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Fog collection's role in water planning for developing countries

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In certain locations, the combination of meteorological conditions and topography are such that persistent fogs cover coastal or interior mountains. The droplets from these fogs are collected by trees or other tall vegetation. They can also be collected by appropriately designed man-made collectors, to provide large volumes of water for domestic, agriculture or forestry uses. The largest project to date has provided, since March 1992, an average of 11000 litres of water per day (l/d) to a village of 330 people in the arid coastal desert of northern Chile. This project and others are reviewed. The impact of the deforestation of high elevation areas, and the subsequent loss of fog water input in a watershed are discussed, as are guidelines for water planners.

Precipitation is normally considered as the only source of groundwater. In fact, in many regions it is the only source, or was the only source of fossil water in the past. However, there are areas, primarily in upland regions, where the collection of fog droplets by vegetation can not only support the vegetation but also make contributions to aquifers. In the humid tropics these regions are known as cloud forests because the source of the fog is clouds moving over the terrain [9,21]. The persistent fog not only provides water but maintains conditions of high humidity, which limits evaporation from the soil and transpiration from the vegetation. Similar conditions exist in temperate latitudes, for example on the west coast of North America from British Columbia to California. In the arid tropics and subtropics, isolated pockets of vegetation survive in a similar fashion. What is critical to bear in mind, especially in coastal deserts, or denuded upland areas, is that even in the absence of vegetation, the fog will rollover the terrain and provide a potential water resource. Just like an underground aquifer, the water is there to be utilized. This paper will focus on projects in arid regions; however, the applications are by no means limited to these areas.

Precipitation and fog

Precipitation takes many forms, both frozen and liquid. A brief discussion of the liquid forms is valuable in understanding the different ways that water drops interact with the terrain and with obstacles [17].
Raindrops have diameters from 0.5 mm to approximately 5 mm and fall velocities which range from 2 to 9 meters per second (m/s). Drizzle drops have diameters from 40 mm to 0.5 mm and fall velocities from 5 cm/s to 2 m/s. Fog droplets have diameters from about 1mm to 40mm and fall velocities from less than 1 cm/s to approximately 5 cm/s. All of these fall velocities are sufficiently low for the angle of fall of the drops to be influenced by horizontal winds of a few metres per second, and even the largest raindrops will normally fall at an angle. In the case of fog droplets, the fall speeds are so low that, even in very light winds, the drops will travel almost horizontally. This means that the appropriate collector for fog droplets is a vertical, or near vertical surface. Trees can be good fog collectors depending on their height and leaf structure [15] and artificial collectors used to provide water for villages [5] are built in the form of vertical mesh panels (see Figure 1).

Scale of the water resource

The amount of liquid water present in a cubic metre of cloudy air varies tremendously, from perhaps 0.05 g/m^3 in wispy clouds to 3 g/m^3 or more in thunderstorms. At coastal fog collection sites, values such as 0.2 g/m^3 would be typical [19]. The amount that can be collected then depends on the surface area of the collector, the efficiency with which the collector captures the droplets, and the wind speed. A simple way to present the amount of water collected is to normalize it per square metre of vertical collection surface and use units such as litres per square metre per hour ($l/m^2/h$) or per day ($l/ m^2/d$).

A review of the collection of fog by isolated trees [15] has shown that the vertical cross section of a tree collects at a rate of about 10 $l/ m^2/d$. This led to depths of water produced on the ground under the trees of 1 to 5 cm/d. The higher rates came from the Dhofar region of southern Oman where two small intertwined olive trees (Olea europapea) dripped an average of 860 lid in one 79 day period in 1989 and 580 l/d over a 83 day period in 1990 (see Figure 2). These trees were in a windy environment and were almost constantly in fog and light drizzle. The trees in Dhofar produced much more water than they required in this humid environment and considerable surface runoff was evident below the trees.

