122901

Sixth IWRA World Water Congress
on Water Resources
Ottawa, Canada
May 29 - June 3, 1988

# The Collection of Fog Water in Chile for Use in Coastal Villages

Dr. Schemenauer, R.S., Environment Canada
Prof. Cereceda, P., Pontificia Universidad Católica de Chile
Instituto de Geografía
Pontificia Universidad Católica de Chile
Casilla 114-D
Santiago, Chile

## ABSTRACT

In many arid parts of the world there is insufficient rainfall, surface water and ground water to support significant human settlement. However, the right combination of marine stratocumulus cloud decks and coastal mountains may provide the conditions where additional water can be obtained. An ongoing field experiment, with yearly intensive observation periods, is underway on the north central coast of Chile to determine the water availability from the camanchaca (high elevation fog) and the meteorological conditions important for its formation.

The fog water collectors being used each consist of a 40 $m^2$ double layer of nylon mesh. The mesh is mounted on two eucalyptus posts a maximum of 6 m above ground. The field site for the intensive studies is at El Tofo at an altitude of 780 m. The flowrate for the first 14 days of November 1987, from one 40 $m^2$ collector, averaged 237 L $d^{-1}$, or 6 L $m^{-2}d^{-1}$. Measurements on the surrounding terrain from 680 m to 1000 m showed that the collection rate varied by a factor of 15. This demonstrates the critical role that topography and meteorology play in choosing the optimum sampling location. With proper site selection, it appears that the camanchaca can provide an economical water supply for small coastal villages.

## INTRODUCTION

Throughout the world the lack of fresh water for human consumption, agricultural purposes and a variety of industrial uses is increasingly becoming a problem. Shortages arise in highly developed countries (e.g. the southwestern United States) as well as in areas lacking the resources to attempt costly remedies for the lack of water (e.g. north central Africa). Shortages arise because of over utilization of existing ground water or because of a lack of replenishment of surface and ground water due to short or long term decreases in precipitation. Traditional solutions to the problem have been to better utilize surface runoff with dams, to alter cropping practices, to consider limiting or moving populations and to initiate rainfall or snowpack augmentation programs. There are many reasons why these solutions may not be practical in a particular location and as a result new ideas tailored to a particular locale should be pursued.

In the northern third of Chile, and in Peru, the weather is dominated by the Pacific anticyclone throughout the year. This produces a light southwesterly onshore flow in the lower kilometer of the atmosphere and results in a stratus or stratocumulus cloud deck that extends a few hundred kilometers out over the ocean. Fog events are frequent at altitudes between 500 and 1000 m in the coastal mountains (these high altitude fog events are called camanchacas) where the terrain intercepts the low clouds. Where there is vegetation in this zone it can intercept some fog water and the fog drip can sustain the plant. The importance of fogs as sources of water in certain locations has been recognized for a considerable time. Kerfoot (1968) and more recently Schemenauer (1986) have reviewed the literature pertaining to deposition rates of water from fogs. This paper will deal with the topographical factors relevant to the formation of the camanchaca and the collection of water from it. It will also present some recent data from field experiments in Chile.

## THE CAMANCHACA PROJECT

The International Development Research Centre (IDRC, a Canadian government agency) and the participating research groups in Chile are funding a field research program for a minimum of two years. There are five organizations involved in the planning and field activities of this project. They are the Departmento de Geologia y Geofisica of the Universidad de Chile, the Instituto de Geografia from the Pontificia Universidad Católica de Chile, the Corporation Nacional Forestal (CONAF), the Secretaria Regional de Planificacion y Coordinacion (SERPLAC) and the Atmospheric Environment Service (AES) of Environment Canada. The Camanchaca Project has six major objectives concerned with understanding the camanchaca and the piping of water to a village. Preliminary data dealing with two of these objectives will be presented here. These two are:

i) To identify the optimum fog water collector location, orientation and height at El Tofo in order to define site selection criteria for other coastal regions.

ii) To make a preliminary study of other sites in northern Chile.

