The Potential for the Use of Fog as a Water Resource on the Coast near Lima, Peru

by

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PROLOGO

Como resultado del éxito obtenido en un proyecto sobre captación de agua de niebla para abastecer un pueblo costero en Chile, el Dr. Robert S. Schemenauer del Atmospheric Environment Service del gobierno de Canadá y la profesora Pilar Cereceda de la Pontificia Universidad Católica de Chile, iniciaron investigaciones en el sultanato de Omán y últimamente en Perú.

En febrero de 1989, el Dr. Schemenauer y la profesora Cereceda visitaron Perú con los siguientes fines: sostener conversaciones con diversas instituciones que pudieran tener interés en desarrollar investigaciones sobre el tema; conocer los resultados obtenidos en investigaciones y estudios realizados en el país con anterioridad; y, recorrer la costa para obtener una impresión preliminar sobre el potencial de captación de agua de niebla en el litoral entre las ciudad de Huacho y la península de Paracas.

Un año después, presentaron una propuesta de investigación a ACDI, Agencia Canadiense para el Desarrollo Internacional; esta propuesta fue aceptada por la Oficina de Coordinación de Lima para ser implementada durante el segundo semestre de 1990.

Para llevar a cabo el trabajo de terreno y para adquirir los instrumentos necesarios, los cuales quedaron en manos de la institución cooperante, SENAMHI, se hizo un contrato para la señorita Marcela Suit.

En junio de 1990, Schemenauer y Cereceda estuvieron un período de tiempo en Lima, seleccionando los lugares de experimentación y realizando la planificación y organización del trabajo de toma de datos. En esta etapa la colaboración de la Embajada de Canadá fue de vital importancia para la implementación del proyecto. Durante Julio, Marcela Suit construyó e instaló los instrumentos en los tres sitios de experimentación. Las mediciones se realizaron desde agosto hasta diciembre de ese año.

Los resultados del trabajo de Marcela Suit son descritos en su informe final que fue entregado a la Oficina de Coordinación en enero de 1991. Por su parte, el Dr. Schemenauer y la profesora Cereceda entregarán su interpretación de los resultados y las recomendaciones para el desarrollo de proyectos sobre el uso de agua de neblina como recurso para actividades domésticas, agrícolas y forestales.

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Introduction

There exists a large number of countries in the world where one might consider using high elevation coastal fogs as a water resource (Schemenauer and Cereceda, 1991a) but the most promising locations at present are on the west coast of South America. Cereceda and Schemenauer (1991) have shown that one must design special observation programs to evaluate the frequency of these high elevation fogs and that one cannot rely on the standard meteorological data. The work on fog water collection is most advanced in Chile and the background has been described by Schemenauer et al. (1988) and some of the results from a large fog collector array by Fuenzalida et al. (1989).

In February 1990 a proposal was submitted to the Canadian International Development Agency (CIDA) in Ottawa by Dr. Schemenauer (Canada) and Professor Cereceda (Chile) to evaluate the fog water collection potential on the coast of Peru. Some early work in the 1980s had indicated that there was water available in the fogs but a rigorous program using techniques consistent with those already employed in Chile and The Sultanate of Oman was essential. As a result of the proposal to CIDA, a contract was issued to a Chilean geographer (Marcela Suit) to carry out the field work under the direction of Cereceda and Schemenauer (C & S). C & S arranged for the purchase and shipping of the necessary meteorological and computer equipment and it was expedited through Peruvian customs by Coronel Maguiña, the head of SENAMHI, the cooperating agency in Peru (Servicio Nacional de Meteorología e Hidrología). In June 1990 C & S visited Peru to choose the field site, to specify the design of the project and to detail the equipment to be utilized in the field. In addition to the main site at Cerro Orara, 35 km north of the center of Lima, subsidiary sites were chosen at Pasamayo and Santa Rosa near Orara and Villa María del Triunfo on the south edge of Lima. In July, Suit prepared the specifications for the standard fog collectors and had them constructed. She installed these and other necessary instrumentation at the field site and began routine measurements at the end of July.

