FOG WATER COLLECTION IN BOLIVIA

Experiences with Different Designs, Results and Practical Findings

zabalketa

ICO – Instituto de Capacitación del Oriente – Bolivia

WasserStiftung® Waterfoundation

Munich Re Foundation
From Knowledge to Action

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01

The Search for Solutions to Contend with Water Scarcity

The productivity of most crops is totally dependent on rainwater

Together with climate change, water shortage is one of the greatest challenges facing humanity today. The scientific community and other international institutions warn of the increasingly limited availability of fresh water. In addition to direct human consumption, fresh water is also needed to sustain the agricultural and livestock activities that are essential to ensure our food security. Moreover, far from moderating freshwater consumption, the demand for fresh water continues to grow, even faster than the growth rate of the world's population. Although there is still enough fresh water today to supply the 7 billion people who inhabit the planet, there are problems caused by its uneven distribution, waste, pollution and mismanagement.[6]

In 2023, **water scarcity affects more than 700 million people in 43 countries around the world**, the majority of which are countries with poor economic development indices. The bottom line is that those who suffer the most from water scarcity are often those with the least capacity, means and resources to cope with it.

6 https://www.un.org/spanish/waterforlifedecade/scarcity.shtml

Condensation of atmospheric moisture droplets on a spider web

This great challenge calls for innovative solutions that guarantee a water supply of sufficient quality that is both accessible and equitable (as stipulated by the human right to water, recognised by the United Nations General Assembly in 2010). As part of this endeavour, particular value is placed on **nature-based or nature-inspired solutions**, i.e., solutions conceived according to the principles of biomimicry.

Biomimicry invites us to observe nature and its processes, materials and structures, as well as its organisational models and systems, among other features. In nature, we discover examples of efficiency in the use of materials, energy savings, symbiotic relationships and resistance. The fog collection technique employed in this study is a case of a biomimicry, as it reproduces the natural phenomenon of the "passive" collection of environmental moisture that occurs in the branches and leaves of trees, and the condensation of water on surfaces such as spider webs. One illustrative example is the Garoé tree, a species native to the Canary Islands on the island of El Hierro, which is said to have released large quantities of water from its branches; water that was used by the island's native inhabitants. This phenomenon enables certain plants to survive in arid regions with virtually no rainfall. Another example is the Namibian beetle, whose rough outer shell facilitates the condensation of water droplets from the fog, which then run down into its mouth.

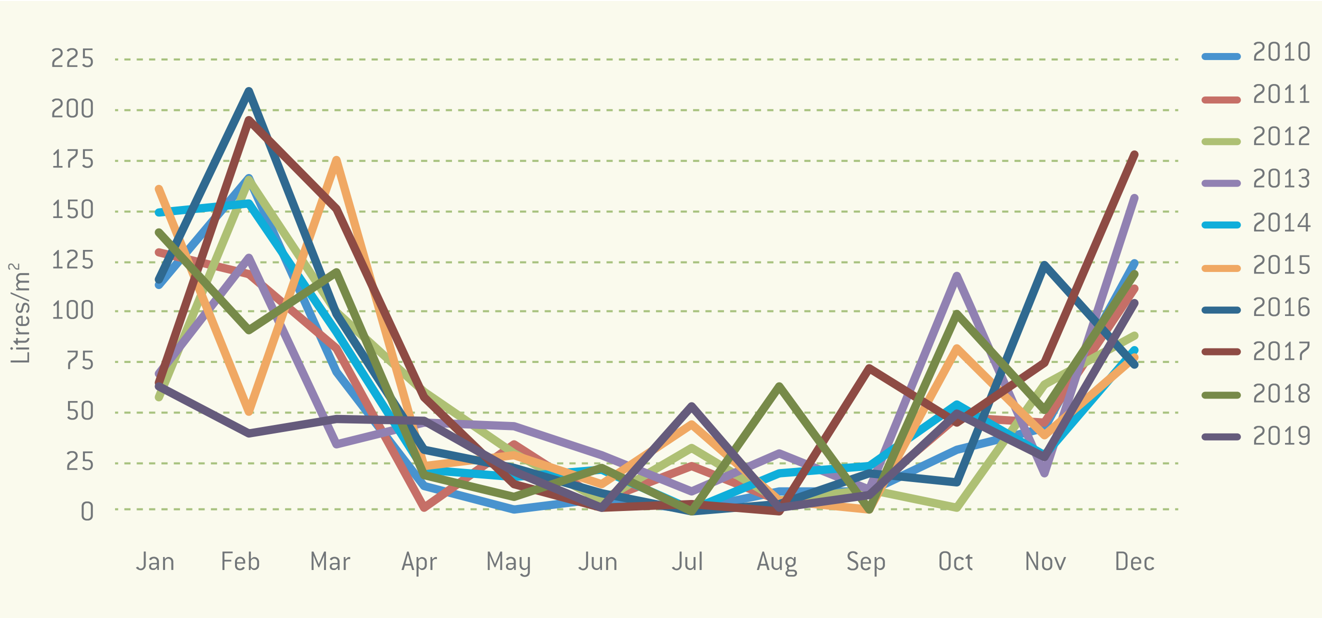
Bolivia, and specifically the sub-region of the valleys known as the "Valles Cruceños", is particularly familiar with this worldwide water shortage problem.

Agricultural landscape of the Valles Cruceños

Bolivia's **Valles Cruceños** extend across 12,855 km^2 of land, forming a transitional zone between the rainforest area and the high plateaus, with differences in altitude that range from 500 metres to 3,500 metres above sea level. Climatic conditions also vary from one zone to another, although, in general, it has been observed that the dry months are becoming increasingly longer, the rains are delayed and when they do arrive, they fall more intensely over a shorter period of time.

Figure 1 shows the data recorded over a decade (2010-2020) by the weather station located in the city of Vallegrande, located in the centre of the Valles Cruceños, at 2,000 metres above sea level. The rainfall pattern is clear: during the months of November to March, it usually rains more than 100 litres per square metre per month; however, during the months of April to August, precipitation barely reaches 30 litres.

Figure 1. Rainfall in Vallegrande (source: SENAMHI - Bolivia)



