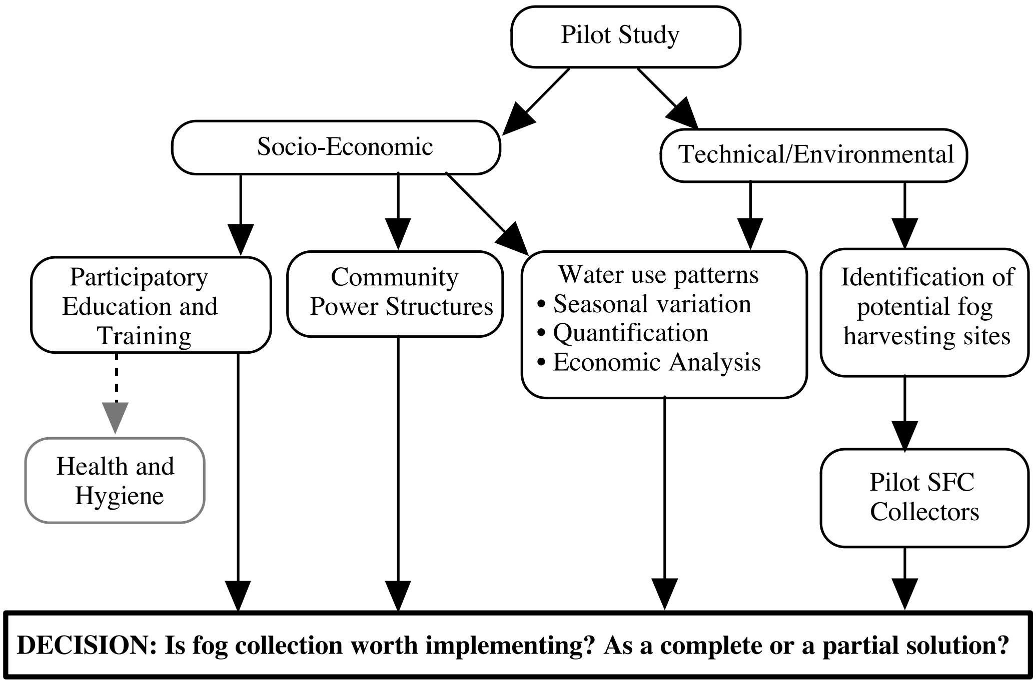
Observations by local people may be a useful source of historical, localised information. Unfortunately, this is unlikely to be accurate. There is a danger of the people wishing to please by saying ‘Yes’ to any question, so phrasing is important[39]. Locals are also unlikely to know about fog conditions during the night[30].

Paid local observers were used as a low-cost option in a remote coastal area in Chile. However, interpretation was limited by short and discontinuous records[32].

3. Pilot Study

The objective of the Pilot Study is to get sufficient data to make a reliable estimate of the daily yield throughout the year. It is important to deduce any seasonality and the best placement and orientation of the large collectors for greatest yield. This information is vital to design process, to ensure best performance at an affordable cost. Figure 3-1 shows the principal activities required to generate the information and capacity on which to decide whether fogwater harvesting should be implemented.

Figure 3-1 Pilot Study Scheme



3.1 Participatory Education and Training

This is two-way process with the following objectives[30]:

- Educating the community on how water supply works, its opportunities and constraints[15].
- Defining a suitable water management, maintenance and payment system.
- Identification and election of community members for a village water committee.
- Training in required skills for construction, maintenance and administration.
- Maintaining interest and motivation and creating sense of ownership of the scheme.

With the time available it would also be advisable to embark on a health and hygiene education programme as this would greatly increase the chance of improved community health over just increased water supply. If done, it should not be seen as a tagged-on extra, but an integral part the information-exchange process that occurs the whole way through the project and beyond.

3.2 Community Power Structures

Participatory Rural Appraisal (PRA) techniques[40] and stakeholder analysis should be used to determine power relationships. This will help throughout the project[15,25] and particularly when dealing with land tenure[23].

3.3 Water Use Patterns & Economic Assessment

This is really just building on the methods of the Initial Survey. The objective is to quantify seasonal changes in water supply, population and demand. In addition a detailed economic analysis should be undertaken. This information will allow designs to cope with the worst time of year, which may not have coincided with the Initial Study period [26].

3.3.1 Cost of Fogwater

Once the yield and quality have been determined, the unit cost of water produced should be calculated. A decision must be made as to what the fogwater will be used for. In Peru, three possible scenarios were identified[23].

1) Fogwater for Reforestation

Though intended more for environmental management than agroforestry, it is not clear why this is not considered part of scenario 3. This application is not covered in this paper, but is discussed elsewhere[41,42].

2) Ex Situ Water Use

Collected fogwater can be transported off-site by pipe or less conventional means. It has several uses that are not mutually exclusive:

- *Domestic Water Supply* - for scattered rural communities where the opportunity cost of water is high. Fogwater is usually of sufficient quality, but this must be checked and regularly monitored. The supply also needs to be reliable with some kind of contingency.
- *Agricultural Production* - vegetable cultivation has been done to help diversify diets[15].
- *Energy Production* - it is suggested that the water could be used to drive a small turbine[23]. It seems unlikely that there would be a sufficient supply from fog for this use.

3) In Situ Water Use

In Chile, 36% of the total system cost was the 6.2km pipeline between the collectors at El Tofo and the users at El Tofo-Chungungo[15]. In such cases it would therefore be much cheaper to use harvested fogwater in the immediate vicinity of the collectors. Possible uses include specialised agriculture and agroforestry[23], but domestic supply is less likely.

3.3.2 Comparing Fog with Alternatives

Standard cost-benefit analysis comparison of fog collection and alternatives can be used. However careful consideration of non-monetized values is required. Such values include:

- Time saving or cost to the user - can be expressed as an opportunity cost.
- Reliability of supply.
- Water quality - can be expressed as the cost to treat the water to a required standard.
- Environmental costs and benefits - an often difficult and controversial area to monetize.

Such analysis in Chile[15] and Namibia[45] found fogwater harvesting a good option.