The results of the 1990 field measurements are described in detail in a separate report by Suit (1991). An assessment of these results is given here, followed by recommendations for future field work and recommendations for the overall development of fog collection as a water resource in Peru.

The Field Sites

The conventional wisdom in Peru regarding the fogs on the coastal mountains was that they were persistent in the winter, much less frequent in the spring and autumn and non-existent in the summer. Various short term data sets of varying quality were available to support this viewpoint but none were obtained within 40 km of the center of Lima. In February (summer) 1989, C & S visited Lima and found that there was daily coastal fog in the city. A brief examination showed the presence of fog along the coast to the north as far as Huacho (120 km) and as far south as the Paracas Peninsula (200 km). These summer fogs were apparently not considered of any importance since they occurred at elevations below (100 to 400 m) the extensive wet season (winter) loma vegetation. The area long considered to have the most extensive fogs was the Pasamayo area just north of the city of Ancón and there are signs warning drivers of fog on the highway.

In June 1990 C & S chose the main field site at Cerro Orara (11° 49'S, 77° 09'W) 35 km north of the center of Lima. It is 3.5 km from the coast, has a maximum altitude of 438 m and a site altitude of approximately 430 m. It was chosen according to topographic criteria described elsewhere (Schemenauer and Cereceda, 1991b) and for its proximity to an area of poor settlements with a population of 6000 and an extremely limited water supply. The altitude was considered too low by SENAMHI to be acceptable since it was near the winter cloud base but it was felt by the authors that lower bases at night and possibly in the autumn, coupled with its other advantages, made it an excellent location.

Several subsidiary sites were chosen to answer specific scientific questions. Two sites were established at Pasamayo (Loma Ancón) 10 km north of Orara: the first was at 430 m to determine how the collection compared to that at the same altitude at Orara; the second was at 750 m to determine the vertical variation in fog water collection. A low elevation site at 170 m was found just south of Santa Rosa and on the extension of the Cerro Orara ridge. It was hoped to operate this site year around; however, despite it being on the outside edge of a military base, SENAMHI could not obtain permission to work there. Another site was chosen on the south edge of Lima just inland of Villa María del Triunfo (Lomas de Atacongo). Standard fog collectors were established at two altitudes 550 m and 730 m. The purpose of the site was to obtain comparable fog data at a site 50 km to the south of Orara and to determine the altitudinal variation in collection at a second site. The data from this site were to be collected, analyzed and reported on by SENAMHI and were not discussed by Suit and will not be discussed here.

The Frequency of Fog

The instumentation at the field sites was designed to measure the amount of fog water that could be collected from different directions, how two different types of collecting material performed and what the contribution of drizzle (garua) was to the total amount of water collected. The data also provide the most fundamental of assessments, that is, how frequently fog was present on the mountains.

The longest and most reliable data base in Suit (1991) is that for the omnidirectional collector (Suit, Table 2). It extends from the 5th of August to the 15th of December with only 6 missing days. Fog was collected on 115 of the 126 days of record (91.3 %). There were never more than two days in a row without fog. Five of the 11 days without fog occurred in the last 21 days of measurement indicating the lessening availability of the fog as one approaches summer.

A second independent data set confirms the high fog frequency on Cerro Orara. A standard fog collector had been erected facing west (Suit, Table 3) to look at the fog contribution from an orientation 90° to the preferred direction. Fog was collected on 110 of 128 days (85.9 %) even in this less desirable orientation. Nine of the 18 days without fog occurred in the last 21 days, a similar result to that noted above.

There are 91 days of observation, at the 430 m elevation site at Pasamayo (Suit, Table 4), from the 2nd of August to the 3rd of November. Fog was collected on 88 (96.7 %) of the days. It was also collected on 88 of 90 days of observation (97.8 %) at the 750 m site at Pasamayo.

It appears that the fog frequency on the coast of Peru north of Lima was very high in 1990 and that at an elevation of 430 m one could collect water on about 90 % of the days from early August to mid-December. From work done at the sites in June and July, the impression is that similar values occurred in these months. One might expect lower, but by no means zero, values as one progresses into early summer.