Fruits and vegetables in Vallegrande market

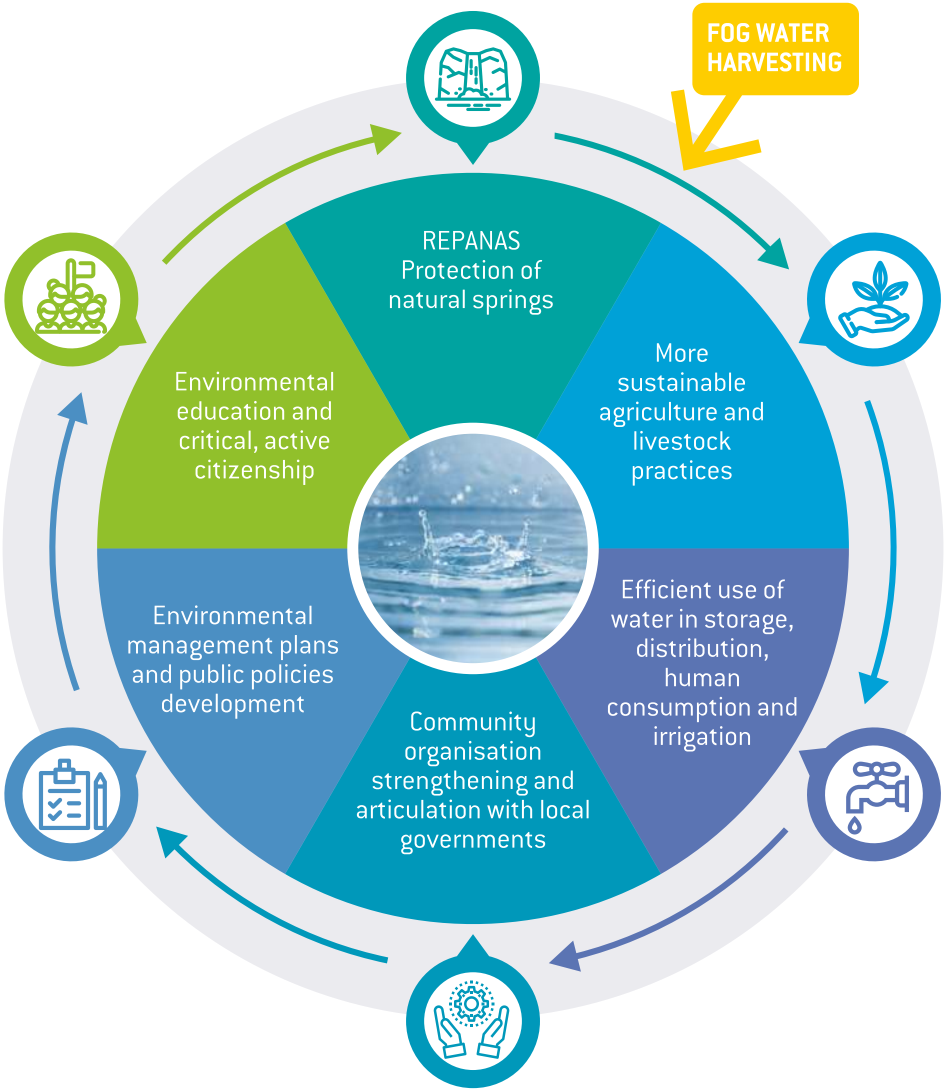
The irregular distribution of rainfall throughout the year, combined with the lack of large water storage and distribution infrastructure, limits the availability of water for the local communities, for both human consumption and productive activities, which primarily consist of livestock and agriculture. This region produces a large percentage of the fruit and vegetables consumed by the roughly 3 million inhabitants of the city of Santa Cruz de la Sierra, the region's capital, which in turn generates a high demand for production, and consequently, a high demand for water.

The NGO known as the **Instituto de Capacitación del Oriente (Eastern Training Institute, or ICO)** has been actively present in the Valles Cruceños area since 1982, and in collaboration with the Basque NGO **Asociación Zabalketa**, it supports farming families, to promote their sustainable and equitable development. In this regard, the availability of water is an imperative factor.

Figure 2 shows the work strategies that are being promoted in the region to achieve sustainable water management based on the specific conditions of the area:

- Establishment of Natural Heritage Reserves (REPANA), involving the physical and legal protection of natural springs and high mountain areas that act as water recharge zones for the micro-watershed.

Figure 2. Strategies for sustainable water management with a territorial approach



- Adaptation of production activities through the promotion of organic agriculture with efficient irrigation systems, and controlled livestock farming with natural grazing fields, particularly near environmentally vulnerable areas and water recharge zones. These measures prevent the pollution of the water, optimize its use and improve its filtration into the subsoil.
- Multi-level environmental governance through drafting municipal public policies and environmental management plans with the participation of community organisations and critical citizens.
- Environmental education, to increase ecological awareness and promote good habits and care for the natural environment.
- New techniques that will improve the collection, storage and/or efficient use of water for human consumption and productive activities. Fog water harvesting is part of this strategy.

Natural springs are the main source of water in Valles Cruceños

The collection of fog water through fog catcher is a technology that allows the collection of atmospheric humidity present in fogs, in a simple and environmentally sustainable way. The water collected serves as a supplementary contribution to other sources of water supply for the local communities.

This technology is new in Bolivia, although it has been known and used in other countries for a long time. The first prototypes were developed in Chile in the 1960s, and consisted of a panel with a metal frame and a double layer of Raschel mesh (35% shade coefficient). The simplicity of the materials and design, together with the good performance, has led to the implementation of this system in different countries.

Traditionally this technique has been used in coastal areas by placing the panels on hilltops to catch the fog that regularly reaches the coastline, carrying moisture from the sea. Nevertheless, it can also be applied in valleys between inland mountains, as illustrated by the experience described here.

Low clouds over the mountains of the Valles Cruceños

In recent years, fog collector designs and materials have been improved in order to achieve higher performance and thus expand their application possibilities in new locations and with new uses

In recent years, new companies have perfected the materials and designs to optimise the performance of fog collectors, resulting in a quantum leap in the potential for new locations and purposes.

One shortcoming of some designs is the inability to withstand strong or permanent winds. This leads to torn meshes within a short period of time and results in a failure to deliver sustainable improvements for local communities. To remedy this problem, **WaterFoundation** began working with Aqualonis[7] and the **Technical University of Munich** to develop a more efficient and sustainable design for fog harvesting structures. The result was the CloudFisher®, a registered trademark of **WaterFoundation.**

In 2019 WaterFoundation and Munich Re Foundation jointly issued a call for tenders. Working with a team of experts in engineering, water management and development, they evaluated the bids submitted and ultimately selected the project proposed by ICO and Zabalketa. The funding for the project was provided by WaterFoundation and Mu-

7 www.aqualonis.com

nich Re Foundation, with additional support from ICO, Zabalketa, the Municipal Government of Pampa Grande and the beneficiary community.

Representatives of Munich Re Foundation (Martina Mayerhofer), Aqualonis (Peter Trautwein), Zabalketa (Teresa López de Armentia) and ICO (Eliana Quintana) with Veladero School teachers and principal, in September 2019

This publication presents the working experience and the results obtained from the use of CloudFisher fog collectors in two communities in the Valles Cruceños in Bolivia during 2022 and part of 2023.

2 Zabalketa and ICO Experience with Fog Harvesting

Images of the pilot project carried out in 2012 and 2013

Zabalketa and ICO both have a great deal of experience working with fog collection in different places and for different purposes, resulting in them amassing considerable practical knowledge about this technique.

The first steps were taken in **2012**. With the financial support of the **Basque business group NER**, Zabalketa launched an initial pilot study to implement the fog harvesting technique in several locations in Peru and Bolivia. The aim of this first experiment was to determine the potential of this technique as an alternative source of water to be used for the cultivation of native saplings for the restoration of degraded forest areas. To this end, simple panels consisting of metal structures and Raschel-type plastic mesh (shade mesh) were installed. The results of this fieldwork experiment, which was carried out in 2012 and 2013, were published in the book "*Experiencias de captación de agua de niebla para reforestación. Investigación en campo en territorios con escasez pluvial de Bolivia y Perú.*"[8]

8 Zabalketa, 2014. https://zabalketa.org/archivos/publicaciones/libro-captacion-agua-niebla-reforestacion.pdf

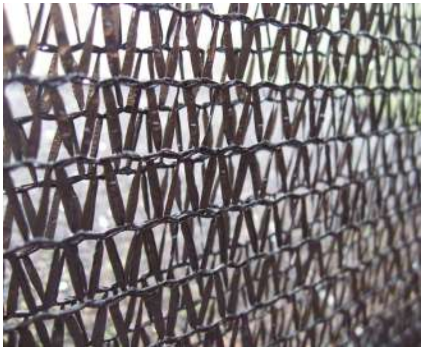
Installation of large Raschel mesh fog collectors (2015)

Later, in **2015**, a project was carried out with the support of the **Getxo Town Council**, consisting of the installation of fog collectors with a mesh surface area of 12 square metres. The idea was to collect large volumes of water to distribute to groups of homes located in remote areas that have difficulty obtaining water by other means.