3.4 Project Costs

Community participation will help reduce labour costs and create a deeper sense of ownership. It will also provide local people with experience that will be important for Operation and Maintenance (O&M) and any local development of the technology and expansion of the system[22].

Government and/or donor subsidy will probably be necessary in the initial stages. One possible solution is cost-sharing in which users pay for the O&M and some of the capital costs and the external funders pay for the remaining capital expenditure[22].

The modular nature of fogwater harvesting means that collectors can be installed over a period of time. This permits spreading the capital costs to make the project appear more favourable financially. However, it must be appreciated that in El Tofo-Chungungo the FCUs represented only 23% of the overall system capital costs[15].

Other capital costs are the land and supporting infrastructure (pipes, tanks, treatment, etc.). Careful consideration should go into whether this infrastructure should be designed to handle future supply or whether it would be cheaper to upgrade along with the number of FCUs.

3.5 Identification Of Potential Fog Harvesting Sites

Though the general environmental conditions are examined in the Initial Survey a more detailed investigation is needed. The first step is to identify potential sites using the following criteria[30]:

1) Crestline And Upwind Locations

The best site for collectors has been found to be flat-topped mountains and ridgelines, although they can also be used lower down on the windward side. It is important that the collectors are not in the lee of a hill or ridge as the fog descends and dissipates due to adiabatic warming.

2) Altitude

It is recommended that collectors are located at two-thirds of the cloud thickness above the base as this is the area with the highest liquid water content. In Chile, the cloud was 100-300m thick and at 500-1200m above sea level with the collectors at 780m[43]. At a new location, careful observation and a vertical profile array of SFCs may be necessary to determine the optimum altitude[19].

The top of the cloud will often be limited by the height of the temperature inversion and is likely to vary seasonally. Though the crest of a ridgeline is an optimum site, if the inversion regularly drops below it, the fog will flow around the ridge and not over it.

3) Collector Space And Arrangement

The amount of space available dictates the potential yield[15]. 12m long collectors should be arranged in a row and separated by gaps of at least 4m to allow wind to blow around them[30]. An array of 50 $48m^2$ (12m x 4m) collectors with 4m spacing would require approximately 800m. It is possible to use parallel rows at slightly lower elevations.

4) Relief In The Surrounding Area

If a low inversion occurs then the fog may travel horizontally until it reaches a pass, which is probably a good location for harvesting. However, in complex terrain, choosing a suitable site is difficult as wind speeds and directions can be unpredictable.

Depressions or basins inland of the collection site may, in arid areas, lead to greater surface heating. The resulting vertical transport and low pressure will locally enhance the sea-breeze circulation, increasing wind speed (Figure 2-2) and thus yield[30].

5) Orientation

It is important that the longitudinal axis of the range of hills or mountains is roughly at right angles to the wind supplying the fog. In this way the cloud will pass over ridges or through passes with reasonable regularity and predictability[31]. Clues from plant distribution (phytogeographical analysis) can also help[31].

If the orientation of the SFCs is not directly into the fog then the yield is likely to be underestimated[44,]. In Namibia, the use of a bi-directional fog collector was suggested to provide more accurate information for choosing the best orientation for the large collectors[45].

6) Slope And Microtopography

Gently rising slopes are ideal. Cliffs or steep areas produce a strong vertical wind component that reduces the yield. Microtopography, such as small hills, large boulders, vegetation, buildings and converging valleys can produce complex air flow and turbulence that are likely to reduce collection efficiency.

7) Distance To User

As already noted, pipe costs from collectors to the point of use are one of the major infrastructure costs. Thus, it is important to minimise pipe length. Not only is cost an issue, but also hydraulics must work. Thus the collectors must be high enough above the users for sufficient pressure for water delivery. Such problems are common to spring-fed gravity water supplies[3].

8) Access

If the collectors are to be maintained and monitored by the user community then they need good access. Consideration must be given to who goes to the collection site and the available transport. The less accessible collectors are, the more likely it is that they will not be maintained properly.

9) Land Tenure

It is a key task to ensure that land required can be secured. The best is government-owned or unclaimed land. Difficulties arise where land tenure is very fragmented, or insecure where an absentee landlord cannot be contacted. Securing land use rights is likely to be a lengthy, costly and highly political process that must be handled by experienced negotiators who are familiar with local power structures and protocols.

3.6 Climate Study

The aim of the climate study is to find the best site and orientation and determine the yield per m^2 that can be expected during the year.

3.6.1 Methodology

It is recommended[46] that the study site has several sub-sites nearby. Each site has Standard Fog Collectors (SFCs) in order to examine the relationship between fog yield and the parameters in Section 3.3.1 that vary locally, such as altitude, orientation etc. The number of sub-sites used has typically been 5-6.

The variables listed below are required to quantify the magnitude and reliability of supply and the orientation[54] and sturdiness[45] required by Fog Collection Units (FCU):

- Fog-water yield (m^3 m^{-2} day^{-1})
- Annual variation and seasonality of yield
- Rainfall (mm day^{-1})
- Wind speed (m s^{-1})
- Wind direction during fog events
- Water quality - see Section 4.1

In order to get a representative assessment of fog harvesting potential it may be necessary for daily measurements to be taken for a whole year. If the location has a known fog season, such as the monsoonal fog of Oman[4], then study can be shortened.

Fog collectors will harvest not only fog but also rain and drizzle. It is important to determine the relative importance of rainfall to fog[54]. If the majority of the collected water is from rain then implementing rainwater harvesting, with the possible addition of rooftop mesh panels[54], is likely to be more cost effective than large scale fogwater harvesting.

3.6.2 Instrumentation

The following equipment is required:

- Standard Fog Collector
- Tipping bucket gauge
- Anemometer with data logger
- Automated wind vane with data logger

SFCs are $1m^2$ panels of mesh held 2m above the ground by a supporting structure[47]. Appendix 1.1 shows a kit design based on one used by the author in Namibia[58].

One can have a wider range of instruments but the cost and risk of damage to the necessary equipment must be justified by the usefulness of the information gathered. Instruments can be attached to the SFC but care must be taken to ensure that the structure does not affect the readings[47]. The limitations of the equipment must also be known. Wind vanes are unlikely to turn in low windspeeds (below 1.5m/s)[48]. This should not be a problem as little fog collection occurs at low wind speeds.