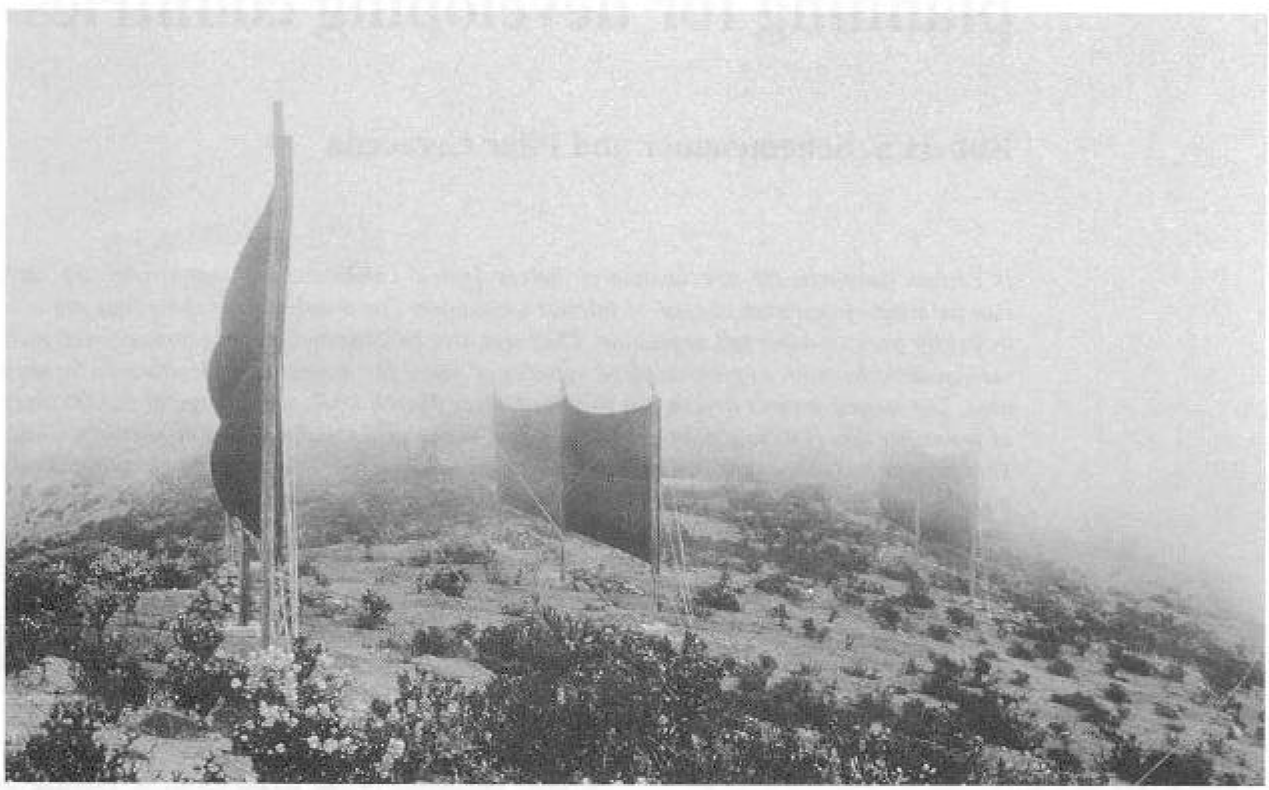

Figure 1. Fog being blown by the wind, from right to left, through the collectors on the ridge at El Tofo, Chile.

The collection of fog water by forests is more difficult to quantify. Lovett [10], among others, has shown that most deposition occurs near canopy top and results from impaction. Collection rates are about 0.1 mm/h, when converted to a depth below the tree. Vong et at [22] have reviewed the importance of chemical deposition by fog to forests. In addition, Coe et at [7] have looked at turbulent deposition rates to grass covered hilltops. To calculate accurately the collection of fog by a forest covered mountain, one needs to know the wind flow over the complex terrain, which is a difficult challenge [2]. A simple calculation can, however, demonstrate the amounts of water that are involved.

The upper section of a small semicircular watershed might be 20 km in length (13 km in diameter) and covered in frequent fog due to the passage of clouds. If a 500 m wide band was planted with trees spaced 10 m apart, it would allow for good exposure of the trees to the fog bearing winds. The 100 000 trees can collect water amounting to approximately 250 l/d during their fog season [15]. If the season is one-half of the year, the total water collected in a year is 45.6 m^3 per tree, or 4.5 X 106 m^3 in total. If even 25% of this water is surplus to the immediate needs of the trees, about 106 m3 will percolate down slope in a year. This is equivalent to having an extra 100 mm of precipitation fall on the 10 km^2 plantation in a year. In arid regions, this can equal or exceed the annual precipitation. This is water gained if trees are planted and is an indication of the water lost if forests are cut and not replanted.
Some details of fog collection rates by large 48 m^3 collectors (Figure 3), will be given in subsequent sections along with data obtained with standard fog collectors (SFC) having an area of 1 m^3 (see Figure 4).

Fog collection in Chile

Village water use

The largest fog collection project to date has taken place on a ridgeline above the fishing village of Chungungo (290 27'S; 720 18'W) on the north central coast of Chile. Up until 20 years ago, Chungungo received water from the iron mine of El Tofo. When the mine closed, water was trucked to the 330 villagers from a well 40 km away. The water delivery was irregular, the water not of the best quality, and the cost high.