In this case, the work focused on the Valles Cruceños area of Bolivia, which had shown very promising results in the 2012 pilot project. Moreover, being a non-coastal area, this was an innovative application, as the water was harvested from inland fogs. It was found that simple panels strategically placed high in the mountains were able to collect small droplets of water suspended in the air in the form of fog, and drop by drop, they were accumulated, reaching considerable volumes. The favourable results of these fog collectors led the local communities of Valles Cruceños to take an increasingly great interest in this simple and functional technique.

In **2018**, as part of a participatory environmental governance project in Valles Cruceños funded by the **Basque Agency for Development Cooperation**, a study was carried out to identify new potential zones where fog water could be collected.

The ICO technical team selected 10 sites in different municipalities and at different altitudes (table 1). At each site, they installed fog gauges, which are fog collectors with



Raschel mesh and neblinometers in Sivingalito

a surface area of 1 square metre, according to the internationally standardised design (Standard Fog Collector[9]), with a Raschel mesh with a 50% shade coefficient. Additionally, weather stations were set up to monitor the weather conditions at each site and the fluctuations throughout the year.

This experimental study, which lasted a full year, afforded a better understanding of the dynamics of the fog and the collection technique, while also providing interesting data on fog collection. The findings showed that, in general, fog formation in the Valles Cruceños is fairly stable throughout the year and that it could serve as a useful source of water. Among the ten sites tested, **El Churo, El Pino and Sivingalito** displayed the greatest potential: in the **months of the dry season**, El Churo and El Pino collected **more than 7 litres of water** per square metre of mesh surface **per day**, and Sivingalito collected **over 5 litres per day** (table 1).

9 Schemenauer and Cereceda (1994) "A proposed Standard Fog Collector for Use in High-Elevation Regions". *Journal of Applied Meteorology* 33 (11), 1313-1322.

Table 1. Results obtained in the research study carried out in 2018

	Municipality, zone	Community	Altitude (M. A.S.L)	Average monthly values of water volume collected during the dry season * (l/ $m^2 \cdot d$)	Average monthly values of water volume collected in the most favourable month (l/ $m^2 \cdot d$)
1	Moro Moro	Abra del Astillero	2,595	0.07 – 0.49	5.31 (April)
2	Vallegrande, Chapas	Chapas	2,608	1.64 – 5.31	8.93 (March)
3	Comarapa, Siberia	El Churo	3,334	5.43 – 7.43	7.30 (March)
4	Vallegrande, Loma Larga	El Pino	922	1.51 – 7.01	4.32 (February)
5	Vallegrande, Loma 25	K'jasamonte	420	0.59 – 1.48	3.92 (October)
6	Pucará	Loma larga	2,234	0.20 – 1.05	3.33 (February)
7	Comarapa, Siberia	Manzanal	3,071	0.48 – 1.25	2.69 (October)
8	Racetes	Racetes	2,131	0.16 – 0.80	6.33 (December)
9	Pampa Grande, Rodeo Pampas	Sivingalito	2,091	1.50 – 5.46	3.09 (February)
10	Postrervalle	Tierras nuevas	2,133	0.18 – 0.75	3.09 (February)

*The dry season is typically lasts from April to August.

Large Raschel mesh fog collectors to supply water to the population of Veladero

The experimental results of this study were analysed and interpreted in depth by a partner team from the Department of Agriculture, Food, Environment and Forestry of the University of Florence and published in a scientific journal[10]. Using the data, they were able to demonstrate that the Valles Cruceños area is an ideal location for orographic fog collection, with a preference for zones at altitudes of around 3,000 metres and with a north-easterly orientation. They also concluded that the promotion of this technique would contribute to guaranteeing the food security and food sovereignty of the local communities, whose main livelihood is family agriculture, particularly during the summer months (dry season, with low temperatures).

10 Castelli, G., Cuni Sanchez, A., Mestrallet, A., Montaño, L. C., López de Armentia, T., Salbitano, F., & Bresci, E. (2023). Fog as unconventional water resource: Mapping fog occurrence and fog collection potential for food security in Southern Bolivia. *Journal of Arid Environments*, *208*. https://doi.org/10.1016/j.jaridenv.2022.104884

At the end of **2018, ICO and Zabalketa** signed a collaboration with the submission of a proposal to the German foundations **WaterFoundation** and **Munich Re Foundation.** The proposal outlined the development of a fog collection project in Bolivia using the WaterFoundation's advanced design called **CloudFisher**, which incorporates an innovative three-dimensional mesh to improve the performance of the fog harvesting. The sites chosen in this project for the location of the CloudFisher collectors were as follows: (1) Veladero, which had simple collectors that needed to be upgraded; and (2) Sivingalito, which was one of the highest yielding sites in the 2018 study.

This project, which is the focus of this document, represented the first application of CloudFisher in South America.

3 Installation of CloudFisher Collectors in Bolivia

CloudFisher Midi at Sahuintito site

3.1. Design of the CloudFishers

Fog collectors have been used in numerous countries and are an effective method of addressing groundwater scarcity in regions with suitable conditions. However, many fog collectors have design deficiencies, particularly their inability to withstand sustained or high winds. This causes the nets to break quickly, meaning that there are no sustainable improvements for the local population. To address this issue, the WaterFoundation began working with Aqualonis and the Technical University of Munich (TUM) to develop a more efficient and sustainable design for fog collection structures. The result is the CloudFisher®, a registered trademark of the WaterFoundation.

The CloudFisher design has been internationally acknowledged, with awards including the Climate Change Award of the UN Framework Convention on Climate Change.

The CloudFisher design was developed, tested and perfected over a period of 18 months, starting in 2013. The pilot project was designed by WaterFoundation and implemented through the Moroccan partner Dar Si Hmad. Engineering and research professionals from Aqualonis and the Technical University of Munich installed and closely monitored the set-up and the water collection of ten different types of meshes, which included woven mesh, stainless steel fabrics and three-dimensional spacer fabrics. The meshes were secured by a solid steel structure. Daily values for wind speed and direction, humidity, temperature, rainfall and the amount of water collected provided a clear image of the local conditions and the effectiveness of each of the mesh types tested. The results overwhelmingly revealed that the three-dimensional meshes were the most effective material for water collection, primarily owing to the fact that they


CloudFisher Midi and image of the three-dimensional mesh and the water collection gutter

had a larger surface area than the flat mesh. To cross-check the data, the researchers changed the position of each mesh three times, to ensure that the measurements reflected the differences in the quality of the meshes, rather than their location. Following the pilot phase, the first CloudFisher installations were successfully implemented in Morocco and Tanzania.

To start a new CloudFishers project, the WaterFoundation and the Munich Re Foundation published a joint call for proposals in autumn 2019. Together with a team of technical experts in engineering, water management and development, the submitted proposals were evaluated and the project prepared by ICO and Zabalketa was selected. Funding for the construction of the 14 CloudFisher fog collectors was provided by the WaterFoundation and the Munich Re Foundation.

For the project in Bolivia, the CloudFisher *Midi* model was chosen. This consisted of 3 panels together, with a metal structure measuring 4 metres high and approximately 3 metres long to support each mesh panel. Each **mesh had a surface area of 7.89 metres** (2.87m long and 2.75m high).