## THE NORTHERN COAST OF CHILE

The study area extends for 1600 km along the northern coast of Chile from latitude 17° 30' S to 32°S. The majority of the field work to date has been done in the southern part of the area, in particular at the El Tofo ridge site (780 m, 29° 26'S, 71° 15'W) and the nearby (6 km) coastal village of Chungungo. Schemenauer et al. (1987) describe the small collectors (neblinómetros) used to measure the amount of fog water deposition. Networks of neblinómetros, Fig. 1, are being used to determine the optimum locations for the large collectors (atrapanieblas).

The precipitation in the area increases from less than 2 mm $y^{-1}$ in the north to 100 mm $y^{-1}$ in the south. In the north the coastal plain is narrow, or non-existent, and a 1000 m cliff parallels the coast. As well, a broad mountain range reaches altitudes of 2000 m. In the south, the plains are wide, the cliffs are rarely found and mountains are 1000 m high. There are only 7 rivers in this 1600 km stretch of coast with a permanent flow of water. Other intermittent rivers provide some sources of underground water. The landscape ranges from true desert in the north to semidesert in the southern part of the area.

A major problem along the northern coast of Chile is an adequate supply of water. For the city of Antofagasta (200,000 pop.), water is delivered from the Andes through a pipeline 360 km long. An expensive solution such as this is not possible for the small fishing and mining villages and thus the resources of the region are often not exploited. Water rationing often occurs in the cities but the real problems occur in the villages. Because water delivery is by truck the delivery is irregular at the best of times and proper sanitary precautions are sometimes not taken.

## TOPOGRAPHICAL INFLUENCES ON FOG WATER COLLECTION

Although the camanchaca is generally present along the northern coast of Chile, its exact location is controlled by the physiography of the coast. Some conclusions in this regard have been presented in Carvajal (1982), Larrain and Cereceda (1982, 1983), Cereceda (1983) and Schemenauer et al. (1987). On the regional scale there are 4 aspects of relief that are important. First, there must be a mountain range with an average altitude of 500 m or more. This will be high enough to control the boundary layer flow and to intercept the camanchaca. Second, the principal axis of the range should be perpendicular to the predominant wind direction (southwest) at the altitude of the camanchaca. Third, the preferred site location is on a mountain range close to the coast. This minimizes the loss of cloud water due to evaporation before the clouds reach the site. Fourth, the presence, to the east of the mountain range, of a broad basin that produces an ascending region of warm air due to high daytime heating (thermal low). This serves to suck the oceanic air through the coastal mountains.

Fig. 1. Neblinómetro (left center) mounted on El Tofo to measure the fog water deposition rate.

