FOG WATER TO QUENCH A DESERT'S THIRST

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By Robert S. SCHEMENAUER*

Introduction

The provision of adequate supplies of fresh water for human consumption and agricultural use is one of the major problems facing the world today. If underground aquifers can be tapped through a system of wells, this is probably the least expensive source; if sufficient seasonal rainfall occurs to justify building dams or cisterns for storage purposes, then this may be a desirable approach. But in some parts of the world there is neither potable groundwater nor enough rainfall to justify storage mechanisms. The northern Pacific coast of Chile is just such a region: annual rainfall varies from approximately 70 mm at La Serena (30°S) to 1 mm at Arica (19°S), with the Atacama Desert, perhaps the driest place on Earth, lying in between. Areas such as this uire innovative solutions to water supply problems.

Even in desertic regions with low humidity, a tremendous amount of water vapour passes overhead each day, but it is not possible to convert it into liquid water without enormous expenditure of energy and money. Areas with cloud cover are another matter. Clouds are composed of small liquid droplets; if the clouds are deep enough and if certain other conditions are met, cloud seeding may induce precipitation. But even if successful, such a project incurs the dual drawbacks of high cost and the need to prove that additional water was actually produced by seeding the clouds. An alternative technique to capture cloud droplets directly shows promise of providing large quantities of water at relatively low cost.

Fog-water deposition

It has been known for a very long time that shrubs and other types of vegetation intercept fog droplets and deposit the water on the ground through a process known as 'fog-drip'. Kerfoot (1968) has summarized some early observations of fog-water productivity. More recently, Schemenauer (1986) looked at measured rates of fog-water deposition. Low-elevation surface-generated fogs usually have low liquid-water content (LWC) and thus relatively low deposition rates. At higher altitudes,

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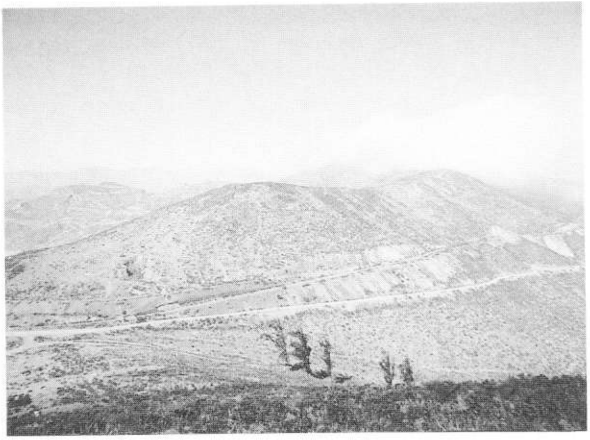
clouds move over the terrain producing fogs. These high-level fogs have a greater LWC, and, since the winds are usually stronger than at lower levels, deposition of water is much greater. The actual amount of fog-drip depends upon the type, duration and LWC of the fog and on the vegetation cover and wind speed. In areas with no significant precipitation, fog-drip rates of one to ten centimetres per month can have a marked impact on the ecosystem; for instance, the coastal desert of Namibia exhibits many examples of plants that rely for water on fogs moving inland from the Atlantic Ocean. The question of whether fogs can be used as a managed water supply needs to be addressed, and a project to investigate the feasibility and cost of using fogs on a large scale for this purpose is currently under way in Chile.



