FOG COLLECTION AS A COMPLEMENTARY WATER RESOURCE IN EGYPT

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ABSTRACT

Fog is an environmental water resource of great importance. It plays an integral role in many diverse ecosystems. A very special part of the fog activities in the world today is focused on fog collection to provide water for managed use. One of the most exciting aspects of this resource is that in many regions the supply of water will be limited only by the number of collectors one chooses to install. In addition, since the source of the fog is normally the movement of marine stratocumulus deck over coastal mountains, the water quality is good and the water can be used for drinking and other domestic and agricultural purposes. Fog has the potential to provide an alternative source of freshwater in semiarid and arid regions if harvested through the use of simple and low-cost collection systems known as fog collectors. This application -in Egypt- depends on finding locations where there are high horizontal fluxes of fog water in regions with an acute water need. The aim of this paper is to describe what is arguably the first truly innovative source of freshwater that shows significant potential for use in certain semiarid and arid land. The Paper introduces the definition of fog, fog collection potential in the world, standard fog collectors, fog water collection, guidelines for initiating fog collection program in Egypt, fog-water production, fog-water cost, environmental considerations, cultural acceptability, the fog collection project decision and fog collection sustainability and climate change.

INTRODUCTION

For centuries, people have known that trees collect the tiny water droplets that make up fog. This covert water input, in the mountainous and coastal regions of our planet, was called occult precipitation in the last century and the terminology persists in some of the literature to this day. The fog not only provides water but maintains conditions of high humidity, which limits evaporation from the soil and transpiration from the vegetation. 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 roll over the terrain and provide a potential water resource. Just Like an underground aquifer, the water is there to be utilized.

The ever-growing need for fresh water in Egypt is indisputable and both increasing populations and the contamination of existing supplies will lead to constantly escalating demands. Egypt should, therefore, begin to consider the use of non-traditional water supplies such as the collection of fog. As clouds move over hills and mountains, the hilltops and ridgelines are enveloped in fogs. Just as the leaves and needles of trees can collect some of the water in these fogs, large artificial collectors can produce a flow of potable water.

Fog is an atmospheric water resource of great importance. 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 tail vegetation. They can also be collected by appropriately designed man-made collectors, to provide large volumes of water for domestic, agriculture or forestry uses.

FOG WATER COLLECTION

Fog is composed of liquid droplets. Fog, in the simplest of terms, is a cloud which is touching the ground and the type of fog is then determined by the physical process which has created the fog. When a cloud, with a base some distance above the sea or the land, moves over a mountain, the mountain is covered by fog. Fogs produced by the advection of clouds over higher terrain tend to have higher liquid water contents than do fogs produced at the land or sea surface and it is these high elevation fogs that are of primary interest for the production of water in arid lands. The collection of fog droplets depends on the diameter of the droplets, the wind speed and the nature of the collection surface. Fog droplets have diameters which are typically from 1 to 30 µm in dimmer.

Fog collection is a resource that should be evaluated in areas where other traditional sources of water, for example, surface water, wells or rainwater collection, cannot meet the needs of the people and where a water pipeline or desalination plants are impractical or too costly. Fog-water collection is a resource that should be seriously examined in certain semi-arid and arid regions of the world. It is particularly attractive in areas where conventional sources of water are nonexistent or are disappearing.

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.

Fog Collection can only become an effective water tool through links to the scientific community and through improvements in fog climatology, fog forecasting, fog instrumentation and the remote sensing of fog.

THE DEFINITION OF FOG

Fogs are defined as a mass of water vapor condensed into small water droplets at, or just above, the Earth's surface. The small water droplets present in the fog precipitate when they come in contact with objects. The frequent fogs that occur in the arid coastal areas are traditionally known as *camanchacas.* These fogs have the potential to provide an alternative source of freshwater in this otherwise dry region if harvested through the use of simple and low-cost collection systems known as fog collectors.

Fog has a very clear definition and it is fog that we work in when we are on mountains. Sometimes, however, the work is termed an in-cloud study, which gets the concept across but is not precisely correct. The fog may be formed in part, or completely, from clouds that advect over the mountains. In meteorological definitions of fog, it is further stated that it is composed of tiny water droplets and that it is present when the visibility is below 1 km

REVIEW OF FOG-WATER COLLECTION

This review of fog-water collection in arid lands shows that at 47 sites, in 22 countries, on six continents, references exist to the collection of fog-water by plants or man-made devices. The latter experiments indicate that fog has been considered as a water resource in some arid or desert environments but it has never been developed as a serious water supply. The Camanchaca Project (1987-1989) at the El Tofo site in Chile has gone the necessary next step and combined a scientific study with the implementation of a large-scale pilot project. It has clearly shown that at the El Tofo site, along the Chilean coast, substantial amounts of water can be obtained from persistent high elevation coastal fogs. In addition, it appears that the water cost presents an attractive alternative to trucked water.