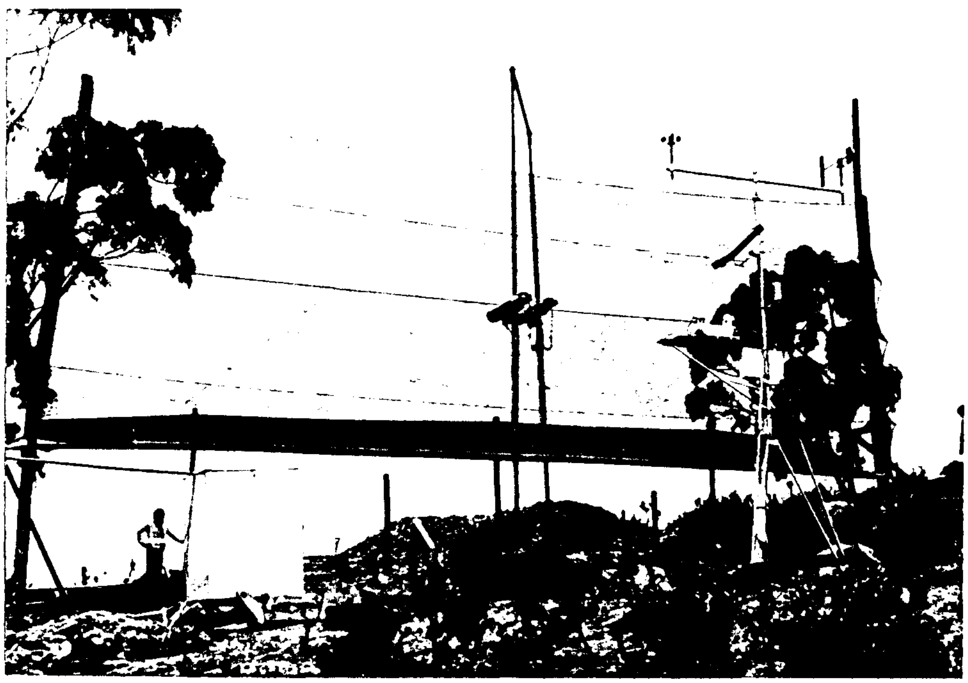

Fig. 2. Atrapaniebla (40 $m^2$ fog water collector) on El Tofo plus a meteorological station and droplet measuring equipment.

### The Atacama Region

The Atacama Region (26°S - 29°S) was studied in 1987. Six different macro scale areas were identified from satellite and cartographic studies. A detailed analysis of each area yielded 60 small areas with potential for the capture of fog water.

A parallel study of rural settlements using census data and field trips was also carried out. In the 7,500 $km^2$ (300 km x 25 km) coastal zone 6,250 people live. Of these, 5259 live in 4 towns each with more than 500 inhabitants, the rest live in 41 smaller settlements. The larger towns use river water; the smaller ones use well and spring water that is usually trucked in.

Four representative small settlements were chosen as sites for neblinometros. The initial data (May-Oct., 1987) from 2 of them are shown in Table 1. The collectors were placed at similar altitudes and oriented to the southwest on a slope facing the sea. Obispo

Table 1. Average fog water collection at two sites.

| Site | Latitude | Altitude (m) | Collection ($L\ m^{-2}\ d^{-1}$) |
|---|---|---|---|
| Obispo | 26°30'S | 600 | 0.41 |
| Obispo | 26°30'S | 800 | 0.74 |
| Las Bombas | 26°05'S | 600 | 1.08 |
| Las Bombas | 26°05'S | 700 | 0.61 |

is 3 km from the sea, Las Bombas is 25 km. The values in Table 1 are averages of monthly averages and show a range of values from 0.4 to 1.1 $L\ m^{-2}d^{-1}$ at the 4 sampling locations. The translation of these data into water obtainable from large collectors will be discussed below. The consistency of the cloud cover at the Obispo site over the period is shown in Table 2. The average percentage of days with

Table 2. Monthly cloud coverage at the Obispo site.

| Month 1987 | Total obs. (days) | In cloud (days) | Occasional Cloud (days) | Clear (days) |
|---|---|---|---|---|
| June | 18 | 12 | 2 | 4 |
| July | 31 | 17 | 4 | 10 |
| August | 31 | 24 | 2 | 5 |
| September | 30 | 13 | 10 | 7 |
| October | 30 | 21 | 4 | 5 |
| Total | 140 | 87 | 22 | 31 |
| % | 100 | 62.1 | 15.7 | 22.1 |

some fog on the mountain is 77.8%. The data are obtained from observations taken 2 h before sunset each day by an observer on the coast.

### The El Tofo Site

The intensive field site for the Camanchaca Project is centered on El Tofo in the Coquimbo Region. It is a mountain range 6 km long that forms a crescent facing the sea. It consists of a small plateau at 800 m with summits of 1000 m on either side (see sketch, Schemenauer et al. 1987). Two saddle points separate the plateau from the summits. Instrument installations on the plateau are shown in Figs. 1 and 2.