View south over El Tofo ridge with stratocumulus arriving from the sea

Photos: R. S. Schemenauer

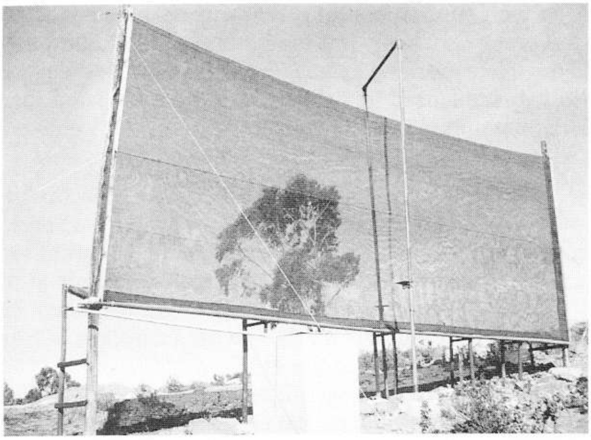
The Camanchaca Project

In the north of Chile, mountains rise rapidly from the sea. Altitudes of 1000 m or more are commonly found within five to ten kilometres of the coast. These coastal mountains are high enough to intercept the stratocumulus layers that form over the Pacific Ocean and move inland, and the resulting high-level fog is called the *camanchaca*. Schemenauer *et al.* (1988) discuss in detail the meteorological conditions leading to the formation of the camanchaca as well as earlier studies on its potential in water production. The main site of the Project is at 780 m on a ridge called El Tofo, situated at 29°26'S, 71°15'W. Small valleys separate the ridge from higher mountains to the north and south.

The Camanchaca Project has been designed to study the meteorological, topographical and microphysical conditions associated with the formation and presence of the camanchaca. A massive array of mesh *atrapanieblas* or fog-water collectors has also been constructed, and the cost of producing water by this technique will be determined. Previous projects in the area were rather small and of short duration, not permitting costs to be assessed.

The major source of funds for the Camanchaca Project is the International Development Research Centre in Ottawa (Canada). Additional research support in terms of staff and infrastructure comes from the Geophysics Department of the University of Chile, the Geography Department of the Pontifical Catholic University of Chile and the Canadian Atmospheric Environment Service. Construction work at El Tofo is supervised by the National Forestry Corporation of Chile's Region IV.

Initial funding is for the period April 1987 to March 1989, and by the mid-point of that period two meteorological stations had been set up to provide a continuous record of conditions on the mountain. In addition, fifty fog-water collectors, each 48 m^2 in area, were in place on El Tofo and their output of water conducted through pipes to flow meters. A two-week intensive observation period took place in November 1987 when an instrumented aircraft, a boat, radiosondes and microphysics probes were used to study the lower atmosphere, sea-surface temperatures and properties of the camanchaca. A second such observing period is planned for November 1988, by which time construction will have started of a pipeline to lead the water six kilometres down to the village of Chungungo on the coast.


A 4 x 12 m fog-water collector with flow meter housing and support for instruments to measure droplet size and numbers

The fog-water collectors

The fog-water collector consists of a double layer of nylon mesh four metres high by twelve metres long, supported by cables strung between two posts of eucalyptus wood. The mesh is inexpensive and made in Chile; the woven fibre is flat and about one millimetre wide. The small fog droplets impact on the mesh and accumulate to form drops that run down the mesh into a trough. Modifications are currently being made to the design in order to ensure that all the water collected flows into the trough and ultimately through the flow meter into a reservoir. The flow meter measures continuously the flow of water and the measurements are stored as five-minute averages on the same data-logger that records the meteorological data.

Schemenauer and Joe (1988) have examined the collection efficiency of the fog-water collectors. With a wind speed of 6.5 ms^{-1} at the centre of the collector, 69 per cent of the total fog LWC was removed by the double layer of mesh, but in the droplet size range 9-13 μm (the mode of the LWC distribution), this proportion rose to 82 per cent. These collection efficiencies are sufficiently high to suggest that a search for other more efficient meshes is probably unnecessary. However, the collection efficiency as a function of wind speed and position on the screen will be examined more thoroughly during the second intensive field experiment.

Role of topography and meteorology

The relief in the vicinity of the site at El Tofo is very irregular. The wind speed and the profile of wind speed above ground vary considerably over the terrain. The upwind slope of the ridge generally has fog on it, whereas the downwind slope is often clear since the fog evaporates in the subsiding air. But the situation is complicated by the fact that the cloud layer is confined below a strong trade-wind inversion that is nearly always present. The top of the cloud layer can vary from around 500 m to 1000 m, with 800-900 m being the most common level. It is therefore important to study how the fog-water collection rate varies over the terrain at a particular site in different meteorological regimes.