The purpose of the tipping bucket rain gauge is so that times of fog occurrence can be matched with the wind data. A less sophisticated approach would be to have several SFCs at the sub-site with different orientations and rely on manual measurements and observations.

3.7 Site Survey

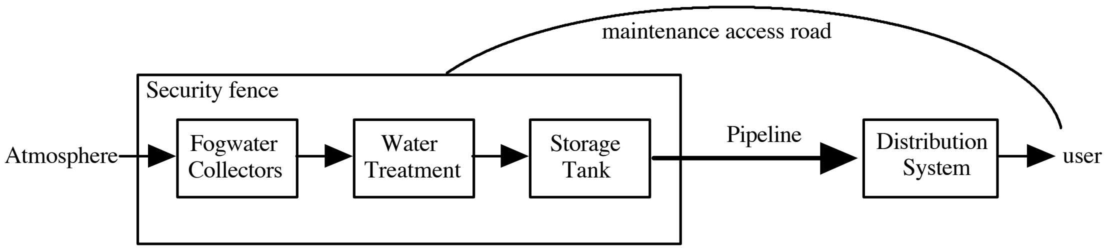
After the pilot study has found the area with the best conditions, the location must be thoroughly surveyed to determine:

- Slope
- Micro-topography
- Vegetation and other obstacles
- Below ground conditions

4. Detailed Design

Using the information gathered during the preceding two phases the detailed designs can be created. Figure 4-1 shows the main components of the water supply system and the flow of water. This section examines the aspects influenced by the nature of fogwater harvesting.

Figure 4-1 Fogwater Harvesting Physical Infrastructure



4.1 Infrastructure Components

4.1.1 Fog Collector Units (FCUs)

The design for a basic a 48m^2 FCU is presented in Appendix 1.4. This is the basic collector design used at El Tofo and other projects. Double or triple length collectors can be used to lower unit costs[15].

4.1.2 The Mesh

Extensive research with various meshes has found that the best is double-layered 35% polypropylene[15]. The fibres are 0.5-1.5mm in width and typically 1mm wide and woven into a triangular pattern with a spacing between horizontal lines of 13mm. Local meshes are preferable, but should be compared against a standard (e.g. the Chilean Raschell mesh) [30]. The key characteristics are:

- Collection efficiency.
- Fast drainage of collected water.
- Resistance to solar UV.
- Resistance to extreme strong winds, rain and sun.
- Local manufacture for low cost and easy replacement.

4.1.3 Pipeline, Storage Tanks and Distribution System

These aspects are well covered in other texts[3,49].

4.1.4 Access Road

This should provide access to a main road to allow materials and labour to be brought in by vehicle during the construction phase. There also needs to be good access to the user village for those involved in maintenance and monitoring. How easy this is depends very much on the terrain, the vegetation and land rights.

4.1.5 Site Fence

Fog collectors can be easily vandalised and materials sold off. Livestock and wild animals can also damage the collectors and any vegetation being irrigated by fog water[19]. It may therefore be necessary to fence the site to prevent access by curious people and animals. If future expansion of the system is planned, then a decision needs to be made whether to fence off the whole area at the start, or whether expanding the fencing at the same time as the collectors would be cheaper.

4.2 Water Quality

Where fogwater harvesting has most potential, water quality can be expected to be good. At El Tofo, Chilean and WHO standards were met[30]. However, samples should be tested using methods such as those described by Bartram and Ballance[50].

4.2.1 Chemical Characteristics

Chemical water quality of collected fog depends on:

- The materials used for fog harvesting.
- Dissolved ions from the moisture source (usually marine salts[30])
- Composition of condensation nuclei (natural dust or anthropogenic emissions)
- Fog droplet sizes

- Solids deposited in between fog events.

The chemical characteristics of fogwater are discussed in more detail in Appendix 1.3 and by Schemenauer and Cereceda[51] . There are some practical implications:

- Using polypropylene mesh does not significantly affect water quality[51].
- The first flush after non-foggy period can be brackish and turbid due to algal and solids accumulation on the collectors. Dust can cause low pH and poor clarity and high levels of Pb, Cn, Cr, Cu, As, Fe and Mn[52]. This water should either be treated or used for non-domestic purposes.
- The generally low pH may cause corrosion problems. The use of PVC, rather than metal, for pipes and fittings is advisable as it is less corrodable[51].

4.2.2 Biological Characteristics

In El Tofo-Chungungo it was assumed that faecal coliform concentrations were negligible[51], which another study confirmed[43]. However, the high humidity of operating conditions promotes growth of algae, lichen and other microflora on the mesh and in the pipes and tanks. Other sources of contamination are insects, decomposing plants and faeces of birds and small reptiles[52]. Thus a potential health risk is present that should be addressed in the planning stage.