The CloudFisher designs displayed the following improvements over the simple Raschel mesh panels that had been used in previous experiments:

- Three-dimensional mesh: The circular shapes formed by the strands of the mesh help guide the droplets of water down the mesh into the trough. Specially manufactured monofilaments for the three-dimensional fabrics were developed for use in food safety and for exposure to extreme UV radiation.
- Flexible expanders: The use of rubber expanders to attach the mesh to the metal frame, rather than a non-flexible material, allows the mesh to flex with the

Veladero School and its geographical location

movement of the wind, resist its force and return to its original position. These expanders are inexpensive and easy to replace. Moreover, their replacement requires only simple tools and no technical skills, therefore facilitating the local management and maintenance of the CloudFisher installations.

- Fixed position of water trough: The underside of the mesh is positioned inside the water collection trough, so that the droplets run off the mesh fall directly into it. This prevents the mesh from being blown out of position by the wind.
- Stability: The vertical and diagonal anchoring system to the rear makes the structure very sturdy, guaranteeing its stability and resistance to the force of the winds. This translates to greater longevity.

3.2. Location

Based on the results obtained in previous tests conducted by Zabalketa and ICO, as described above, the following locations were chosen for the installation of the CloudFisher systems:

a) The community of Alto Veladero, within the municipality of Moro Moro, where CloudFisher fog collectors were installed in 3 separate but neighbouring locations, all at an **altitude of around 2,850 metres** (table 2).

In this community, 12-square-metre collectors built in 2015 had previously been used with very good results. Moreover, the local community has always shown

Alto Veladero School

great interest in this technique and has always been cooperative. The families living near the areas with the collectors undertook the tasks of observation and the daily recording of the presence of fog, the periodic cleaning of the panels and the measurement of the volume of water collected.

One of the installation sites in this community was near the **Alto Veladero School**. The water supply for this school runs through pipes from natural springs, yet it is frequently cut off during the months when there is no rainfall to feed the springs. This shortage is compounded by episodes of water contamination due to the excessive use of agrochemicals in the fields near the springs. The fog water planned to serve as an extra supply of pollutant-free water and, therefore, suitable for consumption and the irrigation of the school vegetable garden, which provides the source of food for the school's daily lunch.

Alto Veladero School, which provides primary and secondary education, is attended by a total of 110 children between the ages of 6 and 18, and has a staff of 15 teachers. Some of the children come from remote communities, meaning that they remain on campus as boarders from Monday to Friday. The school also has a cook and 2 other support staff members for administrative and school maintenance tasks. In all, 128 people have benefited from the improvements in the water supply system.

In addition to the school, this zone of the Veladero community includes groups of scattered houses that are connected to a main water supply system. During the

Geographical location of CloudFishers at Sivingalito

winter months of the southern hemisphere, when there is no rainfall, there is not enough water flow to reach all the homes, causing serious supply problems.

ICO worked with the community authorities and the members of the Water Committee (a community organisation in charge of water management) to analyse the problem. Together, they reached the conclusion that in order to increase the flow of the main water supply system, it would be appropriate to install two CloudFisher collector systems at the sites known as **Central** and **Sahuintito**, and to connect both systems to the community's main water supply network.

As a result, the CloudFishers at the Central and Sahuintito sites have ensured a year-round water supply for a total of 43 families, whose homes are connected to the Veladero community's main water supply network. In all, a total of approximately 170 people are served by these CloudFishers.

b) The **community of Sivingalito**, which belongs to the Pampa Grande municipality and is located at an altitude of 2,100 metres.

Like the case of Veladero, simple fog collectors had been tested here in the past, and the local community also suffers from water shortages at certain times of the year.

Another factor that led to the selection of this community was the Pampa Grande Municipal Autonomous Government's support for this initiative, which aimed to improve the water supply for the local community. This institution committed to covering the costs of the connection pipes from the CloudFisher panels located at the top of the mountain to a reservoir within the community's main water supply network, located 1,100 metres away.

The CloudFishers in Sivingalito provide water to the Sivingalito community's main water supply network, benefiting 32 families, or approximately 120 people.

Table 2. GPS coordinates and altitude of each of the CloudFisher installation sites

Location	GPS coordinates (UTM zone 20K)		Altitude
Veladero – Escuela	366292.60 m E	7969885.00 m S	2,833 m
Veladero – Central	365366.00 m E	7970062.00 m S	2,872m
Veladero - Sahuintito	367353.00 m E	7969792.00 m S	2,846 m
Sivingalito	378000.00 m E	8019124.00 m S	2,103 m

3.3. Orientation of the fog collectors

One of the key factors for fog collection is the orientation of the collectors: they must be **positioned as perpendicular as possible to the direction of the wind that propels the fog**.

To determine the predominant wind direction at each site, three weather stations (*Davis Vantage Vue* model) were installed at the locations of the collectors. These devices measure the temperature, relative humidity, rainfall and, of course, the direction and speed of the wind constantly (every hour).

In addition, the orography, or physical geography, of the site must be considered, in order to identify possible “corridors” between mountains where the air moves, or conversely, barriers that might shelter the area from the wind.

CloudFishers and weather station sensors at Sivingalito

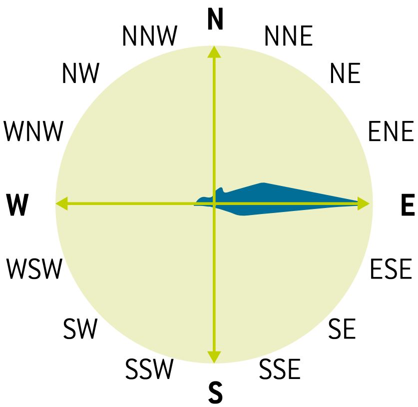
The relief of the site can also to some extent influence the orientation of the systems, which requires a sufficiently large and flat surface for the adequate installation of the foundations and the rear supports of the CloudFisher collectors. In the case of Sivingalito, for example, some of the CloudFisher systems had to be positioned in a "staircase" formation, in keeping with the shape of the mountain.

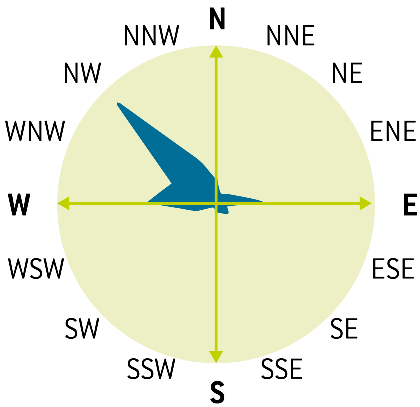
Table 3. Orientation of the CloudFisher and predominant wind direction

	CloudFisher orientation	Predominant wind direction
Veladero – Escuela	From 110 º to 130º SE	NW
Veladero – Central	125º SE	E
Veladero – Sahuintito	310º NW	-
Sivingalito	Entre 280º y 320º NW	NNE

The weather station data provided the predominant wind direction at each site (table 3), although it was also found that the wind direction could vary seasonally. Figures 3, 4 and 5 illustrate the predominant direction recorded by the weather stations at each site during the months of May, June, July, August, September and October, which are typically the months when it rains the least in the Valles Cruceños area, and therefore, when it is most important for the collectors to "trap" as much fog as possible.