Orientation of the Collectors

When choosing and laying out the site at Orara, C & S specified that the standard collectors be oriented to the south to optimize the collection. The most productive collector orientation is a function of the prevailing wind direction, the topography and diurnal changes in wind direction. The layout called for other collectors to be oriented to the west for comparison purposes and for a collector with a wind vane to orient it into the wind (omnidirectional) to be installed. The omnidirectional data (Suit,

Table 2) showed that 80.8 % of the collection occurred with south winds and that the other directions combined accounted for 19.2 % of the collection. The percentages contributed by the other directions were: NW 4.7 %; SE 4.3 %; N 3.4 %; SW 2.4 %; W 1.8%; NE 1.6 %; E 1.1 %.

The Volume of Water Collected

The expectation was that the primary measure of fog water production would be the southward facing standard collector on Cerro Orara. However, because of problems with the data recording device, the period of good record turned out to be very short. The omnidirectional data (Suit, Table 2) will be used instead, coupled with the data from the south facing standard collector that was covered by a roof (Suit, Table 5) to exclude some or all of the drizzle.

On the 126 days with data from the 5th of August to the 15th of December, the omnidirectional collector collected an average of 9.4 L m^{-2} day^{-1} of water. Of this, an average of 7.6 L m^{-2} day^{-1} was produced with south winds. The southward oriented roofed standard collector, between the 2nd of August and the 15th of December, collected an average of 7.0 L m^{-2} day^{-1}. The roof would have reduced any contribution from drizzle to the collector but the measured amount of precipitation (Suit, Section 3.4) was extremely low in any case. A comparison of an uncovered southward facing standard collector to the roofed standard collector for 47 days (Suit, Table 1) showed that it collected 20 % more water. Therefore, just as one cannot expect to achieve values as high as the omnidirectional values, one should expect to obtain values higher than those produced when there is a roof over the collector. The best estimate of the water available during the period on Cerro Orara is 7.0 x 1.2 or 8.4 L m^{-2} day^{-1}.

There are 86 days of overlapping fog collection data from Pasamayo (Loma Ancón) and Cerro Orara. The collection rates averaged 5.1 L m^{-2} day^{-1} at 430 m at Pasamayo and 7.6 L m^{-2} day^{-1} at 750 m (Suit, Table 4). The best value for comparison at Cerro Orara is that for the roofed standard collector (Suit, Table 5) for the same 86 day period. The value is 8.8 L m^{-2} day^{-1}, and when corrected (as above) for an unroofed exposure, it is 10.5 L m^{-2} day^{-1}. This is more than twice the value at the same altitude at Pasamayo and 38 % higher than the collection rate at the higher elevation site at Pasamayo. Clearly, in terms of the amount of water that can be produced, Cerro Orara enjoys significant advantages.

One other matter deserves discussion here. The standard 1 m^2 fog collectors were covered with a double layer of Raschel mesh from Chile. There is a 47 day comparison (Suit, Table 1) of a standard collector with Raschel to one covered with a Peruvian mosquitero material. The latter has smaller fibers and small square openings. The exact specifications need to be obtained. The mosquitero collected 7.3 L m^{-2} day^{-1} during the period versus 5.3 L m^{-2} day^{-1} for the Raschel. It is not obvious why this should be the case and in a comparison of a mosquitero-type material to the Raschel in Oman, the mosquitero-type produced less water. This experiment should be repeated to see if indeed it is a better collector for the conditions in Peru. Though, as Suit points out in Section 4.1, the mosquitero is only available in small widths and at a cost that is 20 times higher than the Raschel. Nevertheless, it may have some application in Peru, if the collection is indeed 38 % higher.