The fog collection system

The coastal ridgeline (780 m elevation) at El Tofo, above the village of Chungungo, is frequently covered in fog. The incoming cloud layers are thin, 100 to 300 m, and rarely produce drizzle or rain. Their tops vary in altitude from perhaps 500 to 1200 m, depending on the height of the temperature inversion that persists through- out the year. Since 1987 El Tofo has been the site of a large pilot project to evaluate the potential for using high elevation fog as a water supply in the arid north of Chile. Areas of investigation included coastal meteorology; interactions of topography

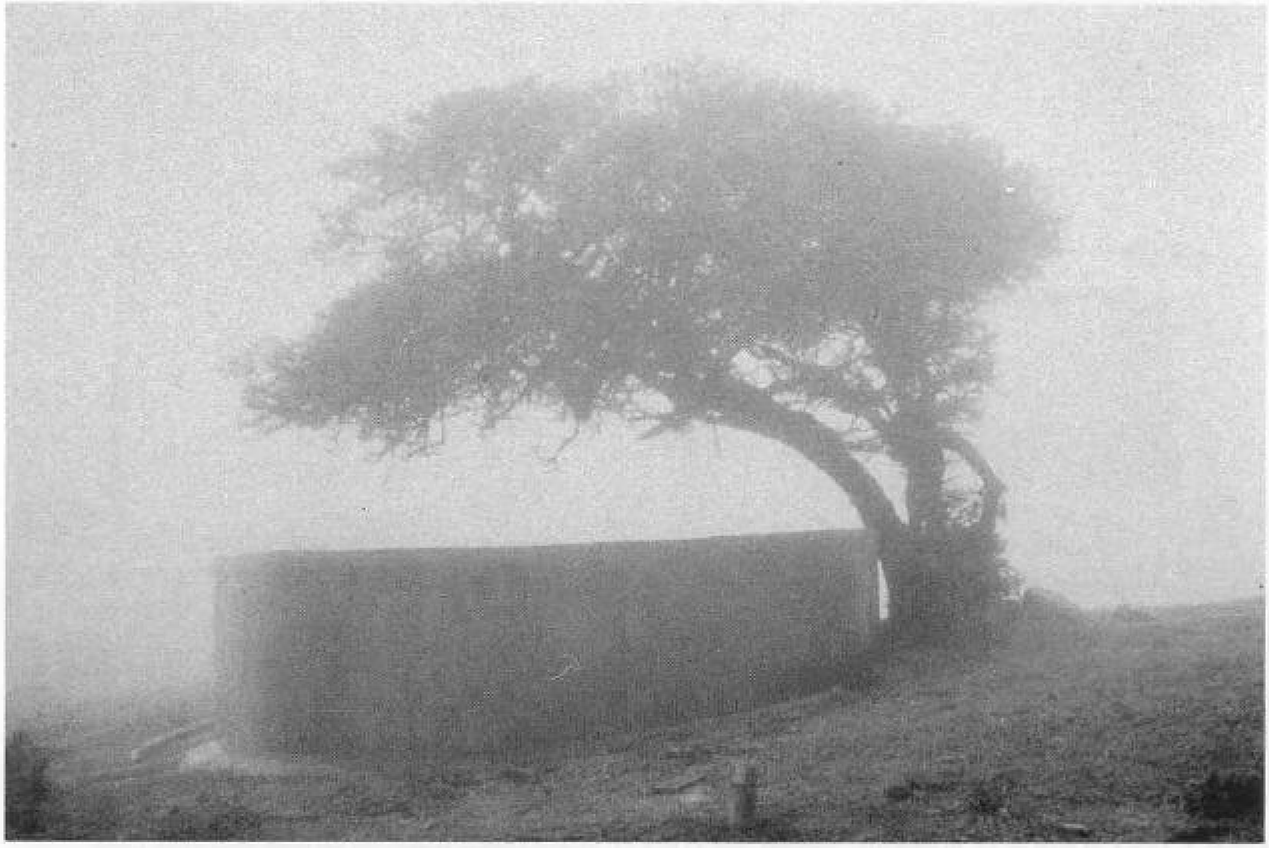

Figure 2. Intertwined olive trees drip fog water into a 5 m diameter reservoir, in the coastal mountains of the Dhofar Region of the Sultanate of Oman.

and wind; fog micro- physics; fog water chemistry; water costs; water production rates; and environmental and social considerations in fog collection projects.

At the El Tofo site 50 large fog collectors, each consisting of 48 m2 of a double layer of polypropylene mesh, were constructed by the Corporaci6n Nacional Forestal (CONAF) in late 1987 with funding from the International Development Research Centre (IDRC, Ottawa), as part of a multi-agency scientific and operational programme [12]. In 1992 25 additional collectors were constructed and a 6.2 km pipeline to the village of Chungungo was completed with help from the Canadian Embassy. A 100m3 storage tank above the village feeds fog water through a PVC distribution system to 106 houses. The system has been operational since March 1992.

The average water production from the collectors has been approximately 3 $l/m^2/d$ of collecting surface from November 1987. This is an. average production of 11 000 l/d. Production rates vary with conditions, from zero on clear days, to a maximum of about 100 000 l/d. With the current array size, each of the 330 villagers should receive about 33 l/d of water.