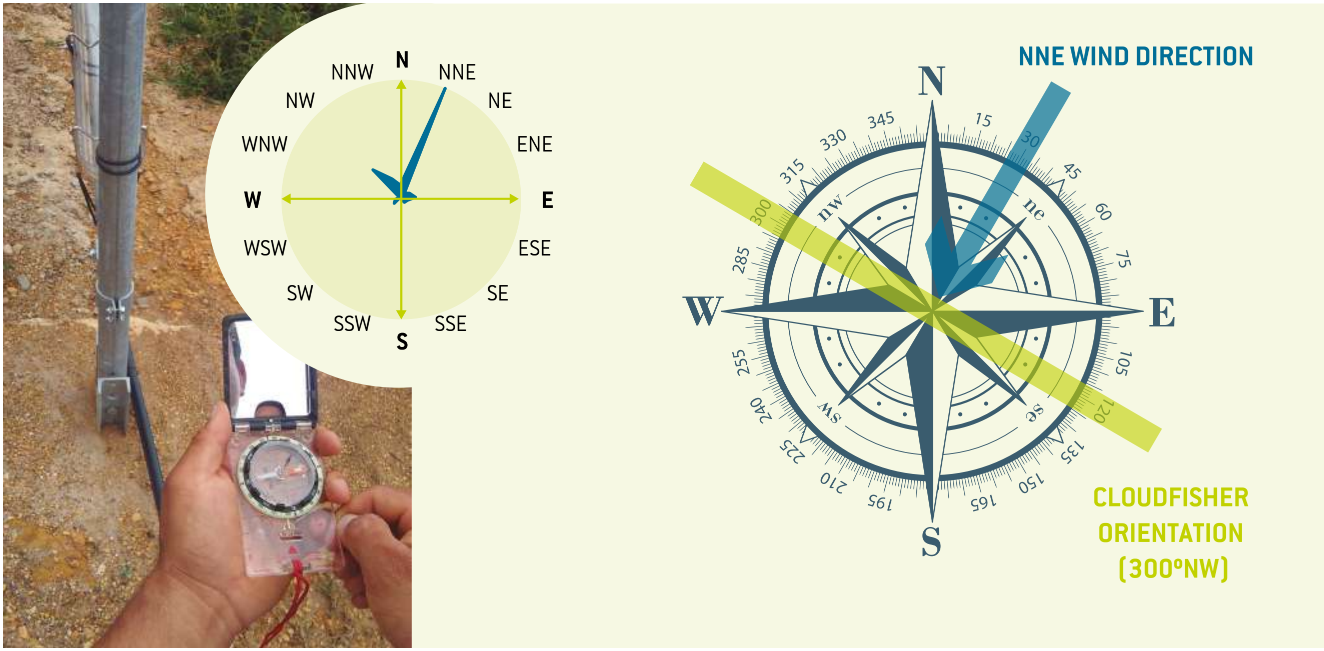
Figure 3 and 4. Predominant wind direction at Central and Veladero School sites





In the case of Sivingalito, for example, the predominant wind direction was NNE and the collectors were positioned at an orientation between 280º NW (the first one) and 320º NW (the last one). In other words, they were oriented virtually perpendicular to the wind, as shown in figure 5.

Figure 5. Compass measurement of CloudFisher orientation and graphic of the predominant wind direction at the Sivingalito site



The maximum wind speed values of 60 km/h at Veladero (figure 6) and over 40 km/h at Sivingalito (figure 7) have not endangered the stability of the structures.

Figure 6. Wind speed (km/h) from January 2022 to March 2023 at the Veladero School site

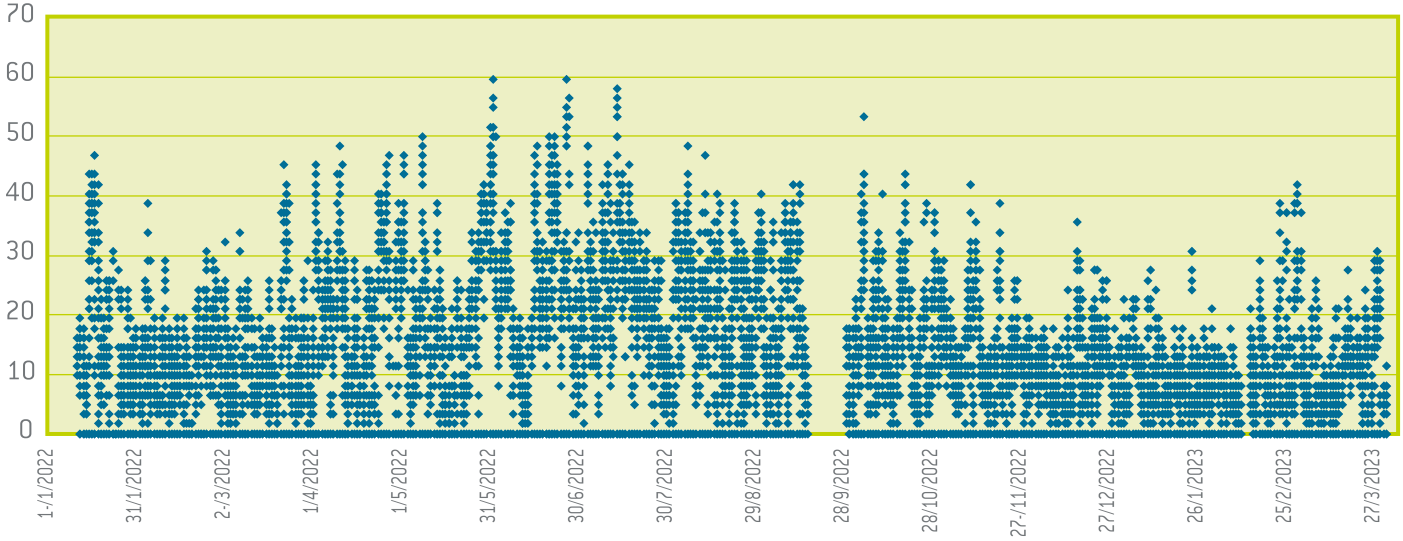
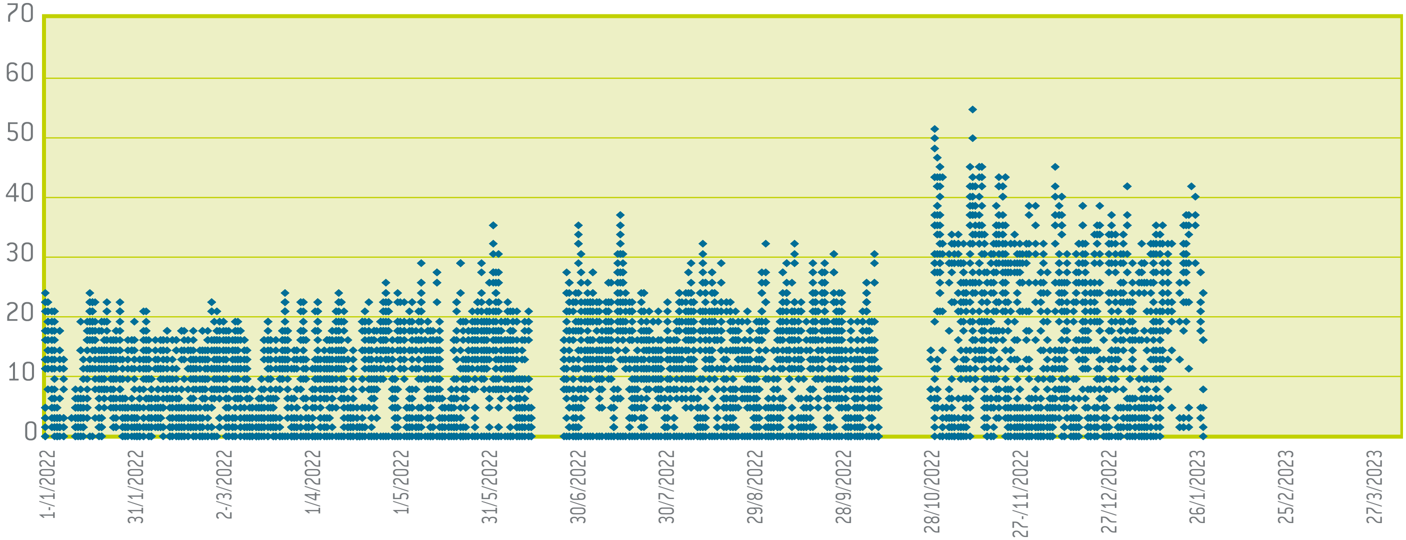