The Meteorological Data

The general climate of the Lima area is described by Suit (1991) in Section 1.2 and a discussion of the meteorological conditions on Cerro Orara, from the 1st of July to the 14th of October, is given in Chapter 3. It is worth specifically mentioning the precipitation data. Very little drizzle was measured in this time period and though no measurements were made in June and July, these months appeared to be wetter based on observations of the soil and rocks at the site. Suit's measurements were:

July	3.75 mm	total	which	occurred	on	14	days
August	4.25	"	"	"	"	16	"
September	2.5	"	"	"	"	9	"
October	0.0	"	"	"	"	0	"

The entire meteorological data set, from the 1st of July to the 1st of December, was quality controlled at the Atmospheric Environment Service in Toronto, Canada. A brief overview of the wind data is presented here.

Table 1 gives the average, maximum and minimum wind speeds for each of the five months. The measurements were made at a height of 2.5 m above the ground on the crest of the ridge at the Cerro Orara site. This height corresponds to the center of the standard fog collectors. A wind speed observation was made each 5 s and the values were averaged for 15 min periods.

The monthly average values (Table 1) increased from July (4.06 m s^{-1}) to August (4.14) to September (4.36) to October (5.37) and then decreased in November (4.46). The maximum wind speeds showed a similar pattern with the highest value (15.2 m s^{-1}) being recorded in October. Thus, in part, the lessening availability of fog in the spring is compensated for by increased wind speeds. The minimum values are the instrumental start up value of 0.45 m s^{-1}.

As we have seen above, 81 % of the fog collection occurs with south winds. Table 1 also summarizes the conditions when the wind was from the south. The average wind speed was 5.6 m s^{-1}, the average temperature was 13.7°C and the average humidity 100 %. These are excellent conditions for fog collection with constantly saturated air and wind speeds that generate high collection efficiencies (Schemenauer and Joe, 1989). The maximum humidity value reported of 107 % is simply reflecting a possible error in an individual measurement of ± 5 %.

The frequency distribution of wind speeds at the Cerro Orara site is shown in Figure 1. About 60 % of the winds were from 2 to 6 m s^{-1}. High winds were rare and damaging winds did not occur. This is an important consideration for the design of large fog collectors. Each site in Peru will have a somewhat different wind speed regime depending on the topography and altitude. In addition, if the site is hundreds of kilometers removed from Cerro Orara, there may be differing large scale circulation patterns.

Fog Water Quality in Peru

As with any water supply that will be used for domestic purposes, there is a need to determine whether the water meets national and international drinking water standards. Water quality is of somewhat less importance when it is used solely for agricultural purposes, since it will be highly modified once it is in contact with the soil. In addition, water quality standards for agricultural use are normally less refined and at this time C & S do not know of any for Peru.

In March 1991 a copy of the recommended microbiological, physical and chemical drinking water standards was obtained. Our concern at the moment is primarily with the chemical standards, since problems with the other tests are expected to be minimal. There are fewer substances listed than would be the case in Canada and, of those listed, it appears that only about one-half are actually measured with any frequency due to instrumental and technical limitations (Otto Rosasco, private communication).

In October and November 1990, a small number of water samples were collected from Cerro Orara and vicinity for analysis in Canada by the laboratories specified in Schemenauer and Cereceda, 1991c. Due to the very small number of samples, the need to relax some of the sampling protocols and the fact that the fog water samples were collected under light, variable wind conditions in the early morning (0300-0800), the results will only be stated in general terms.

A look at the three fog samples, taken from the specialized AES fog collector after careful cleaning, indicates that the nine ions that were measured plus pH were in basic agreement with the Peruvian drinking water guidelines. The ion concentrations were generally lower than in two water samples taken from a house in Los Rosales and the Ancón pipeline in October. In the case of the latter samples, two ions were present in borderline acceptable concentrations. The three fog samples were also analyzed for 23 trace elements. In a few cases values above the Peruvian standards were obtained. The house and pipeline water had the occasional exceedance as well, though the concentrations were normally lower than in the fog.

The fog water quality in Chile and The Sultanate of Oman has been found by the authors to be acceptable and there is no reason to expect that it should not be so in Peru as well. The case of Cerro Orara is somewhat unique in that it is immediately downwind of the urban industrial complex of Lima. This not only affects the fog water quality but the air people breathe and the composition of plants and surface soils. A small project should be undertaken with a university group to examine fog water quality both upwind and downwind of Lima as well as in a more remote location. This would provide guidance on how the water can best be used.