Water quality

Water in the incoming fog and from the fog collectors can be expected to be of good quality. It will contain some marine salts and soil dust but little contamination from anthropogenic sources given the remote locations of most proposed sites. The ion and trace element concentrations in the fog water at the El Tofo collection site have been studied in detail [13] and found to meet Chilean and World Health Organization (WHO) drinking water standards. As with any water supply system, once the source water is known to be acceptable, the quality at the point of use will depend on having suitable maintenance procedures for the system. The above studies did not address the question of bacterial concentrations, but work by the University of Chile (unpublished) has shown the absence of faecal coliform, as would be expected. Other bacteria will be eliminated by the chlorination treatment that is required by law for domestic water supplies in Chile.

The management of the fog water supply

In the case of the fog water supply system for Chungungo, because of the unconventional nature of the system, and because the capital funding came from Canada, a non-standard organizational structure evolved. The collection portion of the system is managed by CONAF which holds the lease on the land; the distribution in the village is aided by the Sanitary Services Company of Coquimbo (ESSCO), which is a part of the national Public Works Ministry (CORFO), but the distribution system is not an official ESSCO programme. A potable water committee (PWC) in the village has been set up and is run by the villagers. The villagers were aided by a social worker who helped them define how they would commit their time to the PWC. The PWC has five elected, unpaid members from the village and a paid administrator. He maintains the main 100 m3 storage tank and the distribution system, monitors water use in each home, and collects a monthly fee based on consumption. The fee pays the administrator's salary and minor maintenance costs, and a portion is saved to meet future expenses.

Another important role of the PWC is to regulate consumption in the village. Because the supply of water varies with the presence of fog on the mountain, the PWC monitors the main reservoir and alerts villagers to reduce consumption in periods of low supply. In turn, in periods of excess production, water is diverted to a large 400 m3 open reservoir for agricultural purposes. Initially, 0.3 ha of a 0.7 ha plot is being irrigated. The change from the storage of trucked water in 200 1 oil drums, and paying for the water when it arrives, to using metered water taps and paying once a month has been a significant adjustment for the villagers. In particular, because the water is now so easy to obtain from the water taps, the people must be careful not to use more than they can pay for and they must restrict consumption in periods when the water production is lower. Overall, the current level of village involvement in the distribution of the water appears to be working well. Aspects where more involvement should have been encouraged are in the construction of the collectors and the pipeline themselves, and in the maintenance of the collectors on the ridgeline.

Acceptance by the villagers

Two surveys have been carried out to determine the level of acceptance of the fog water collection system by the people of Chungungo. The first (Sl) was carried out on 4 January 1993 and the second (S2) on 28 December 1993. Sl had replies from 55% of the homes and S2 from 65%. No one was present in the other homes at the time of the surveys.

The ease of having water run from the taps initially led the villagers to a strong perception that they were using more water. In Sl 70% felt they were, in S2 53% felt they were. In fact consumption in October, November and December 1992 had increased to 22, 23 and 28 l/d per capita, from 14 l/d per capita before the pipeline bringing the fog water was installed.

In S1 82% of the respondents felt that the water was cheaper than the trucked water. In S2 72% felt that the water was cheaper; however, 20% felt that it was more expensive. This was only a measure of the perception of the people and not a study in each household of the actual amount paid for water before and after the pipeline was installed. It does not account for the fact that in some households the consumption may have increased dramatically. It also perhaps reflects the fact that some people are unhappy with the sliding rate used to calculate the water payments. There was a fixed charge of US$I.38 per month (US$I.OO = 435 pesos) per household plus a charge based on consumption. In 1993 the total charges were US$1.26/$m^3$ for 3 m^3; US$I.06/ m^3 for 5 m^3; and US$1.10/ m^3 for 10 m^3. In early 1992 the subsidized rate for the people was US$2.30/ m^3 for the trucked water and in early 1993 US$2.87/ m^3. In 1988, at the time of the survey of Cereceda et al [5], the people were paying US$1.80/ m^3 for trucked water; in addition, the municipality was adding a subsidy to bring the total cost to US$7.25/ m^3. Effectively the rate has thus decreased for the families and decreased substantially for the municipality. The municipality's only responsibility at present is to send a truck with water on the rare occasions when the PWC feels that the fog water supply will not meet the demand. This may be a result of a problem in the distribution system or a lack of adequate production by the collectors.

Regarding the taste and clarity of the water from the fog system, in S1 77.7% of the respondents said that the fog water tasted better than the trucked water and in S2 73%; 70.6% in S1 felt that the water from the fog was clearer and in S2 71.4%. In S2, 9.5% felt the water had similar qualities to the trucked water. The supply system has undergone an evolution over the two years of operation, particularly to improve the removal of particulates in the system by sedimentation and filtration. Reliability of the components of the system as well as maintenance procedures have also undergone improvement as the operators become more familiar with the system.

Fog collection in Peru

There has been a history of small fog collection experiments along the coast of Peru (eg Pinche-Laurre [II)). The desert coastline is mostly sand and rock except where it is cut by small rivers carrying water from the Andes. The rural villagers are extremely poor and suffer from both a lack of water and contaminated water.