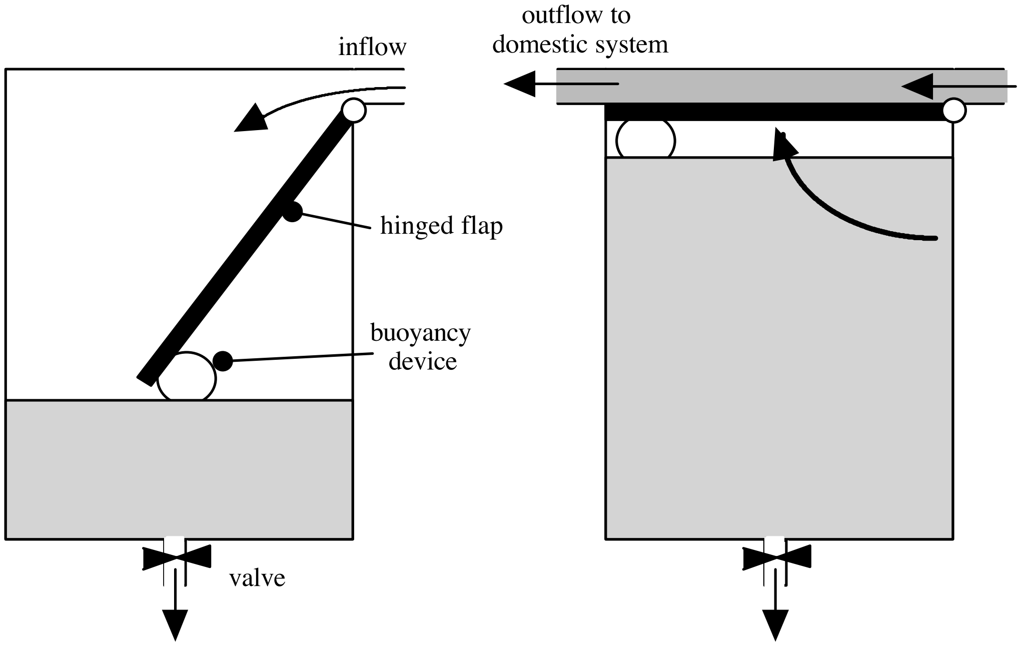
4.2.3 Water Treatment

The issues and technical details will not be discussed here as they are well covered in texts[53]. However, the processes used and suggested include chlorination[15,30], sedimentation[30,45] and pH adjustment[51].

4.2.4 First Flush water removal

Because of poor quality it is important not to allow the first water after a non-foggy period to reach the consumer. A rinsewater tank has therefore been proposed[45]. The first water fills a 120 l tank and a buoyant flap seals the top of the tank automatically. Water thereafter flows over the top (Figure 4-2).

Figure 4-2 Rinsewater Tank Design



Source[45]

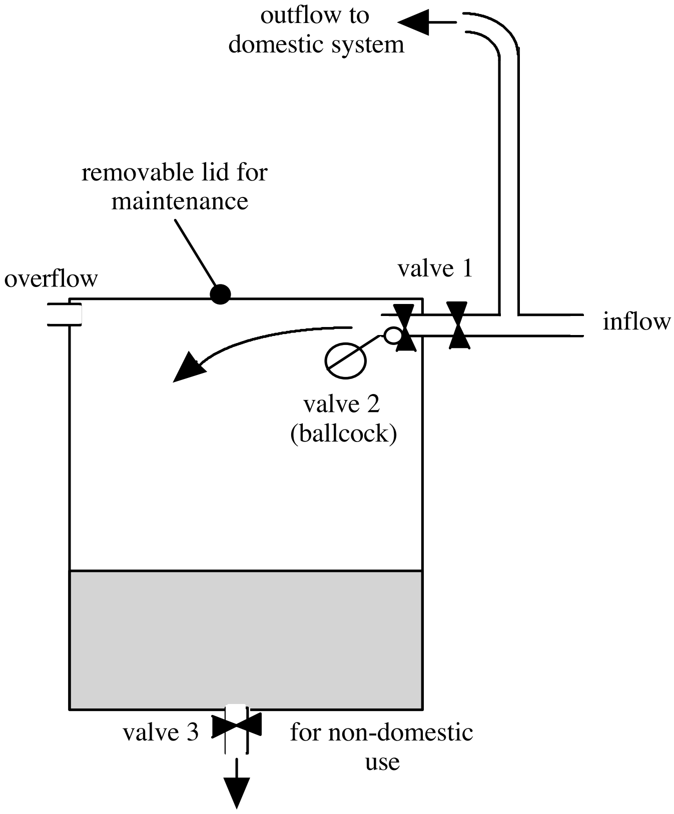
Such a design is likely to jam and not provide an effective seal. There also needs to be a way of securing the flap so that the first flush water can be drained and used for non-domestic purposes. However, leaks are still likely to occur.

Figure 4-3 shows an alternative design using standard plumbing components. During a dry period, valve 1 is closed and 2 and 3 are open. When the first water arrives it flows into the tank until the ballcock automatically closes valve 2. Further water will then flow up into the domestic system, as long as there is sufficient head.

Should valve 2 fail, then excess water will come out of the overflow, indicating to the caretaker that there is a problem. Valve 1 can be closed to prevent valve 2 leaking and also allow the rinsewater tank to be drained, inspected, cleaned and any problems repaired without interrupting the water supply.

The dimensions and pipe specifications depend of the volume and pressure of the flow. The value of 120 l appears to be empirically derived, probably based on typical volume of unacceptable water plus a safety factor.

Figure 4-3 Alternative Rinsewater Tank



4.3 Estimating Net Area

The Pilot Study should produce a figure for the required water demand for the community. Along with other information this needs to be turned into an estimate of mesh required to meet this demand. This can be done using the equations presented in Appendix 10.3. Though used in El Tofo-Chungungo[54,52], their validity in any new project should be checked through monitoring and evaluation.

5. Implementation and Construction

Once plans have been drawn and agreed then implementation can proceed. The pilot study should be continued to identify any modifications that may be required and to maintain involvement of the community in the project process.

5.1 Activity Organisation

Figure 5-1, based on that by Cruzat[52], shows the procession of activities for building and installing large fog collectors. The changes are the removal of planning activities from this phase and making purchasing materials and building components a parallel activity with site preparation and excavation as they are not mutually dependent.

Figure 5-1 Gantt Chart of Fog Collector Construction

Principal Activity							
Purchase Materials	■						
Build components (posts, drain, cables etc.)		■					
Site Preparation	■						
Excavate Foundations for posts, cables and pipes		■					
Raise Posts			■				
Install Mesh				■			
Install collection drain					■		
Tension mesh						■	
Install and connect pipe network to collectors							■
Time→							

The main addition is site preparation which includes:

- Building site access
- Clearing obstructing vegetation
- Setting out where collectors, pipe and tanks will be located.
- Securing building materials from being stolen.

5.2 Training

FCUs and supporting infrastructure do not require specialised skills. However, basic masonry, carpentry and hydraulics training should be given, as required, to those involved. This is important not only for construction, but also for maintenance. Such training should be given to women as well as men for they should be equally committed to the success of the project.

6. Operation & Maintenance

6.1 Decision-making and financial management

The project stakeholders need to work out a workable and financially self-sufficient way of ensuring that O&M costs are paid for. In El Tofo-Chungungo, metered taps and differential tariffs were used to discourage over-consumption. Different rates were applied based on consumption levels, and also took into account seasonal variations in supply[15,30]. However, any scheme must be transparent and open to scrutiny by both users and local government to prevent misuse of the system.