The application of the Chilean technology and the results of the experiments, to other locations in the world, is neither simple nor automatic. Before an operational or even a pilot project could be undertaken at a site, an initial site assessment needs to be done. The fog frequency and altitude range need to be identified; a wind climatology is necessary; the topography has to be examined to locate preferred sites; and the fog liquid water contents and droplet sizes should be measured. Data from these and other studies can normally be obtained at relatively low cost and are essential for the design of the appropriate large collector and for the choice of sites. Ideally one would prefer a long-term record of all parameters before proceeding but fiscal or other restraints often preclude this. Therefore, a one year field project followed (if warranted) by a parallel research and pilot project seems to be the logical progression at potential sites.

Fog Collection in Africa

Africa has arid and desert conditions in both the extreme north and the extreme south of the continent. Fog-water collection systems may have application at many locations in Africa but of date there have been few experiments to verify this. One of the most interesting reports was of a tree in the Canary Islands, which as early as 1764, was said to have produced large amounts of fog-water for the islanders. The different aspects of the technology and the project results have been documented in the literature and it deserves strong consideration in regions that are arid or seasonally arid. Namibia is the first African country in which the possibility of using fog collection as a water supply for indigenous peoples is being evaluated. There have also been scientific evaluations underway for several years in both the Canary Islands and South Africa. All show positive results.

Fog Collection in Middle East

Almost the entire region lacks readily available freshwater in the form of rivers and lakes. There are though, extensive supplies of groundwater in many areas. One non-traditional source of water that has historically received considerable attention in this region is the deposition of dew on plants. This, however, does not provide a managed water supply.

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. During the southwest monsoon (Khareef), the mountains (Jebel) of Dhofar (17^0 0'N, 54^0 4'E) are covered in a thick deck of fog with frequent drizzle. The maximum duration of the Khareef 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 $Lm^{-2}d^{-1}$ [2] were obtained for a three month period. 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 Jebel. However, a study of the water quality [4] has shown that the water is potable and, therefore, suitable for all purposes.

STANDARD FOG COLLECTORS

A fog collector is simply a frame that supports a section of mesh in a vertical plane. The large, operational fog collectors are typically made of two supporting posts, and cables on which the mesh suspended. In addition, there is a network of guy wires to support the posts, a plastic trough to collect the water, and pipes to move water from the troughs to a reservoir or cistern. The large collectors are usually 12 m long and 6 m high. The mesh covers the upper 4 m of the collector. This gives a collecting surface of 48 m^2 and typical water production rates from one collector of from 150 $Lday^{-1}$ (litres a day) to 750 L day^{-1} depending on the site. Sustained production rates over periods of two and one-half months in the Sultanate of Oman were as high as 70 L m^{-2} day^{-1} or 3360 L $collector^{-1}$ day^{-1}. The 48 m^2 fog collectors cost about US$400 each to build and arrays for villages' number from 30 to 80 collectors. The 1 m^2 Standard Fog Collectors cost from US$ 10 to US$ 20 to build depending on the country and the materials. A portion of the array of large fog collectors at El Tofo, Chile, with distance between posts is 12 meters is shown in Figure 1.

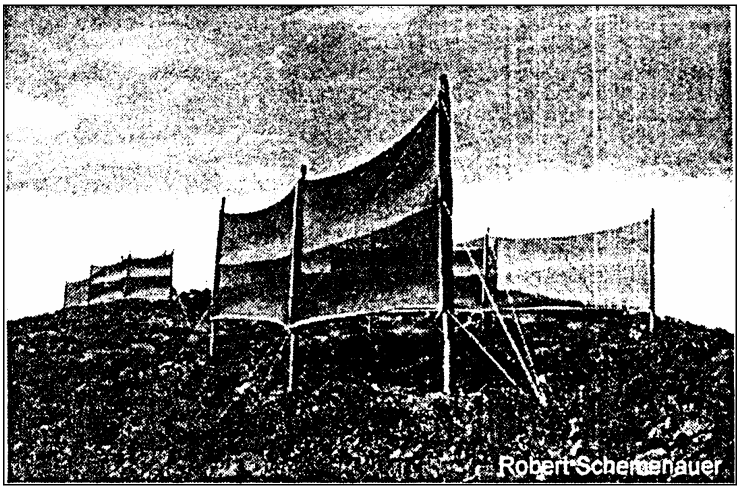

Figure 1 A portion of the array of large fog collectors at El Tofo, Chile

Fog collectors work best in coastal areas where the water can be harvested as the fog moves inland driven by the wind. However, the technology could also potentially supply water for multiple uses in mountainous areas-should the water present in stratocumulus clouds, at altitudes of approximately 400 m to 1 200 m, be harvested.