In 1990 the Canadian International Development Agency (CIDA) provided funding to carry out an assessment project near Lima, with the assistance of the Canadian Embassy and the Servicio Nacional de Meterologia e Hidrologia. A site at 430 m was selected just north of the city (110 49'S, 790 09'W) using established criteria such as are listed below. It was 3.5 km from the coast and above a pueblo joven (squatter settlement) of 6000 people.

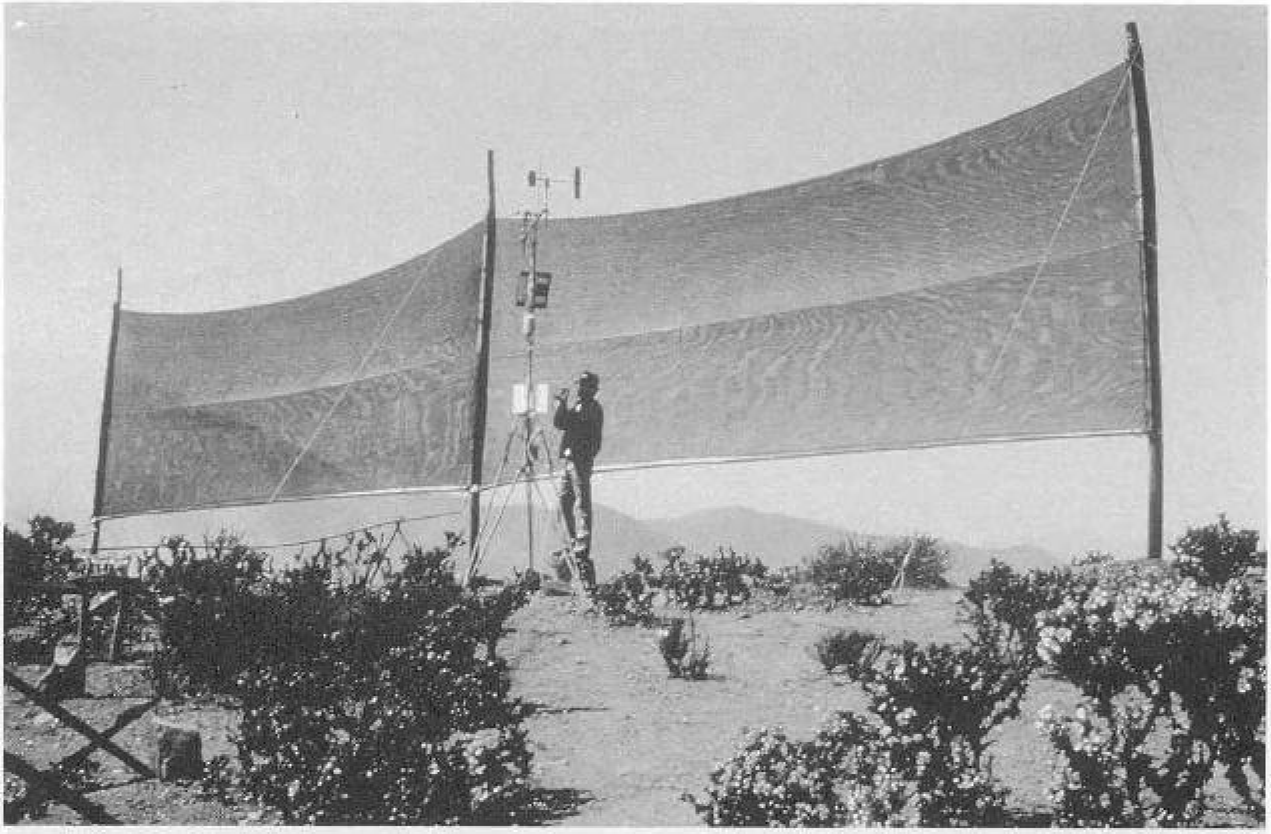

Figure 3. Two 4 m high by 12 m long fog collectors, and an upwind meteorological station, on the ridge at El Tofo, Chile.

Fog and drizzle were frequent at the Cerro Orara site during June and July as the site and the instrumentation were prepared. Field measurements using a set of standard 1m^2 collectors began in July and continued well into December when the fog, though less frequent, was still present. A continuously recording meteorological station operated throughout the period. The results showed [16,6] that this site, on an annual basis, should have a greater productivity than the El Tofo site in Chile. This is in part because of higher wind speeds and in part because of light drizzle that falls from the thicker cloud decks.

These results formed the first rigorous base on which to build fog water supply systems in Peru. Subsequently, two private companies were established to build systems. At a school near Lima 1200 m^2 of mesh were installed to provide fog water for the school, in a park north of Lima 500 m2 of mesh were installed to produce fog water for reforestation purposes, and several other small projects were undertaken. In addition, in 1993 IDRC provided funding through a non-governmental organization (NGO), TECNIDES, for a large agricultural and forestry project on the edge of Lima, an area which receives only 5 mm of annual precipitation. The project will collect fog water to use for production of agricultural and forest products to support the desert community of Collanac. An additional component of the project is the reforestation of the hillsides, which have been virtually cleared of all trees and shrubs. A native tree called a Tara (Caesalpina tinctorea) is being reproduced in vitro for planting in numbers that may approach 100 000. The 1993 survey of fog water availability in the mountains surrounding the community indicated the presence of high enough collection rates to support the operational programme.