6.2 Maintenance Organisation

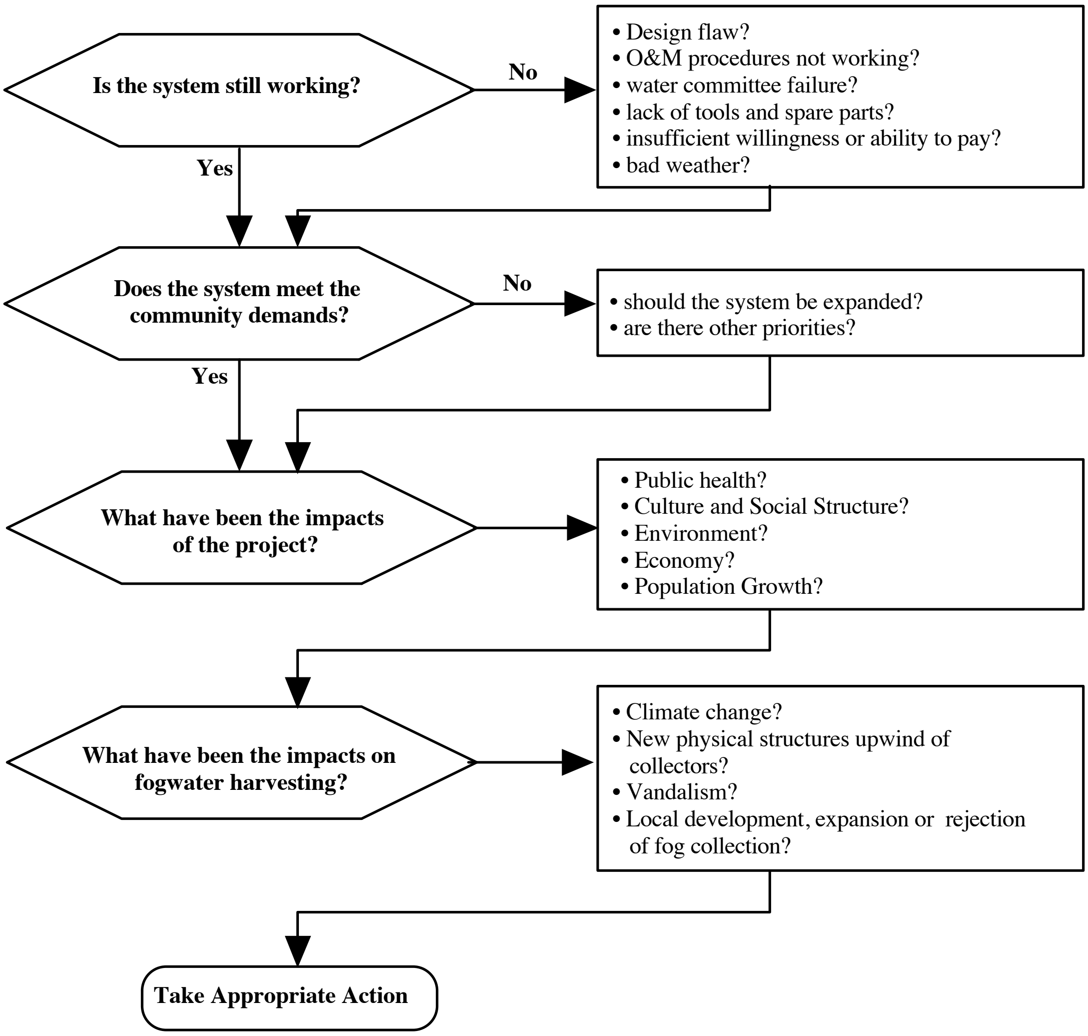
Fog collectors are a low maintenance technology, mainly due to the design being both simple and passive. The most common problem encountered has been the mesh coming loose in high winds that can lead to loss of efficiency and increased risk of damage[55].

The community, through the water committee needs to determine the best method of ensuring that the system is kept maintained and working at optimum capacity[15]. This may mean charging for the water to pay a caretaker. An alternative is having children from the village take responsibility[39]. This can work because no specialist technical knowledge or skill is needed. Caretakers also need to alert users when water levels are low[30].

7. Monitoring & Evaluation

Monitoring should be undertaken by the community by means such as Participatory Monitoring and Evaluation (PME)[56]. However, occasional external, impartial monitoring and evaluation are required to assess needs and solve any problems that arise, either within the community or to enlist help from the relevant ministry or agency. Figure 7-1 is a suggested scheme for information requirements. The information can be used to take remedial action to tackle problems or to justify why no action is necessary.

Figure 7-1 Monitoring and Evaluation Scheme



8. Expansion Assessment

The modular nature of fog-water harvesters means that, with care, a system can grow organically to meet demand and the resources available to the community. To allow such a gradual expansion to be successful and work to the optimum, careful planning is important. This stage has not been considered in detail in any of the literature reviewed and is an area of further work.

8.1 Predicting Future Demand

A key issue with increasing water supply is that instead of increasing provision for existing users it may lead to in-migration, or reduced out-migration. This will lead to increased stress on the supply system. Fog collection may not be able to maintain an adequate supply so other sources should be considered.

8.2 Location Planning

Building on what has already been discussed on location planning: when locating the first collectors, take into account the physical space required at each site for further collectors. However any design for future development needs to be accounted for in the pipeline network.

When designing the collector layout and the pipe system, do so for the greatest yield at each site. The whole system does not have to be built at once but can be constructed as demand and funding allow.

An alternative is to leave sufficient space for future growth but leave the final design to those implementing at the time because they will understand the prevailing conditions better. Collector design may also have changed with other factors that are unforeseeable to the initial designers.

9. Conclusion

Fogwater harvesting is an appropriate technology solution that can be built, managed and maintained by rural communities. However, they are likely to require external resources and skills to identify suitable harvesting sites[15].

Because fogwater harvesting has a low yield per area it is most suited to areas of low population density. For urban areas in arid environments, groundwater and desalination are likely to remain more cost-effective.