INITIATING A FOG COLLECTION PROGRAM

There are a number of logical steps one can follow at the initiation of a fog collection program. 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, e.g. 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, one will have an idea if 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, one can begin a simple observation program where the presence or absence of fog on topographica features of interest is noted in each season of the year. The cost is negligible but as [6] have shown the data are most informative.

A more sophisticated program uses standard fog collectors (SFC) of 1 m^2 [6] 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 of the order of $25,000 US depending on the travel involved and the number of SFC 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.

Because fog collection is a very non-conventional method of obtaining water a public education program 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 manner that non-traditional energy sources, such as solar and wind powered generators, require time to be accepted, one must anticipate scepticism when approaching local authorities with plans for a fog collection system. An economic study, undertaken to ensure that the projected water costs will be favorable in comparison to other alternatives such as tanker trucks or water pipelines, can help in this regard.

The next step is to design a system of collection, transportation, 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 $300 to $500 US. It consists of two vertical posts mounted in a hole with packed stones or cement and anchored with galvanized or stainless 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 [6]. 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 $40,000 US and is inexpensive compared to many other water supply systems. The system can be scaled up to provide much larger amounts of water, as normally the terrain chosen can support very large numbers of collectors.

FOG-WATER PRODUCTION

The production of water by an array of fog-water collectors depends on the number of collectors, their size, their efficiency, the fog frequency, the fog liquid water content and the wind speed. For high elevation coastal sites, and conditions of a 3 $m.s^{-1}$ wind, a 40% fog immersion time and a collection efficiency of 50%, 1 km of collector is capable of supporting a large number of people, 3150 for a Liquid Water Content LWC of 0.25 $g.m^{-3}$, if the water requirements are low 20 L $pers^{-1}.day^{-1}$. For a demand of 200 $L.pers^{-1}.day^{-1}$, only 315 people could be supported. However, this could represent the entire population of a small village.

Experiments with small collectors have yielded much higher collection rates in some locations. For example, in some sites collected in excess of 50 L $m^{-2}.day^{-1}$ for two or three months of the year but the annual average will be much lower since the remainder of the year is fog free. In order to determine whether the production of water by the collection of fog is reasonable, one needs to know the range of values people actually use in the rural, arid parts of developing countries, but actual measurements are few, and so some estimates have been included for comparison. It appears that values from 10 to 50 $L.pers^{-1}.day^{-1}$ are estimated and therefore, a value of 50 $L.pers^{-1}.day^{-1}$ should be an improvement for small settlements in most rural arid lands. A properly sited fog-water collection system should be able to provide this amount to more than one thousand people per kilometer of length.

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

	Average Production (L m^{-2} d^{-1})	Days / Year	Annual production (L m^{-2} d^{-1})
Chile	3	365	1095
Peru	9	210	1890
Oman	30	75	2250

Table 1 shows a summary of the production at sites the authors have worked at 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^{-1} 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, one could consider agriculture with several crops in a year, 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.

FOG-WATER COST

The cost of producing water from fog will depend not only on the amount of water produced but on local labor and material costs and on the ease of site access. It has been estimated [3] that the cost of the water produced in Egypt will be about USD 1.5 per m^{-3} on the mountain. This includes all collector costs. The cost will be about USD 3 per m^{-3} delivered to a village 6 km away. The additional cost results from the construction of a pipeline, storage tank and small chlorination plant.

ENVIRONMENTAL CONSIDERATIONS

There are a number of environmental considerations that are important in choosing a site global wind patterns may result in a predominant wind direction, the altitude range of the clouds must be below the maximum terrain heights, a mountain range perpendicular to the prevailing winds and high enough to intercept the clouds is needed, in the case of coastal cloud decks, the mountain range should be within 5 or 10 km of the coast, the mountains or hills must have sufficient space for the fog collector array, there should be no major terrain obstacle upwind of the site, and, the microtopography on the ridge or mountain affects the fog collection rates; collectors are normally located on the crestlines of ridges or slightly upwind of the crestline. The efficiency of the collection process improves with larger fog droplets, higher wind speeds, and narrower collection fibres. In addition, a porous medium with good drainage characteristics is required.

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 determine the success of the site chosen. A number of the most important environmental factors that affect the volume of water that can be extracted from fogs and the frequency with which the water can be harvested will be briefly reviewed here.