Figure 7. Wind speed (km/h) from January 2022 to March 2023 at the Sivingalito site



3.4. CloudFisher construction process

The CloudFisher system installation process at the 4 sites lasted approximately 2 months (August and September 2022), and the cooperation of the local community was essential for this. Each community organised itself in shifts, so that each day a sufficiently large number of people were on-site to support the site supervisor, his assistant and the ICO technician. Peter Trautwein, an engineer from Aqualonis, travelled to Bolivia to lead the installation process of the first panels and to train the local technical staff so that they could continue with the rest of the panels.

The construction phases of the ground anchors and the assembly of the panels were as follows:

1. Clearing and levelling of the terrain

The land on which the structures were placed must be free of vegetation and as horizontal as possible, leaving enough space for the construction of a solid foundation, which will ensure the stability of the structures.

It was important to remember that fog collectors are usually placed high up in the mountains, where the fog rolls through, and that these areas typically have an irregular relief. As a result, this first phase was not always easy.

2. **Measurement and staking out the foundation**

   The CloudFisher base consisted of large concrete footings that supported each of the vertical posts of the structure, as well as each of the rear anchor points.

   To prepare the footings, the distances between the posts were measured and the dimensions of the footings were marked on the ground, for subsequent excavation.

3. **Excavating the holes for the footings**

   The preparation of the holes for the footings was the most physically demanding phase. For this reason, the community members took turns to carry out the work.

4. **Bolting and levelling the anchor points**

   The anchor points were metal structures that are embedded in the cement footings – these were put in place and concrete was poured around them. Once the concrete dries, they are firmly fixed into place. The mesh support frames were mounted on the anchor points. To ensure that all the parts of the collectors fit together perfectly, it was essential to place the anchor points at the precisely correct height and distance from one another.

5. Assembly and installation of the panel frames and the rear anchor points

At this point, all the pipes were connected and the frames and the rear support brackets were installed.

6. Positioning of the mesh panels and water collection troughs

Both the mesh panels and the water collection troughs were attached to the metal frame by means of rubber expanders, which allowed the mesh some movement in the event of heavy winds.

7. Connection of pipes for water collection and storage

To collect the fog water, PVC pipes were connected to channel the water down to a storage tank, drawing on the force of gravity. The pipes were arranged in line and upstream of the water storage tanks.

The volume of the water collected at each location was measured by means of flow meters that were placed at the end of the water trough collection pipes of each of the CloudFishers.

3.5. Complete fog collection systems

The following diagrams (figures 8, 9, 10 and 11) show the set-up of each fog harvesting system. As explained above, the "Veladero School" fog collectors harvest water for the exclusive use of the teachers and students of the educational centre. However, at the other 3 sites, the harvested water is piped to the community's water supply network, meaning that it serves as an additional resource to the existing water supply that flows into the water network from natural springs.