This paper has proposed practical guidelines for fieldworkers investigating the use of fog and cloudwater for domestic water supply. It fits the technology into a project process emphasising its sustainability and value to the community. The next step is the use of these guidelines in the field in order to verify what has been proposed and to build on them.

10. Appendices

10.1 Standard Fog Collector (SFC) for High Elevations

The SFC is defined by Schemenauer & Cereceda[43] and further discussed[44,57]. Figure 10-1 and Figure 10-2 show a design used by author in Namibia[58]. However the cheap materials corroded easily, contaminating the collected water samples, so it is essential to use non-corrodable materials or coatings.

Figure 10-1 Example SFC design

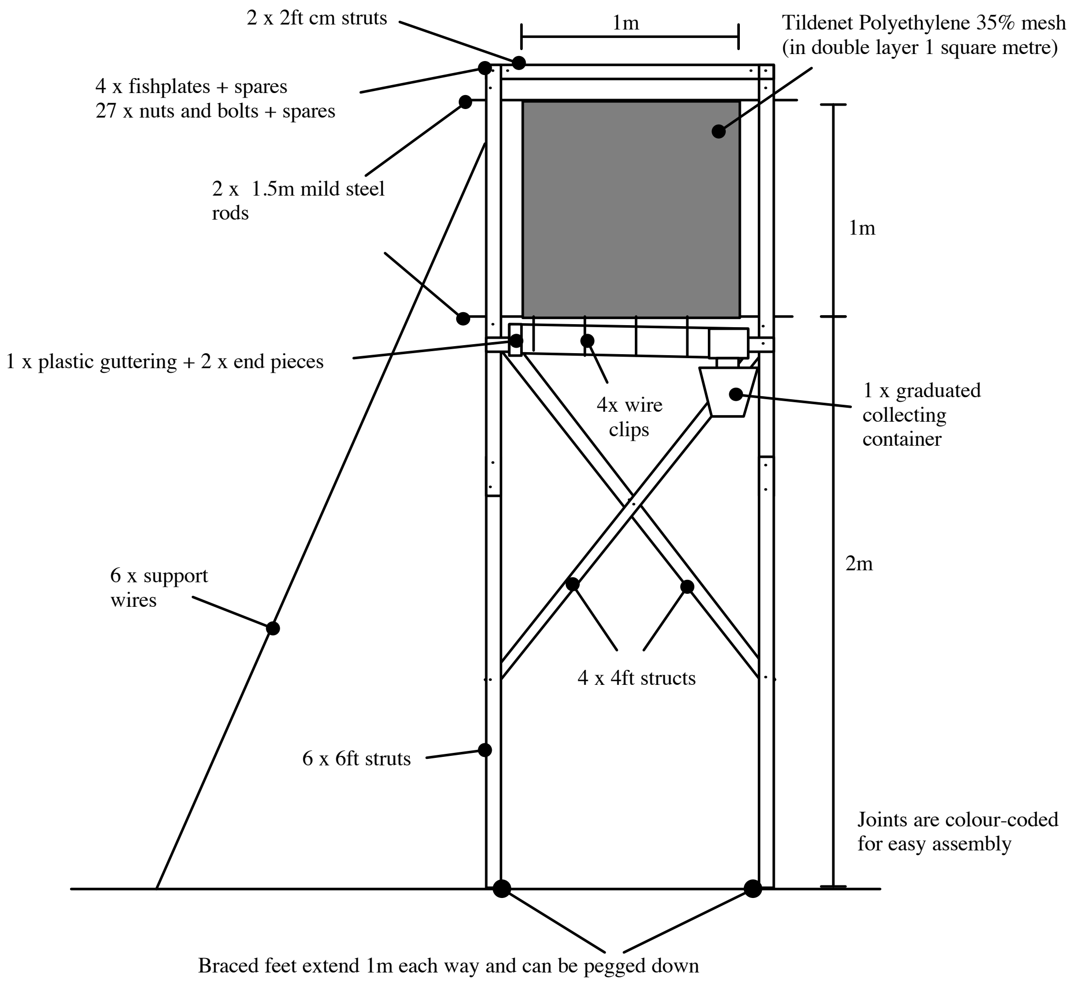
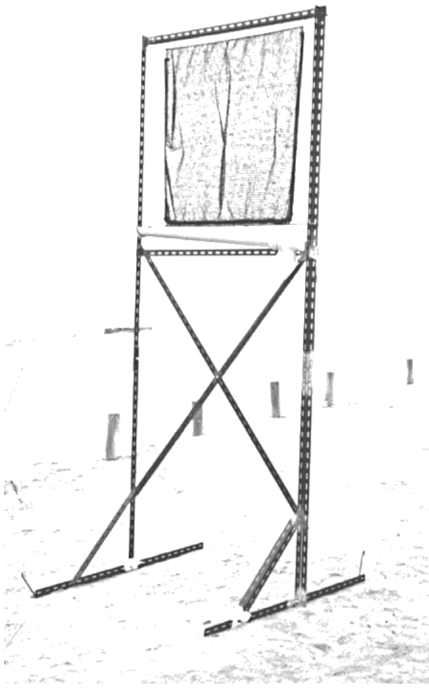


Figure 10-2 SFC at Mile 72 (Namibia)

Source:[58]



10.2 Chemical Characteristics of Fogwater

Table 10-1 Examples of Fogwater Analysis

Chemical Parameters (mg/l)	WHO[59]	Chile[51,60]	Oman[60,61]	Namibia[60]	India[*,62]	Taiwan[*,63]	France[*,64]
pH	6 - 8.5	**4.7**	7.4	6.2	**4.0**-6.5	**4.08**	**3.94**
Fe	0.3	<0.05-0.21	<0.06	-	0.29-**0.96**	**-**	**0.67**
Mn	0.3	0.002-0.283	0.014	-	0.05-**0.96**	-	0.27
NO_3	45	1.6	4.7	3.4	16.1-31.9	5.4	**123.0**
SO_4	400	12.3	3.4	3.2	21.1-110.5	17.0	<0.05
F^-	1.5	-	0.02	-	0.5-**2.4**	-	-
Cl^-	250	8.7	44.1	4.8	12.2-35.4	28.2	49.4
As	0.05	0.012-**0.073**	<0.001	-	-	-	-
Cd	0.005	<0.5-0.006	<0.0005	-	-	**-**	**0.006**
Cr	0.05	<0.001-0.003	<0.005	-	-	-	<0.02
Cu	1.0	0.003-0.218	<0.005	-	0.10-**3.90**	-	0.21
Pb	0.05	0.001-**0.181**	<0.0005	-	**0.09-0.10**	**-**	**0.142**
Hg	0.001	-	-	-	**0.019-0.125**	-	-
Se	0.01	<0.005-**0.016**	<0.005-0.008	-	-	-	-
Ca	200[2]	1.0	15.1	1.2	12.2-35.4	1.9	1.4-65.4
Mg	125[2]	0.7	2.9	0.4	1.6-6.2	1.5	