A set of 30 neblinómetros were installed at El Tofo in late October 1987. They were installed at 100 m intervals on the hillsides from 700 m to 1000 m and were read twice a day. At some elevations a series of collectors were installed with different exposures. As well as fog water deposition, measurements were made of temperature, relative humidity, wind direction, terrain slope and vegetation type and cover.

Measurements from 20 of the collectors have been analyzed at this time. The average flowrate was 1.7 L $m^{-2}$ $d^{-1}$ with a range of 0.3 to 4.7 L $m^{-2}$ $d^{-1}$. Of the 5 highest collection locations, 4 were located on the plateau, and one is in a minor saddle point. The plateau itself is in the major saddle point formed between Cordon Las Carmelitas to the north and Cordon Sarcos to the south. Larrain and Cereceda (1982) discuss saddle points as preferred collection locations. Schemenauer et al. (1987, 1988) discuss how the marine stratocumulus is capped by the trade wind inversion and is blown by the daytime sea breeze towards the warm interior of the continent. Its natural path is to pass through the lowest parts of the coastal mountains, the saddle points.

The data set at El Tofo is still too small to draw definitive conclusions regarding the optimum altitude for collection and optimum slopes on which to site the collectors. Table 3 illustrates the possible size of the effect due to choosing slopes with different orientations on a mountain which is perpendicular to the prevailing southwest winds. The fog water collection at a constant altitude

Table 3. Effects of site exposure on fog water collection.

| Altitude (m) | Average Collection Rate (L $m^{-2}$ $d^{-1}$) West | Southwest | East |
|---|---|---|---|
| 800 | 1.9 | 1.5 | 0.7 |

varied by almost a factor of 3 over the 15 day period.

## POTENTIAL WATER PRODUCTION

### Current Water Use In Chungungo

Chungungo is a small fishing village of 450 people 60 km from a major city. It is very isolated because of bad roads, has no secure water supply and electricity from a diesel generator only 3 hours a day. Presently a truck delivers an average of 10,000 L of water a week to the village. The water comes from a point on the Los Choros river about 60 km away. This means of supply is often uncertain and the people have to make use of nearby spring water of very poor quality. Avera water usage in Chungungo is 3.2 L $d^{-1}$ per person but it can