An overview of the early meteorological measurements at the site was given in Schemenauer *et al.* (1988), whilst Fuenzalida *et al.* (1988) review measurements made during the November 1987 field experiment. The wind regime is dominated by the sea breeze (westerly) during the daytime and the land breeze (easterly) at night. Afternoon winds are strong, reaching peak values of 6-10 ms^{-1}, whereas the nocturnal land breeze is usually less than 2 ms^{-1}. Maximum water collection periods were found to be in late morning and again in late afternoon/early evening; the rate of collection is strongly influenced by the height of the trade-wind inversion, and this is controlled by synoptic- and mesoscale weather features. It is only when the base of the inversion is above the site that fog can reach the collectors.

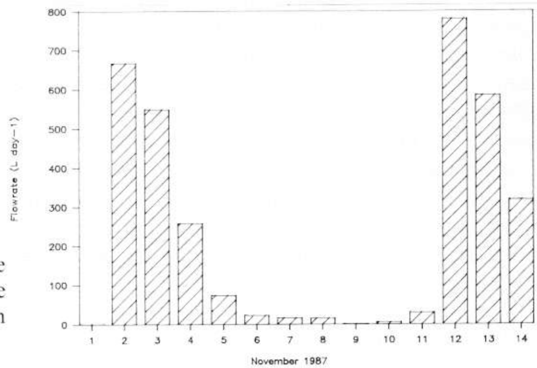
The role of topography in the deposition of fog water is studied by means of arrays of small collectors (50 cm^2) deployed over the terrain (Schemenauer *et al.* (1987)). Schemenauer and Cereceda (1988) and Cereceda *et al.* (1988) looked at the relative rates of collection for 20 small collectors at altitudes of between 700 m and 1000 m during the November 1987 field experiment. They found that collection rates varied from 0.3 to 4.7 $lm^{-2}d^{-1}$, with a mean of 1.7 $lm^{-2}d^{-1}$. Highest collection rates were found to be on saddles at 700 m, followed by El Tofo ridge at 800 m. Collection rates were low to the east of the ridge and at the highest elevations (1000 m). At a constant height of 800 m, the collection rate could vary by a factor of three depending upon the orientation of the slope. This indicates clearly that there must be a site-specific investigation in order to locate the fog-water collectors in the optimum positions.

Water production and costs

The mean daily flow rate from the prototype 48-m^2 fog-water collector on El Tofo during the 14 days of the 1987 field experiment was 237 litres per day. The accompanying diagram shows the individual daily values, from which it will be seen that almost all the water was produced during two three-day periods. The average rate of production over the whole 14-day period would therefore be about 5 $lm^{-2}d^{-1}$.

On that basis, 50 fog-water collectors would yield 12 000 litres per day, or 4380 cubic metres per annum (a full year's measurements should be available at the end of November 1988 to check that estimate). The population of Chungungo is 450, so that the above assumptions would allow each person approximately 27 litres of water per day. That is about eight times the amount of water that the villagers currently purchase from a mobile water tanker.

The cost of the water produced in the Camanchaca Project will also depend upon some other assumptions. Let us assume that the fog-water collectors will have to be replaced after five years and the pipeline after ten years: then the cost of water delivered to a reservoir on El Tofo ridge would be approximately $US 1 per cubic metre, and $US 2 per cubic metre delivered to the village six kilometres away. The cost would be somewhat lower if the materials last longer, or if more fog-water collectors were added to the system since the same pipeline could carry more water. At present, the villagers are paying $US 2 per cubic metre for poor quality water collected from a small river about 60 km away, but the real cost is around $US 8 since delivery is subsidized by the municipality. For the sake of comparison, according to a recent newspaper report, States on the western shores of the Persian Gulf are considering piping fresh water from two Turkish rivers at an estimated cost of $US 11 per cubic metre. Water usage in the Gulf region is currently about 380 litres per person per day, most being for agricultural purposes. At the opposite end of the price scale is Toronto (Canada) where water is obtained from Lake Ontario at a cost of $US 0.47 per cubic metre.