Table 10-1 above shows the results from various fog chemistry studies around the world. Values in bold are those exceeding WHO guidelines. The high levels of As, Pb and Se in Chile are associated with first flush and the preceding quality is closer to the lower values presented[61]. The high levels of heavy metals in India is attributed to the heavy industries such as iron smelting, aluminium production and burning pyrite-rich coal[62].

Concentrations of dissolved ions are greatly influenced by droplet size. Comparison of different droplet fractions has shown higher concentrations in smaller fog droplets[64]. It is not practical in the water supply situation to study fog-droplet sizes since specialised equipment and skills are required and the information gained is unlikely to have much influence on the remedial measures taken.

[*] non metals converted from $\mu eq.l^{-1}$

In Paposo (Chile) fogwater did not meet WHO standards for chlorine and nitrate[22]. Though no explanation or figures are given these ions probably have a marine origin. However, as the table above shows, other studies have found chlorine and nitrate levels to be well within WHO limits, except in rural France which is probably due to high levels of nitrate use in agriculture.

Another impact of agriculture was shown testing fogwater samples from France for 13 different pesticides[65]. The highest concentrations were those used locally; however, long-range transport is likely to be responsible for the presence of DDT and banned organochlorine pesticides. It may be worthwhile testing samples for pesticides if intensive agriculture is practised upwind of a fog harvesting site. However, the cost involved may make this impractical.

One of the most notable characteristics of fogwater is the low pH. The majority of fogwater chemistry studies presented at the 1998 Vancouver conference reported typical values of between 3-5. The main exceptions were in Namibia: 6.2 and Oman: 7.4[60].

10.3 Mesh Area Determination

Source:[52]

Equation 10-1

$$S = \frac{S_t}{DF \times E}$$

Equation 10-2

$$S_t = \frac{N \times C_p}{V_c}$$

Equation 10-3

$$DF = \frac{1 - C_m}{C_t} \times 100$$

Equation 10-4

$$E = \frac{1 - \sigma}{V_c} \times 100$$

Symbol	Description	Units
σ	Standard deviation of the variation of volume collected (V_c) from the median.	$l\ m^{-2}\ d^{-1}$
C_m	Collectors in daily maintenance programme	-
C_p	Daily per capita volume demand	$l\ p^{-1}\ d^{-1}$
C_t	Total number of collector	-
DF	Percentage of collection area in active collection (Equation 10-3)	%
E	Efficiency of system (Equation 10-4)	%
N	Number of users	p
S	Actual mesh area (Source:52 Equation 10-1)	m^2
S_t	Theoretical mesh area (Equation 10-2)	m^2
V_c	Daily water volume of collected - from SFC data (FCU yield = 88% SFC yield)[66]	$l\ m^{-2}\ d^{-1}$

10.4 Specifications & Design a 48m^2 Fog Collector Unit (FCU)

Based on information from [1, 15,22,52,55]

Figure 10-3. 48m^2 FCU (Front View)