We have written to the Ministry of Health in Peru to obtain the latest drinking water standards and the maximum acceptable values. We have also requested information on standards for agricultural use and other related matters.

Volume of Water to be Expected

The project at Cerro Orara operated from the end of the winter through the spring. The minimum amount of water that could be expected is that actually produced during the approximately four and one-half months of operation, that is, an average of 8.5 L m^{-2} day^{-1} for 135 days or 1150 L of water for each m^2 of mesh. In fact it can probably be safely assumed that the early part of the winter (June, July) produced water at at least the same rate. This yields a production of 1660 L for each square meter of mesh. The other five and one-half months of the year will produce an unknown additional amount of water. A value of 1700 L of fog water per m^2 of mesh at Cerro Orara in 1990 thus seems to be a conservative working figure.

Using this value one can calculate what a large collector array might produce on an annual basis. For example, an array of 200 collectors, each of 60 m^2, would generate 20,400,000 L of water in the year, or about 56,000 L per day. This assumes that the large collectors generate water at the same rate as the standard collectors, which was the case in Oman. Other estimates of water production can be made using the values in this section.

Recommendations

A General

1. A means should be found to obtain a set of measurements of fog water availability for a full year at the Cerro Orara or a similar site.

2. Based on the winter and spring data in this study, a conservative water production rate for planning purposes is 1700 L per square meter of collector per year.

3. Expert guidance should be obtained in selecting future sites for medium and large scale projects. This is supported by the fact that the Cerro Orara site, chosen for this study, produced more than twice the amount of water than the Pasamayo site, which was long considered one of the foggiest locations in Peru.

4. One of the initial objectives of this study was to examine a low elevation site very near the coast in order to evaluate the availability of fog water during the warm seasons. This was not possible since permission to use the site could not be obtained.

   It is recommended that a low elevation site between 200 and 300 m be examined, in order to evaluate the possibility of installing individual collectors for the supply of water to homes and gardens. This should be done within the Lima city limits and on an artesano basis.

5. Fog water can be used for domestic consumption, which gives immediate visibility to the project but the maximum level of difficulty. It can be used for agriculture for returns in a matter of months. It can also be used for forestry, which will give a return over a period of years and the lowest costs and fewest problems.

   i) It is recommended that projects which combine all of these uses be considered, somewhat in the manner of huertos familiares. The emphasis, however, should probably be on the production of foodstuffs, i.e. vegetables and fruits.

   ii) It is recommended that a small rural settlement be found with 25 to 50 families that would be interested in participating in a pilot project. Social issues such as community needs and desires, provision of the workforce, the site maintenance and the participation of women in the project should be considered at the very beginning.

   iii) It is recommended that conservative watering techniques such as drip irrigation be introduced into the community.

6. An extensive body of scientific and technical literature exists on the collection of fog water and the construction of collectors in Chile and The Sultanate of Oman.

   It is recommended that before a site is developed for a pilot project in Peru, that the participants familiarize themselves with these publications.

7. No matter what use the fog water is put to, the quality of the water will be important, therefore a program to monitor water quality should be initiated at the earliest oportunity. Corresponding measurements of the existing water supplies in the area should also be made.

8. A Peruvian government department should be found which will be interested in the development of water supplies based on fog water collection for rural areas. The department could take over the initiative in the use of the water once its utility is demonstrated by an NGO working with CIDA and the ODC.

9. Consideration should be given to the use of the water for purposes other than water supplies on the arid coast. Examples are: reforestation on the slopes of river valleys to provide a measure of flood control; reforestation to assist in replenishing underground aquifers; the establishment of new crops such as jojoba in areas that currently lack sufficient water.

10. In a country such as Peru there are large areas of high elevation forest that receive a substantial amount of water from fog. These forests are threatened from many directions with the potential deforestation leading to both the loss of important habitats and the decrease of water in the aquifers fed by these mountains.