• **Frequency of fog occurrence,** which is a function of atmospheric pressure and circulation, oceanic water temperature, and the presence of thermal inversions.

• **Fog water content,** which is a function of altitude, seasons and terrain features.

• **Design of fog water collection system,** which is a function of wind velocity and direction, topographic conditions, and the materials used in the construction of the fog collector.

The occurrence of fogs can be assessed from reports compiled by government meteorological agencies. To be successful, this technology should be located in regions where favorable climatic conditions exist. Since fogs/clouds are carried to the harvesting site by the wind, the interaction of the topography and the wind will be influential in determining the success of the site chosen. The following factors should be considered in selecting an appropriate site for fog harvesting:
Global Wind Patterns: Persistent winds from one direction are ideal for fog collection.
Topography: It is necessary to have sufficient topographic relief to intercept the fogs/clouds.

Relief in the surrounding areas: It is important that there be no major obstacle to the wind within a few kilometers upwind of the site. In arid coastal regions, the presence of an inland depression or basin that heats up during the day can be advantageous, as the localized low pressure area thus created can enhance the sea breeze and increase the wind speed at which marine cloud decks flow over the collection devices.

Altitude: The thickness of the stratocumulus clouds and the height of their bases will vary with location. A desirable working altitude is at two-thirds of the cloud thickness above the base. This portion of the cloud will normally have the highest liquid water content.

Orientation of the topographic features: It is important that the longitudinal axis of the mountain range, hills, or dune system be approximately perpendicular to the direction of the wind bringing the clouds from the ocean. The clouds will flow over the ridge lines and through passes, with the fog often -dissipating on the downwind side.

Distance from the coastline: There are 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 coastline is irrelevant. However, areas of high relief near the coastline are generally preferred sites for fog harvesting.

Space for collectors: Ridge lines and the upwind edges of flat-topped mountains are good fog harvesting sites. When long fog water collectors are used, they should be placed at intervals of about 4.0 m to allow the wind to blow around the collectors.

Crestline and upwind locations: Slightly lower-altitude upwind locations are acceptable, as are constant-altitude locations on a flat terrain. But locations behind a ridge or hill, especially where the wind is flowing downslope, should be avoided.
Prior to implementing a fog water harvesting program, a pilot-scale assessment of the collection system proposed for use and the water content of the fog at the proposed harvesting site should be undertaken.