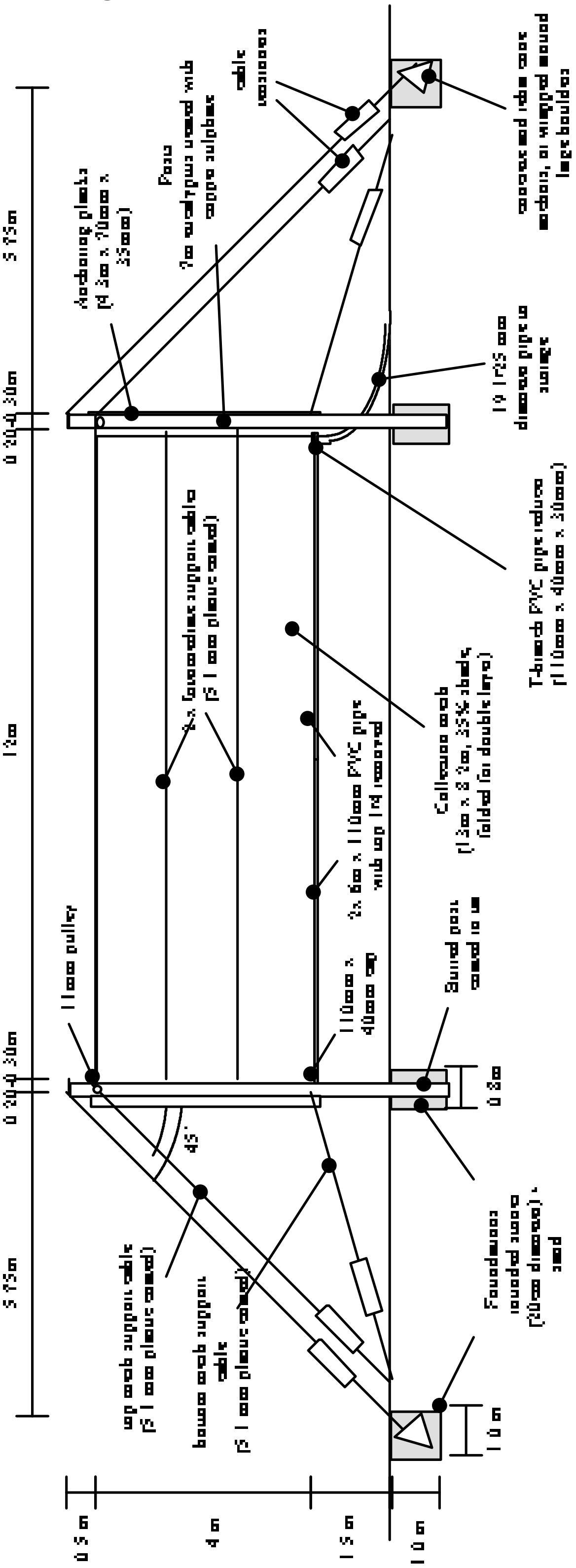
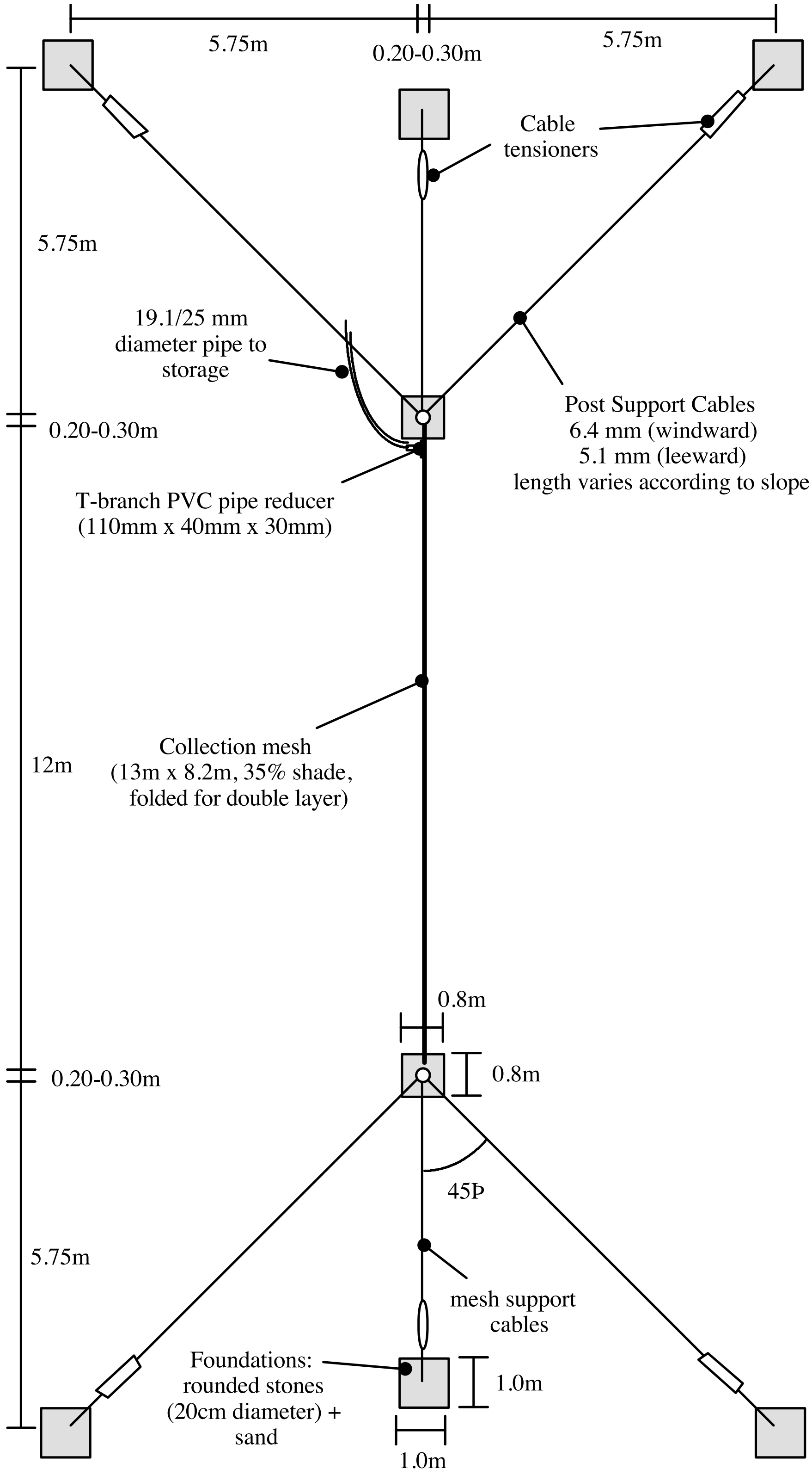


Figure 10-4 48m^2 FCU (Plan View)



10.5 Maintenance Tasks

(based on[19,22,52,55])

Table 10-2 Maintenance Tasks

Inspection of cable and horizontal mesh tension.	If not properly taut, collection efficiency is reduced and there is an increased risk of damage to the mesh panels.
Inspection of cable fasteners	Keeping the fasteners firm reduces the risk of structural failure.
Maintenance of mesh nets.	Any tears should be repaired to avoid replacing the whole panel.
Cleaning mesh nets	Algal growth is a common problem as it can cause bad taste and odour problems. To prevent build-up, the mesh should be cleaned using soft plastic brush on a regular basis. On larger net arrays it is suggested that nets be taken down once a year and the community spends a day or two cleaning them.
Maintenance and cleaning of collector drains	A screen should be installed at the end of drain to reduce solid inputs into the water supply. The drain and screen should be cleaned regularly to prevent build-up of material that will increase the risk of contamination.
Maintenance of pipelines and pressure tanks	Because of the irregular nature of the supply, water velocities in the pipes are likely to be below self-cleaning velocities for much of the time. Thus a tank at the top of the system should be used sufficient water to allow periodic flushing of the system to prevent a build-up of contaminants. Any leaks need to be quickly detected and repaired.
Maintenance of break-pressure and storage tanks.	Tanks should be cleaned of sediment build-up and disinfected with concentrated calcium hypochloride to prevent growth or fungi and bacteria.
Monitoring dissolved chlorine	Where chlorine is used to treat the water, levels must be regularly checked. This can help monitor microbial growth within the system and highlight any potential problems.
Monitoring water quality	It is recommended that water quality is checked on a monthly basis.
Purchasing materials	Money from the water committee should be used to buy spare parts, tools and chemicals (chlorine disinfectant)

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