    It is recommended that support be given to evaluation of the contribution of fog to the water balance of cloud forests in Peru. This should include an assessment of whether specific high elevation forests could regenerate naturally if one removes the trees that currently collect fog water.

B CIDA Action

11. The opportunity should be seized to build upon the results obtained in 1990 and the tremendous positive publicity that followed from the field work at Cerro Orara near Lima.

12. The CIDA staff in the Lima Embassy should produce a one page Newsletter in English and in French describing the results and potential benefits of this technology. The Newsletter should be given widespread circulation within Canadian Embassies in South America and CIDA Headquarters in Ottawa.

13. Funding should be found in FY 91/92 to implement one or more medium scale pilot projects for the provision of water to rural communities or small "pueblos jóvenes". Projects should be funded only if they are visible, accessible and capable of being replicated. Any project that is funded should have an economic evaluation and an environmental assessment. In the economic evaluation, the social benefits should be quantified.

14. A mechanism must be found to fund the projects for two years in order to properly assess the agricultural and forestry benefits. This will also provide time to educate the community in the use of the new water resource.

15. In FY 91/92 a meeting of CIDA personnel, consultants, relevant NGOs in Peru, and Peruvian government and university departments should take place with the purpose of laying the groundwork for future operational fog water collection projects in the country. This meeting will provide timing and cost information to CIDA for use in planing budgets for future FYs.

16. Inevitably, project proposals will be generated which do not fall explicitly within the mandates of CIDA or the ODC. If the projects have merit, assistance should be provided to direct the applicant to a more appropriate funding source, whether it be the Canada fund, IDRC or another governmental agency.

Conclusion

Given the poverty, lack of water, persistent drought, health problems, diminishing availability of river water, the proven fog water production and the capability of producing water in remote areas, it seems essential that serious consideration be given to developing this water resource in Peru.

References

Cereceda, P. and R.S. Schemenauer, 1991: The occurrence of fog in Chile. Accepted by J. Appl. Meteor.

Fuenzalida, H.A., R.S. Schemenauer and P. Cereceda, 1989: Subtropical stratocumuli as a water resource. 3rd Intl. Conf. Meteor. Ocean. S. Hemis., 13-17 Nov., Buenos Aires, Argentina, 199-200.

Schemenauer, R.S. and P. Cereceda, 1991a: Fog water collection in arid coastal locations. Accepted by Ambio.

Schemenauer, R.S. and P. Cereceda, 1991b: Fog as a permanent water resource in arid lands. IWRA Conference on Water as a Sustainable Resource in the 21st Century. Rabat, Morocco, 13-18 May.

Schemenauer, R.S. and P. Cereceda, 1991c: The quality of fog water collected for domestic and agricultural use in Chile. Accepted by J. Appl. Meteor.

Schemenauer, R.S., H. Fuenzalida and P. Cereceda, 1988: A neglected water resource: the camanchaca of South America. Bull. Amer. Meteor. Soc., 69, 138-147.

Schemenauer, R.S. and P.I. Joe, 1989: The collection efficiency of a massive fog collector. Atmos. Res., 24, 53-69.

Suit, M., 1991: Proyecto Captación de niebla en la costa Peruana. Informe final, Agencia Canadiense para Desarrollo Internacional, Oficina de Coordinación, Lima, Peru, Enero 22, 69 páginas mas anexos.