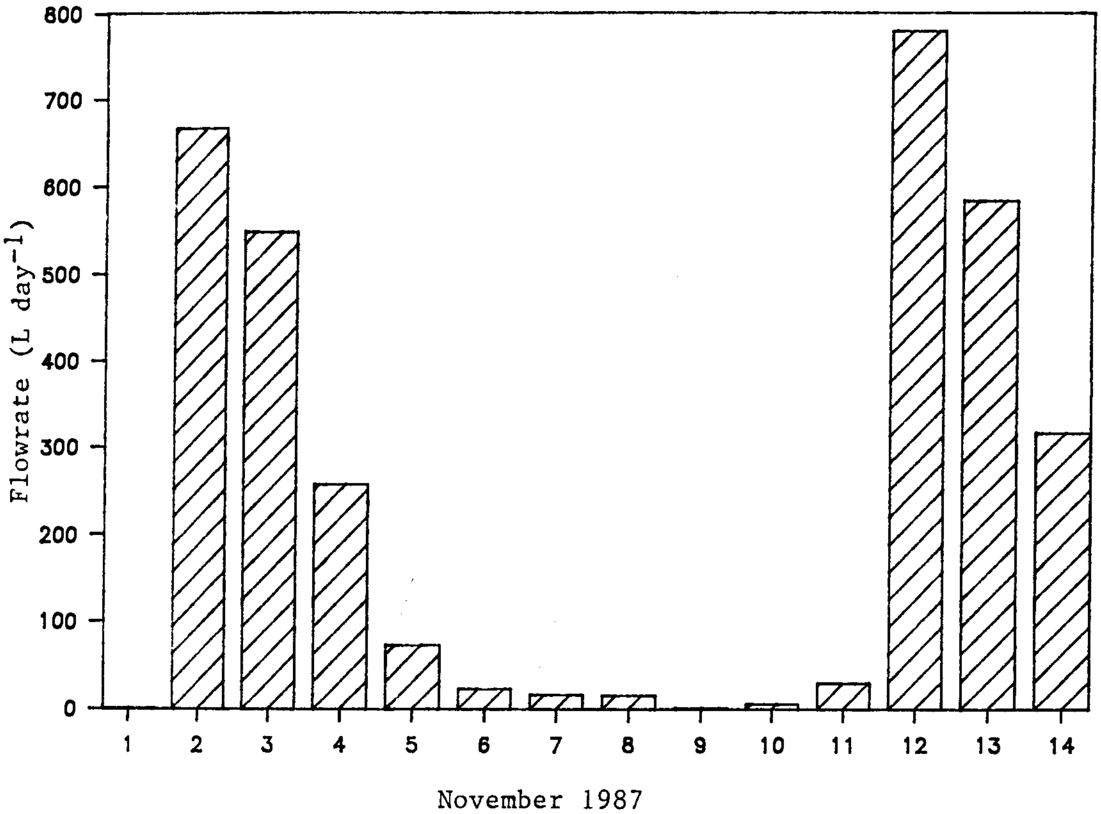


Fig. 3. Mean daily flowrate from atrapaniebla #1 on El Tofo for the first 14 days of November 1987.

be as high as 57 L d$^{-1}$ per person for the wealthier families. Cost is a definite factor in keeping the water consumption so low. The people pay \$2.00 U.S. m$^{-3}$ (\$0.02 L$^{-1}$) for water from the truck. But the water delivery is already subsidized by the municipality and the true cost is ≈ \$8.00 U.S. m$^{-3}$ (\$0.08 L$^{-1}$).

Water from the Atrapanieblas

The prototype atrapanieblas (Fig. 2) consist of 40 m$^2$ of a double layer of a locally available nylon mesh. Soto and Elicer (1985) report average flow rates of 10 L m$^{-2}$ d$^{-1}$ for similar collectors for a two month period on El Tofo. If one applies this to the 60 collectors presently being constructed and assumes they are in fog almost daily for 6 months of the year and about one-half of the time for the other six months (Miller, 1976), the total amount of water collected would be 40 L d$^{-1}$ for each of the 450 people in Chungungo. The cost of this water is estimated in Schemenauer et al. (1988) to be \$1.00 to \$2.00 U.S. m$^{-3}$ depending on the assumptions made.

The atrapaniebla used on the plateau during the intensive field program in November 1987 is a much improved version of the one studied by Soto and Elicer (1985). The daily averages of the water produced by one atrapaniebla are shown in Fig. 3 for the first 14 days of November. The average for the period was 237 L $d^{-1}$ or $\approx$ 6 L $m^{-2}$ $d^{-1}$. Sixty collectors (under construction) operating for the 14 day period would have produced 199,000 L, enough for the village for almost 140 days at current rates of consumption. An alternative way to look at the production is that $\approx$ 32 L $d^{-1}$ per person would have been produced by 60 collectors. This is 10 times the current water consumption in Chungungo. The cost of the water will depend on the final construction costs and the productivity of the system over a period of years. But the cost is likely to be in the \$1.00 to \$2.00 U.S. $m^{-3}$ range, considerably less than the current $\approx$ \$8.00 U.S. $m^{-3}$. In fact the water will be provided at negligible cost to the people of Chungungo. The construction costs were paid by IDRC and the maintenance costs for the atrapanieblas and pipes should be almost non-existent. The cost of the water could be reduced further by adding more atrapanieblas since the pipes to the village will be able to handle a larger flow than will initially be produced.