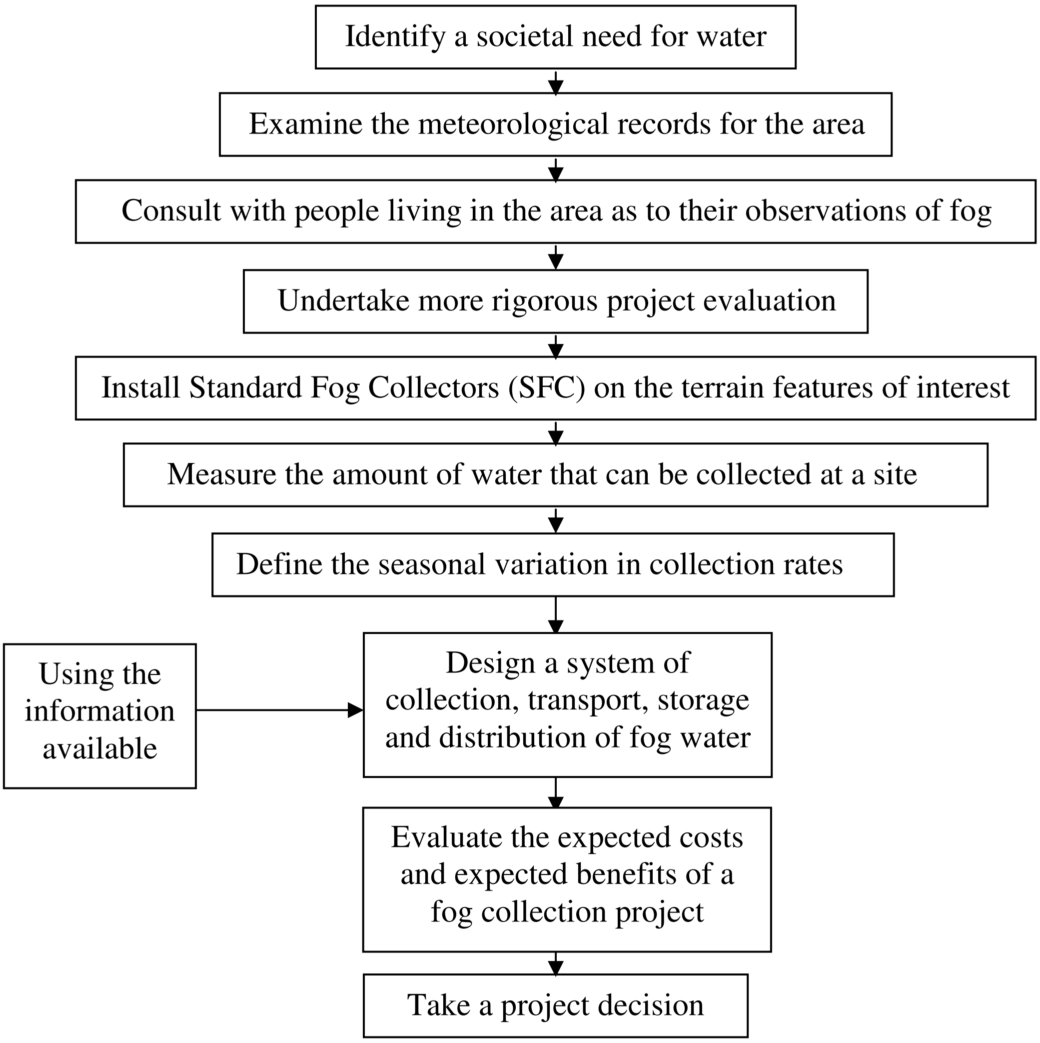

Figure 2. A logical process for the selection of a fog collection project

Cultural Acceptability

Fog collection technology has been accepted by communities in the mountainous areas of Chile and Peru. However, some skepticism has been expressed regarding its applicability to other regions. It remains a localized water supply option, dependent on local climatic conditions.

THE FOG COLLECTION PROJECT DECISION

The selection of a fog collection project follows a logical process. First, identify a societal need for water. There must be a community with a requirement for more water or cleaner water and conventional means are not able to meet the requirement In some cases, the water is not needed for domestic purposes but rather for agricultural or forestry applications. The next steps are as follows; to examine the meteorological records for the area; and, to consult with people living in the area as to their observations of fog on the mountains. Then a more rigorous evaluation project is undertaken. Small 1 m^2 fog collectors are installed on the, terrain features of interest. These Standard Fog Collectors (SFC) measure the amount of water that can be collected at a site and define the seasonal variation in collection rates. Finally, using the information available a system of collection, transport, storage and distribution of fog water is designed. The expected costs and expected benefits of a fog collection project are looked at before a decision is made to proceed. The process is somewhat akin to going into an area and deciding where and whether to drill a well for a community. A logical process for the selection of a fog collection project is shown in Figure 2.

SUSTAINABILITY AND CLIMATE CHANGE

The sustainability of a fog collection project depends on the persistence of the clouds that flow over the mountain where the site is located. Particularly in the case of coastal sites, these cloud decks are produced as a result of large-scale meteorological and oceanographic features, which one has reason to believe have been basically unchanged for thousands of years.

Changes in sea surface temperatures or temperatures in the atmosphere can change the height of cloud bases or influence somewhat the extent of the cloud decks but there is no evidence that major changes will take place in coastal regions. Small changes in cloud base height are unlikely to be a problem for fog collection projects because sites are chosen to be in the middle of the foggy region on the mountain slopes and because it is not a difficult task to relocate the collectors should that ever need to be done.

The lifetime of the mesh on the collectors is about ten years and the lifetime of the other materials about twenty years, so there are periodic opportunities to adjust the sites. It should also be noted that if there were concerns about fog water inputs being modified due to climate change, the primary concern should be directed towards coastal and upland forests in temperate and tropical regions, since they depend to a large extent on fog as a water input.

CONCLUSION

Fog collection is an innovative technology based on the fact that water can be collected from fogs under favorable climatic conditions. Fog collection by man-made collectors may be an unconventional source of water but it is not unproven. Applications exist in many countries where conventional methods cannot provide an adequate supply of water. It has been shown 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 fog water source is sustainable over periods of hundreds and likely thousands of years because the driving forces for the formation of the cloud decks are global in nature and will only change very slowly. The collectors themselves are simple, require no energy other than the wind and deliver their water by gravity flow. Water in the incoming fog and from the fog collectors can be expected to be of good quality. Fog collection will not be the total answer to Egypt's water shortages. However, it is an example of how Egypt can work with what nature gives us and of how developing and developed countries can pool their skills to initiate low-technology, sustainable water projects. Fog collection will complement other water supply systems not replace them. It is recommended that those working in upland areas give consideration to the measurement of the fog water availability in their area and to utilizing this water resource for the better management of the local environment.

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