Fog collection in Ecuador

Ecuador has stretches of semi-arid coastline where the people experience water shortages and high water costs, as in Chile and Peru. There are coastal mountains that are seasonally fog covered; an evaluation of the fog collection potential began in late 1992 near Puerto Lopez, with support from CIDA. Two small evaluation projects were also initiated in the high Andes at elevations of 2830 m at Pululahua near Quito and 2000 m near Celica in the south of the country. These sites are operated by NGOs (CISA in Puerto Lopez and Pululahua; ARCOIRIS in Celica), with some scientific and technical assistance provided through CIDA. The two mountain sites produced large amounts of water from the fog collectors, from December 1992 through March 1993.

The high production rates result both from drizzle and rain being present plus the extended periods of fog each day. The coastal fog collection season begins later in the year and probably extends from May through November. These results are very encouraging and would support undertaking a more extensive evaluation programme.

Figure 4. A standard 1 m^2 fog collector used for initial field investigations, Cerro Orara, Peru.

Fog collection in the Sultanate of Oman

A major fog collection experiment was undertaken in the Sultanate of Oman in 1989 and 1990 based on the work in Chile. The project was funded initially by the United Nations Development Programme (UNDP) , the World Meteorological Organization (WMO) and the government of Oman through the Planning Committee for Development and Environment in the Southern Region (PCDESR). In the second year work was carried out under the auspices of PCDESR. During the south- west monsoon, the mountains of Dhofar (170 OO'N, 540 04'E) are covered in a thick deck of fog with frequent drizzle. The maximum duration of the monsoon is from mid-June to mid-September and it is often some weeks shorter.

Data were collected with both standard 1 m^2 as well as much larger collectors. In the upper elevations, from 900 to 1000 m, average collection rates of 30 1/ m^2/d were obtained for a three-month period [1,8]. Because of the extended dry period between collection seasons, and because of the other options available in Dhofar (boreholes, desalination), a private sector evaluation was undertaken to determine if fog water collector arrays should be included in the five-year plans for the region. If they are, the most likely application will be reforestation of the mountains. However, a study of the water quality [14] has shown that the water is potable and, therefore, suitable for all purposes.

Fog collection potential in other countries

The authors [12] reviewed the literature relevant to fog collection in arid and seasonally arid regions of the world. They concluded that there were 22 countries on six continents where literature references to the collection of fog by trees or small collectors would support an evaluation of the amount of water that could be produced by operational fog collection arrays. In Africa, for example, one could explore the water production rates in parts of the Sudan, Kenya, South Africa, Namibia, Angola, Ascension Island, the Cape Verde Islands and the Canary Islands. Some of these are developing countries in dire need of water. Others are developed countries with water scarcity but with resources for funding other non-conventional sources of water such as desalination. The same pattern exists elsewhere in the world.

California has fog-covered coastal mountains and a demonstrable water need but it also has the resources to pay for major water diversion projects. On the other hand, Yemen also has suitable conditions and may well benefit from a fog water programme that can be implemented in rural areas for either village use or for reforestation.

A broader look at the meteorological and oceanographic conditions on a worldwide basis, as well as the topography, will lead to the conclusion that many other countries may have the potential to benefit from fog collection programmes. Continuing with the example of Africa, evaluation programmes could be considered in parts of Eritrea, Ethiopia, Somalia, Tanzania, Madagascar and Morocco, among others.

The collection of fog water also has extensive application in both seasonally arid countries and in countries or locations where there may be an adequate amount of water but where water may be bacterially or otherwise contaminated.

An example of the former is the Philippines. Annual precipitation in the upland areas may be 4000 mm or more and, particularly during the monsoon season, the people are deluged with water. Rainwater is collected by many homes and spring water is readily available. Yet for six or more months of the year the same people suffer from serious water shortages and are forced to buy water from tanker trucks at rates of US$4.00/ m^3 or more. In rural areas, where the incomes are very restrict- ed, this produces major limitations on living conditions and affects the health of the people. To date no fog collection projects have been undertaken in the Philippines, but discussions with NGOs and villagers in the mountains of northern Luzon, for example, lead us to believe that there may be sufficient fog during the dry season to augment or replace the water that is being purchased from the trucks.

Guidelines for initiating a fog collection programme

There are a number of logical steps one can follow at the inception of a fog collection programme. Normally fog formed on the surface of the ocean, or nocturnal radiation fogs in low lying areas, will lack sufficient liquid water content or sufficient wind speeds for substantial water collection; therefore, the discussion here will be limited to upland areas with fog produced by the advection of clouds over the terrain or, in some cases, formed from orographic lifting on the mountains. We also assume that other traditional sources of water eg wells or rainwater collection, cannot meet the needs of the people.