Optimizing the Site Location

As we saw in Table 1, the exact location of the collectors can significantly influence the amount of water produced. The terrain effects are being examined using neblinómetros with a single layer of

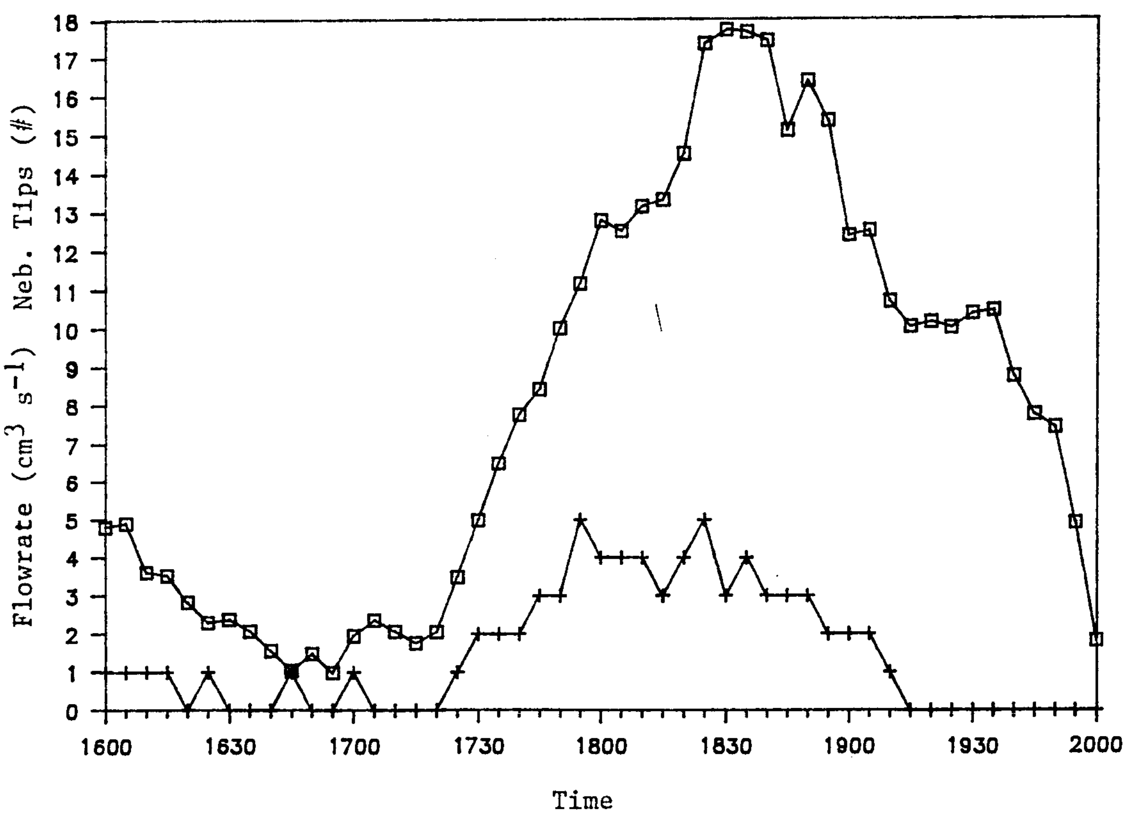


Fig. 4. Comparison of atrapaniebla flowrates (squares) to neblinómetro output (crosses).

nylon mesh. They are 0.25 $m^2$ in size and are mounted 1.5 m above the ground. The atrapanieblas are 40 $m^2$ in size and the mesh is typically stretched from 2 to 6 m above the ground.

In Fig. 4 the outputs from a co-located neblinometro and atrapaniebla are compared. The data points are 5 min averages for a 4 h period on 13 November 1987. Allowing for the different response times of the two collectors, the agreement in describing the fog conditions appears good. The actual average flowrate from the atrapaniebla for the 4 h period was 0.2 $cm^3s^{-1}m^{-2}$. The average flowrate from the neblinometro was 0.07 $cm^3s^{-1}m^{-2}$. A difference would be expected between the two collectors for a number of reasons but the data in Fig. 4 certainly demonstrate the utility of small inexpensive collectors for determining the optimum sites for large collector arrays. Presumably a larger data set will allow a calibration ratio to be determined, such as the 2.9 for the above data, which will enable the neblinometro data to be adjusted to represent a probable atrapaniebla collection at the site.