Figure 8. Diagram of the fog collector system at the Veladero School site

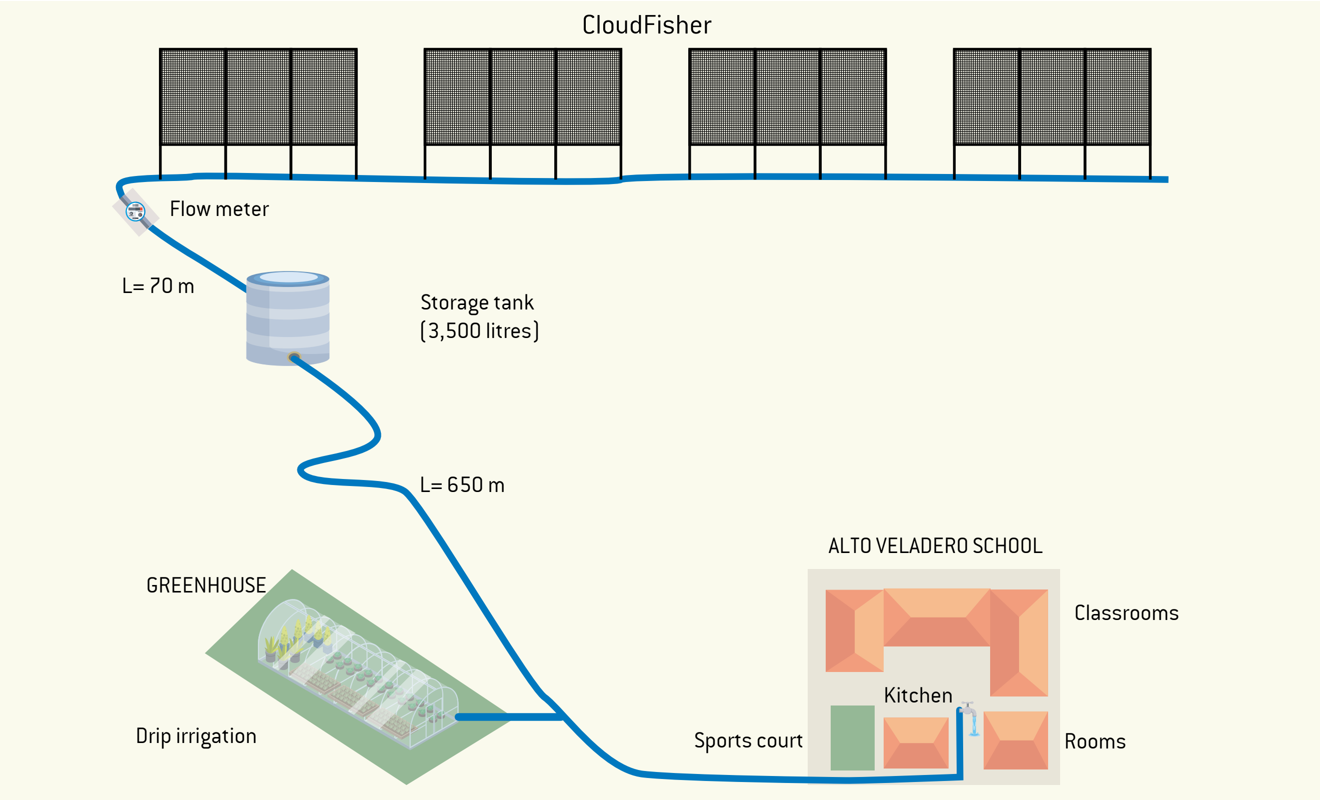


Figure 9. Diagram of the fog collector system at the Central site

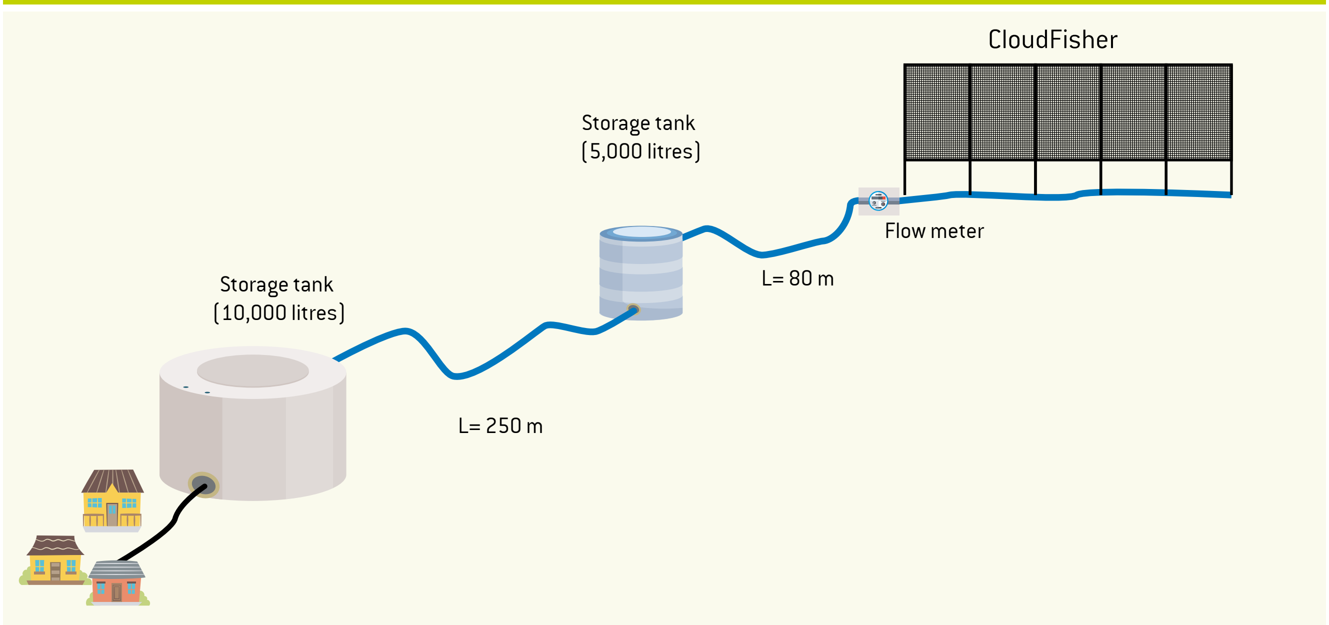


Figure 10. Diagram of the fog collector system at the Sahuintito site

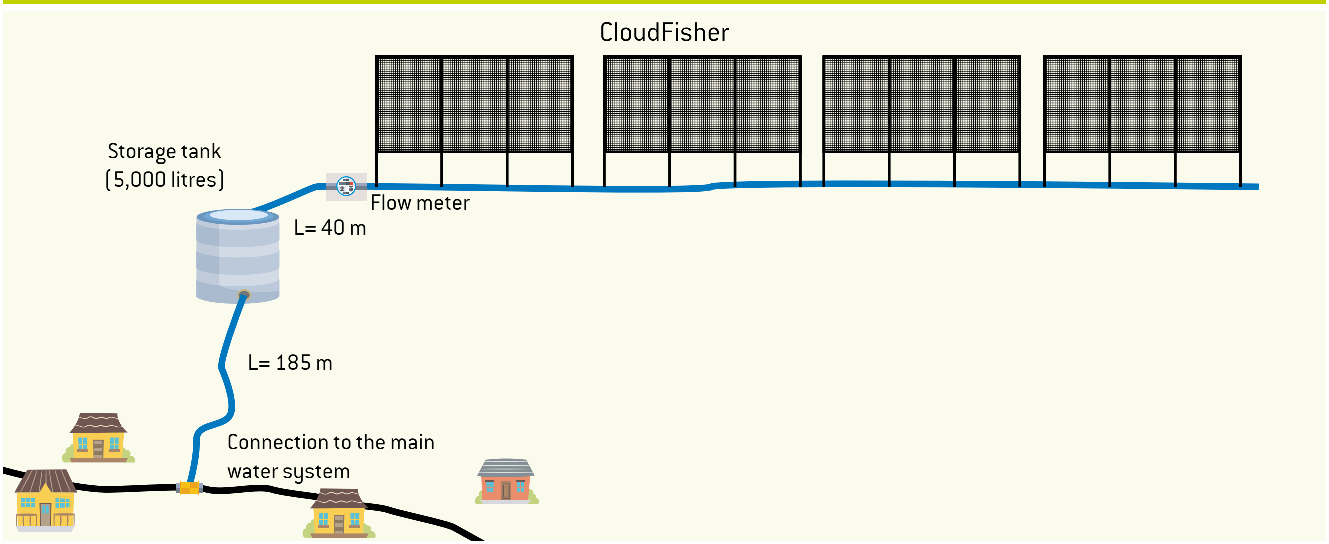
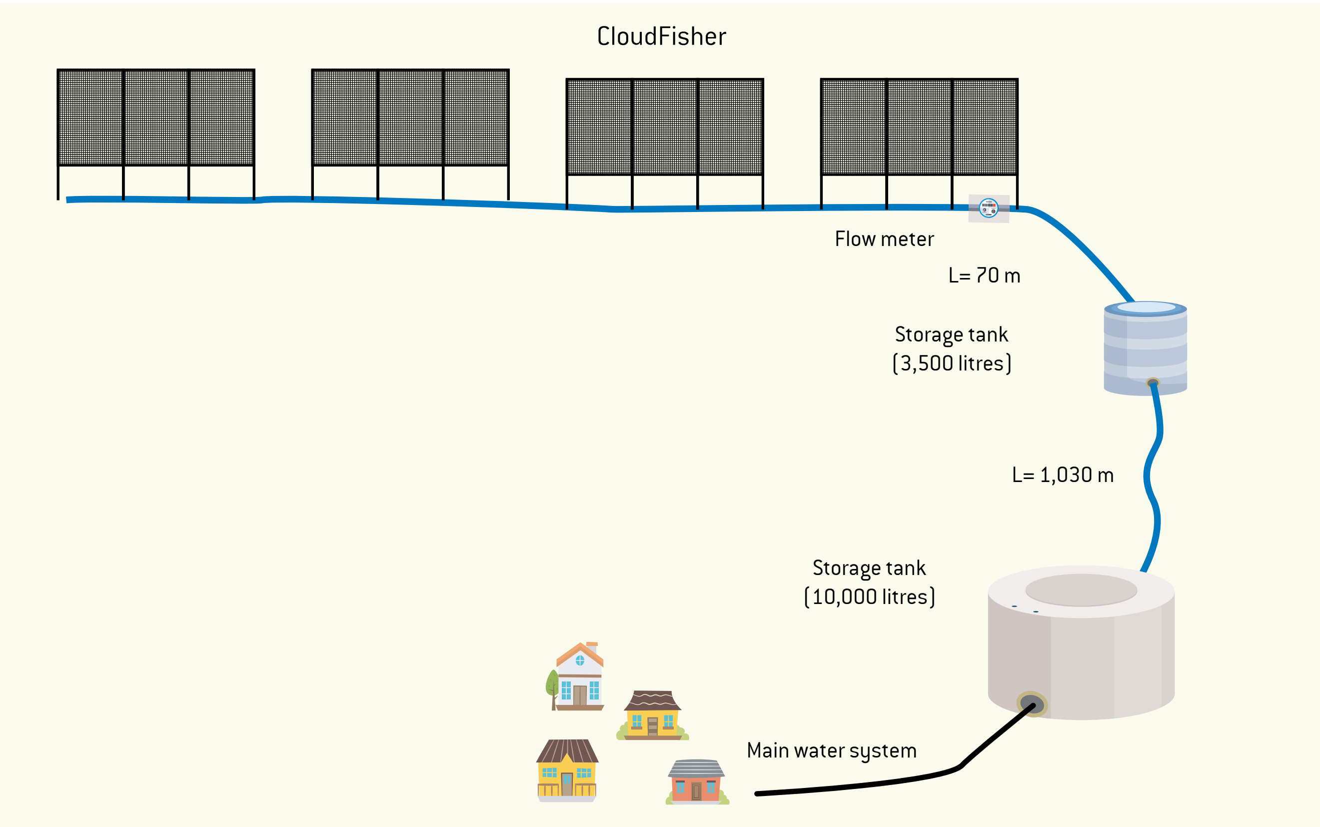


Figure 11. Diagram of the fog collector system at the Sivingalito site



4 Results of the Experience Using CloudFishers

3D mesh of CloudFisher

The construction of the CloudFisher systems was concluded in September 2022 and the data on the harvested fog water volume was recorded between October 2022 and March 2023.