Through travel in a region, discussions with the population, and meetings with government officials and meteorologists, an idea can be obtained whether there are high elevation regions with a water requirement and frequent fog. This cannot be relied upon as definitive evidence for the presence of the necessary conditions, as people rarely are aware, for example, of what is happening in these areas in the middle of the night; but, if the indications are positive, a simple observation programme can be begun where the presence or absence of fog on topographical features of interest is noted in each season of the year. The cost is negligible but, as the authors have shown [3], the data are most informative.

A more sophisticated programme uses standard fog collectors (SFC) of 1 m2 [18] to measure the fog water production rates on specific terrain features and to define the length of the fog season. Geographical considerations in the selection of sites are discussed below. Using the SFC with simple plastic containers (jerry cans) can give daily production figures. If the SFC is used with a data logger and wind speed and direction sensors, then a more detailed understanding of the fog production at a site can be obtained. This evaluation stage will cost approximately US$25,000, depending on the travel involved and the number of SFC units used.

This core information on production potential can then be coupled with the specified water requirement, both type of use and quantity, to plan the next stage. In fact, temporal variations in production can have an influence on the optimum use for the water. Table 1 shows a summary of production data at sites where the authors have worked in three countries, as measured with SFC. The average water collection rates during the fog seasons in Chile, Peru and Oman were 3, 9 and 30 $l/m^2/d$ respectively. But equally as important is that the length of the fog season was 365, 210 and 75 days respectively in the three countries. Thus, in Chile, with a low production for the entire year, the use of the water for domestic purposes is reasonable. In Peru, with a moderately high production for seven months, agriculture with several crops in a year could be considered, or domestic uses with a large storage capacity. In Oman, the short wet season with high production rates is possibly best suited to forestry applications where tree seedlings, native to the area, could be irrigated for about three months and then allowed to be dormant during the dry season. Of course, forestry applications are possible along the arid coastlines of Chile and Peru as well and some have been undertaken.

Because fog collection is a non-conventional method of obtaining water, a public education programme should be started early in any project. It should point out both the advantages and disadvantages of the system and explain clearly how approaches to using water should change. As with any water project, it is a tremendous advantage to have the local population participate in decisions on the water applications, participate in the construction of the system and, as far as is practical, take over the maintenance and operation of the system. Indeed, with full involvement of the local population, they may be able to expand the system in the future using their own resources. Another point is that, in the same way that non-traditional energy sources, such as solar and wind powered generators, require time to be accepted, skepticism must be anticipated when approaching local authorities with plans for a fog collection system. An economic study, undertaken to ensure that the projected water costs would be favorable in comparison to other alternatives such as tanker trucks or water pipelines, could help in this regard.

The next step is to design a system of collection, transport, storage and distribution of the fog water. The cost of this stage will depend very much on access to the site, the distance the water has to be moved, and the use of the water. A collector with a surface area of 50 m^2 should cost in the range of US$300 to US$500. It consists of two vertical posts mounted in a hole with packed stones or cement and anchored with galvanized or stain- less steel cables. The mesh is supported by similar cables, and a PVC or other type of plastic trough is suspended from the lower cable. The water is carried away by tubes of appropriate diameters. Local materials and construction practices can be used but the mesh should be of a type described by the authors [18]. Local meshes may prove acceptable, but they should first be compared with the mesh used successfully in other countries. The cost of 100 large fog collectors, which would be suitable for a village, is of the order of US$40 000 and is inexpensive compared to many other water supply systems. The system can be scaled up to provide much larger amounts of water, as the terrain chosen can normally support very large numbers of collectors.

Table 1. Fog water production and length of fog season at three sites.

	Average production ($1/m^2/d$)	Days per year	Annual production ($1/m^2/yr$)
Chile	3	365	1095
Peru	9	210	1890
Oman	30	75	2250

Geographical considerations for site selection

Since the clouds are carried to the site by the wind, and the fog is then moved through the collectors by the wind, the interaction of the large- and small-scale topographical features with the wind will in large part deter- mine the success of the site chosen. A number of the most important geographical factors will be briefly reviewed here.

Global wind patterns

Persistent winds from one direction are ideal for fog collection. These situations occur where the driving forces are global in scale [4,20]. For example, the circulation around the high pressure area in the eastern part of the south Pacific Ocean produces onshore south-west winds in northern Chile most of the year and southerly winds along the coast of Peru. The trade winds are another example of persistent winds in regions of interest.

Mountain range

It is necessary to have a mountain range that rises high enough to intercept the clouds that are advected into the region. On a continental scale, these can be the coastal mountains of Chile, Peru and Ecuador. On a local scale it can be an isolated hill.