Daily flow rates (litres per day) from one 48 m^2 fog-water collector during the intensive observation period in November 1987

If the final cost of camanchaca water delivered to Chungungo is $US 2 per cubic metre, it will be very reasonably priced for the region. It will also be a cleaner, more plentiful and more reliable source than at present. Initial analysis of the quality of the water does not suggest there will be any problem in meeting drinking water standards. However, it must be emphasized that this does not mean that water can be produced and delivered at such prices everywhere that fogs occur. The final cost would depend upon the frequency and LWC of the fog, the cost of materials and labour, accessibility, distance to be piped and so forth. Each potential site or cluster of sites must be carefully examined before any major operational programme can begin.

Conclusion

The Camanchaca Project uses high-technology instrumentation and scientifically qualified people for evaluating the potential of a field site, with the goal of leaving a low-technology water-production system in place. The fog-water collectors, the pipeline and pressure-relief stations on the mountain will need virtually no maintenance unless repairs are needed due to vandalism. The system can be operated and maintained by villagers with little or no formal education. Should it prove necessary to chemically treat the water in a reservoir or to rebuild fog-water collectors after five or ten years, then some training may be required for those who do that work.

Fog water need not be restricted for use as a drinking water supply and for watering gardens, cooking and sanitary purposes. One of the most direct applications is for the afforestation of the hills. In many semi-arid lands certain species of tree will grow if provided with a minimum of moisture, and they will then stabilize dunes, prevent erosion, provide fruit to eat and shade for livestock, and so forth. El Tofo is an excellent example of what can be done. Nowhere on the surrounding mountains do trees grow naturally, but about 50 years ago the miners decided they needed some for shade and planted some eucalyptus seedlings, using water from the mine to irrigate them. When the trees had grown to a height of about two metres their leaves started collecting water droplets from the camanchaca, these coalesced into larger drops and fell to the ground which was moistened sufficiently to continue to nourish the trees without artificial irrigation. The eucalyptus are now ten metres tall and the small forest is regenerating itself. This process is being duplicated in the Camanchaca Project which is producing water for three hectares of tree seedlings on El Tofo. Thus the potential exists even with small fog-water collectors to markedly improve the productivity of desertic terrain.

In areas with few conventional sources of water, high-level fogs may provide at least a partial solution. Low-level fogs, generated over the land or sea, may also be a useful source, depending upon their frequency and LWC. The western coasts of continents seem to be regions where conditions of arid lands, fog, relief and lack of other water supplies are most often found; northern Chile, southern Peru or parts of Mexico are good examples (California has the aridity, the fog and a suitable terrain, but it has access to other sources of water). Namibia and Angola, as well as some islands off the west coast of Africa, might be suitable regions to apply the techniques described above. It should be possible for the international community to support well documented proposals for research and operational programmes. With the growing concern about the scarcity of fresh water supplies, every potential source needs to be explored.

Acknowledgements

The Camanchaca Project is a co-operative effort and the result of the work of many people. Major scientific contributions have been made by Professor Humberto Fuenzalida and the staff and students of the Department of Geology and Geophysics of the University of Chile, and by Professor Pilar Cereceda and the staff and students of the Institute of Geography of the Pontifical Catholic University of Chile. Mr Guido Soto and staff of the Region IV Office of the Chilean National Forestry Corporation have directed the engineering and technical aspects of the fog-water collector arrays. The International Development Research Centre in Ottawa has provided most of the funds for the Project, and the efforts of Dr Danilo Anton and Mr Robert Rowe of the Centre are greatly appreciated. The skill and dedication of the technical staff of the Atmospheric Environment Service of Environment Canada, especially Mohammed Wasey, Steve Bacic and Richard Poersch, contributed significantly to the success of the Project.

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