## CONCLUSIONS

Networks of small (0.25 $m^2$) neblinometros have been shown to be useful in determining the fog water deposition rates on the coast of Chile. They are also showing the importance of topography in choosing the optimum collection sites. Large (40 $m^2$) atrapanieblas seem capable of producing 5 to 10 L $m^{-2}$ $d^{-1}$ for periods of weeks or months. The ultimate water production potential of the atrapanieblas will not be known until the present multi-year field experiment is completed.

The current field work suggests that the camanchaca may provide a significant new source of water for the arid north of Chile. Initial observations confirm high percentages of cloud cover on the coastal mountains. A large number of mesh collectors located on the coastal mountains near small villages can potentially increase the current meagre water supply tenfold. This has important implications not only for improving the quality of village life and beginning agricultural production in the desert but also for reversing the migration to the cities and for the reforestation of the hillsides.

The direct collection of fog water for use as a water supply has applicability beyond the west coast of South America. Other continental margins and some island locations with little rainfall could benefit in a major way from the application of this technology.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of IDRC for the field work at El Tofo. We would like to thank Humberto Fuenzalida and staff of the Universidad de Chile for their scientific involvement in the Camanchaca Project and Guido Soto and staff of CONAF for the construction of the atrapaniebla. Our special thanks to 4 assistants of the Pontificia Universidad Catolica de Chile, Juan Sebastián Barros, Alejandra Silva, Gonzalo Frigerio and Marcela Suit as well as to the students of the Taller de Geografia Course 2610. The work of Mohammed Wasey, Steve Bacic and Richard Poersch of AES was invaluable in the production of the data presented here and is gratefully acknowledged.

## REFERENCES

Carvajal, N.H. (1982). Antecedentes Generals, Observacion y Cuentificacion de las Neblinas, Sector Temblador IV Region, Chile. Memoria para optar al Titulo de Geografo, Pontificia Universidad Católica de Chile, Instituto de Geografía, 78 pp.

Cereceda, P. (1983). Factores Geograficos que Determinan el Comportamiento Espacial y Temporal de la Camanchaca, Informe Final. Direccion de Investigacion de la Pontificia Universidad Católica de Chile, Santiago, Chile, 121 pp.

Kerfoot, O. (1968). Mist precipitation on vegetation. For. Abstr., 29, 8-20.

Larrain, H. and Cerceda, P. (1982). Camanchaca, Recurso Hidrico Postergado. en Revista Universitaria No. 7, Pontificia Universidad Católica de Chile, Santiago, Chile, 115-127.

Larrain, H. and Cereceda, P. (1983). Aprovechamiento de la Camanchaca, IV Region, Chile. Informe Final para la Intendencia Regional de Coquimbo, Chile, 155 pp.

Miller, A. (1976). The Climate of Chile. Chapter 3 in, World Survey of Climatology, vol. 12, Climates of Central and South America, ed. Werner Schwerdtfeger, Elsevier Sci. Publ. Co.

Schemenauer, R.S. (1986). Acidic deposition to forests: the 1985 Chemistry of High Elevation Fog (CHEF) project. Atmosphere-Ocean, 24, 303-328.

Schemenauer, R.S., Cereceda, P. and Carvajal, N. (1987). Measurements of fog water deposition and their relationships to terrain features. J. Clim. Appl. Meteor., 26, 1285-1291.

Schemenauer, R.S., Fuenzalida, H. and Cereceda, P. (1988). A neglected water resource: the camanchaca of South America. Bull. Amer. Meteor. Soc., 69, xx-xx.

Soto, G. and Elicer, L.R. (1985). Proyecto Abastecimiento de Agua de Camanchaca a Caleta Chungungo. CONAF IV Region, Informe Interno, La Serena, 5 pp.