Altitude

The thickness of the stratus or stratocumulus clouds and the height of their bases will vary with location. A desirable working altitude is at two-thirds of the cloud thick- ness above the base. This region will normally have the highest liquid water contents. In the cases discussed above, the working altitudes have been from 400 to 1000 m (above sea level). Often the cloud tops will be limited by the base of a strong thermal inversion. There will be some seasonality in the height of the inversion but knowledge of it can help provide a guide as to possible working altitudes.
Orientation In the case of a coastal mountain range, it is important that the longitudinal axis of the range be approximately perpendicular to the direction of the wind bringing the clouds from the ocean. This will maximize the opportunity to choose acceptable sites. The clouds will flow over ridgelines and through passes, with the fog often dissipating on the downwind side.

Distance to the coastline

In the case of coastal cloud decks moving onshore, one should try and work as close to the coast as possible, ideally within 5 km, but possibilities exist up to at least 25 km inland. As the marine clouds pass over the continent, there is a strong likelihood that they will mix with drier air and the clouds will begin to dissipate. However, there are also many high elevation, continental locations, with frequent fog cover resulting from either the transport of upwind clouds or the formation of orographic clouds. In these cases, the distance to the coast- line is irrelevant.

Space for collectors
A mountain peak is obviously not a good place to attempt to install a fog collector array. The location must be appropriate for the erection of the collectors. This suggests ridgelines and the upwind edges of flat topped mountains as good sites. The 12 m long collectors should have spaces of about 4 m between them to allow the wind to flow around the collectors. In some cases 24 m long collectors (Figure 3) may also be desirable. This leads to a requirement of 0.5 to 1 km of length for 50 collectors. Similar parallel rows of upwind collectors could also be built at slightly lower altitudes. Smaller sites may be excellent locations, but would only be suitable for small systems.

Relief in the surrounding area
It is important that there be no major obstacle to the wind within a few kilometers upwind of the site. An upwind ridgeline will cause the wind bearing clouds to be diverted both around and over the obstacle, resulting in a diminished collection potential. In arid regions, the presence inland of a depression or basin that heats up during the daytime can be advantageous. This local low pressure area can enhance the sea breeze and increase the wind speed with which marine cloud decks flow over terrain features.

Topography and wind speed
The topography of the ridgeline or mountain influences to a large degree what the site wind speed and direction will be. The prevailing winds will push the fog up valleys and this may result in significant changes in wind direction. If the inversion base is below the height of a ridgeline, the fog at lower altitudes can be diverted horizontally until a pass provides an opening for the wind to push the fog through. These passes are good collection locations. In regions of complex terrain, the choice of a good sampling site with consistent winds is difficult.

Crestline and upwind locations
Studies of wind flow over mountains support the field data showing that fog collection locations along crestlines of ridges, or just slightly upwind of the crestline, are optimum. Slightly lower altitude upwind locations are accept- able, as are constant altitude locations on a flat terrain feature. But locations behind a ridge or hill, especially where the wind is flowing downslope, should be avoided.

Slope and microtopography
Gently rising slopes upwind of the collection sites are ideal. Near vertical slopes produce a strong vertical component to the wind and make collection difficult. The micro topography, on the scale of 10 m or less, can have a significant influence on wind flow through the collectors. Locations where small valleys meet or with many small hills or large boulders are generally not the best sites.

Conclusion
Fog collection by man-made collectors may be a non-conventional source of water, but it is not unproven. Applications exist in many countries where convention- al methods cannot provide an adequate supply of water. It has been shown in the literature that the water can be delivered in large quantities, that it is potable and that the cost is comparable to, or lower than, the cost of other potable water systems in rural arid regions. The cloud decks bring an essentially unlimited amount of water to the mountain sites, so in principle the amount of water that can be collected is limited only by the number of collectors that one chooses to install. However, even with much larger collector arrays than have been installed to date, the amount of water that could be removed from the incoming clouds will be limited, and downwind effects will be negligible. The water source is sustainable over periods of hundreds and probably thousands of years because the driving forces for the formation of the cloud decks are global in nature and will change only slowly. The collectors themselves are simple, require no energy other than the wind and deliver their water by gravity flow.

It is also important to note that in the humid tropics, cloud forests owe their existence to the input of water from both precipitation and from fog. It is clear that deforestation on tropical mountains will lead to reduced fog water inputs, which ultimately results in less water in aquifers and in the streams fed by these aquifers. This, coupled with the erosion that deforestation generates, can result in both seasonal aridity and the production of semiarid highlands. On the positive side, fog covered hills are often encountered in the humid tropics outside of the rainy season, for example in the Philippines, India, Kenya, Hawaii, Central America and the Caribbean. This offers the possibility of collecting fog water in these countries for reforestation of denuded hillsides. The collection of fog provides a managed water supply, which does not have to be transported up to the area of interest. Initial irrigation of the tree seedlings could cease once the trees have reached a height of two metres or so and can collect sufficient water to be self sustaining.

It is recommended that those working in upland areas give consideration to the measurement of fog water avail- ability in their area and to utilizing this water resource for the better management of the local environment.

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