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Table 1

PERU 1990 METEOROLOGICAL DATA

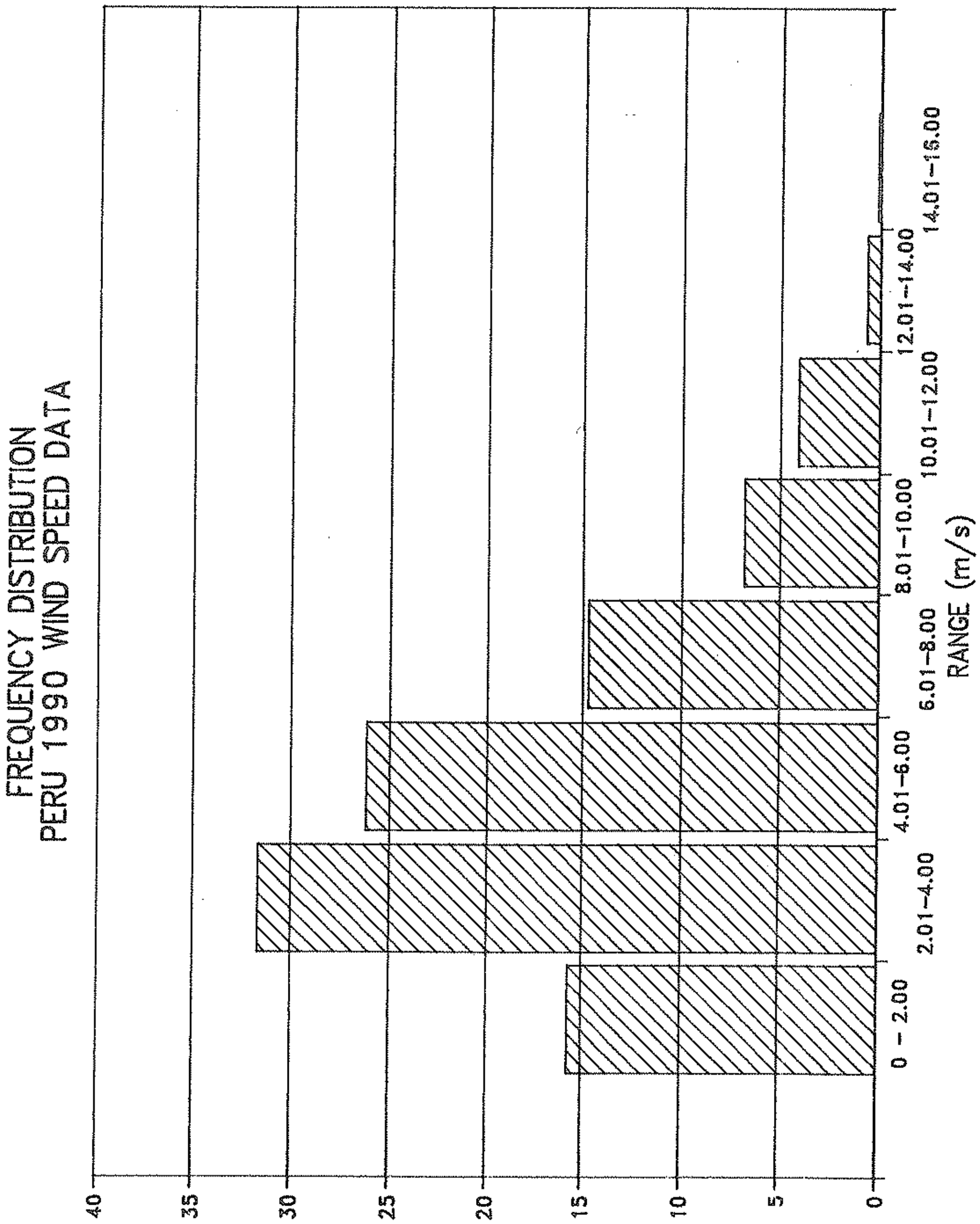
Average and min/max wind speeds for each month

MONTH	Ave WS	MAX WS	MIN WS
July	4.06	12.27	0.49
August	4.14	11.93	0.48
September	4.36	14.98	0.48
October	5.37	15.22	0.46
November	4.46	13.86	0.45

Average parameter for South winds (180° ± 15°)

PARAMETER	AVERAGE	MAXIMUM	MINIMUM
Wind speed	5.61	15.22	0.47
Temperature	13.74	21.78	11.08
Relative humidity	100.01	107.20	76.50

Figure 1


FREQUENCY DISTRIBUTION
PERU 1990 WIND SPEED DATA
PERCENTAGE OF TOTAL
0
5
10
15
20
25
30
35
40
0 - 2.00
2.01-4.00
4.01-6.00
6.01-8.00
8.01-10.00
10.01-12.00
12.01-14.00
14.01-15.00
RANGE (m/s)