These results were assessed based on two important factors: rainfall and the frequency of fog presence each month.

Although the fog collectors were designed to collect fog water, they obviously also collect rainwater. Hence, on days when the fog is accompanied by rain, the volume of water collected increases significantly. Rainfall during the months of October and November was not excessive, yet from December to the end of the study, it remained at levels exceeding 100 millimetres per square metre of surface area, as illustrated in Table 4.

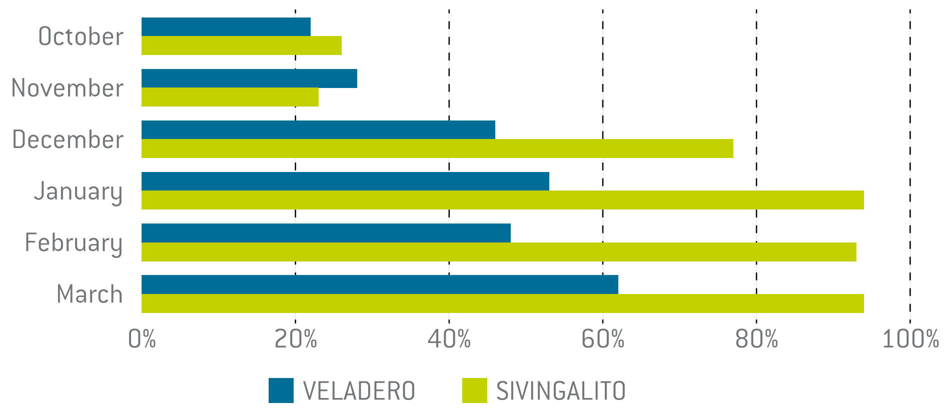
Table 4. Rainfall in Veladero and in Sivingalito

	Veladero (mm or ml/m²)	Sivingalito (mm or ml/m²)
October 2022	10-20	30
November 2022	30-60	30
December 2022	90-150	200
January 2023	140-200	300
February 2023	150-180	200
March 2023	200-250	180

Source: Average data from the weather stations in this study and from other stations in the Valles Cruceños area operated by the Autonomous Departmental Government of Santa Cruz.

Regarding the presence of fog, it was the families who live near the site of each study who recorded whether fog was observed each day, and the specific time of day of its occurrence. According to their records, both Veladero and Sivingalito experienced fog on more than 20% of the days of the month (figure 12). October and November were the months with the least fog, with around 25% of the days per month, and the presence of fog increased considerably in the months of January, February and March (coinciding with higher rainfall precipitation).

Figure 12. Percentage of days on which fog was observed, per month



4.1. Total volume of harvested fog water

Because the number of CloudFisher panels is different at each site, the total volumes collected are considerably different from one site to another. The more CloudFisher collectors there are, the greater the mesh surface area capable of harvesting the fog water and therefore the greater the volume of water harvested. Table 5 shows the mesh surface at each site, accounting for the fact that the surface area of each CloudFisher panel is 7.89 m^2.

Table 5. Total area of CloudFisher mesh at each site

	Number of CloudFisher screens	Mesh area (m²)
Escuela – Veladero	13	102.6
Central – Veladero	5	39.5
Sahuintito – Veladero	12	94.7
Sivingalito	12	94.7

Figure 13. Total volume of water collected by the CloudFisher system, per month at Veladero School site

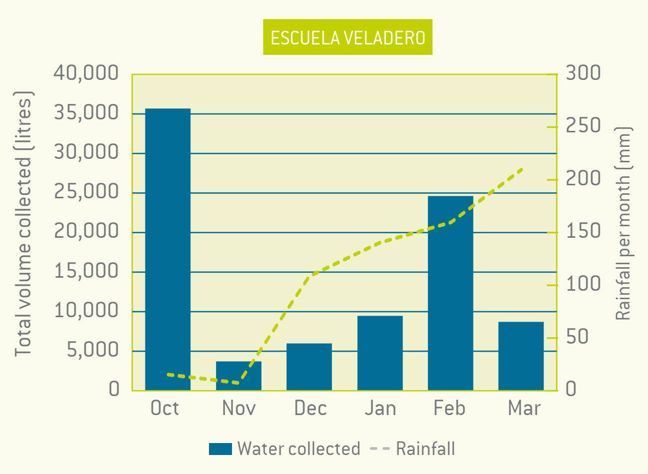


Figure 14. Total volume of water collected by the CloudFisher system, per month at the Central site

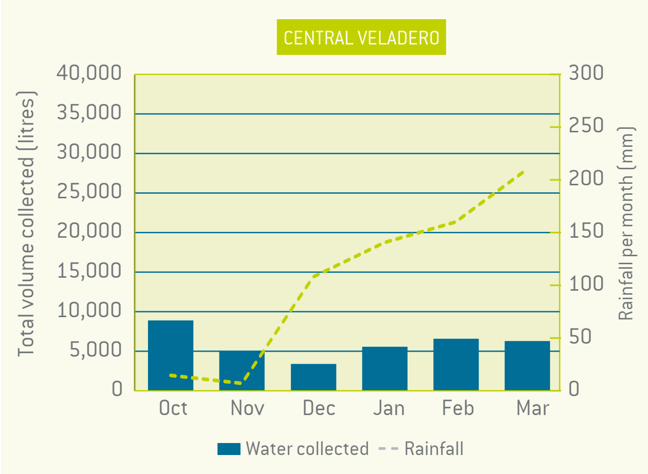


Figure 15. Total volume of water collected by the CloudFisher system, per month at the Sahuintito site

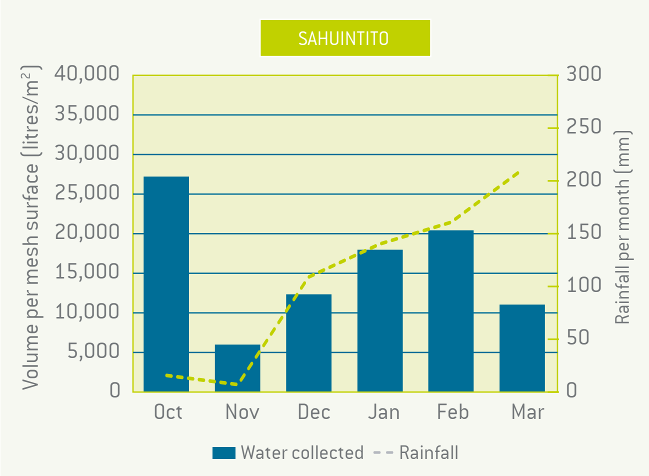
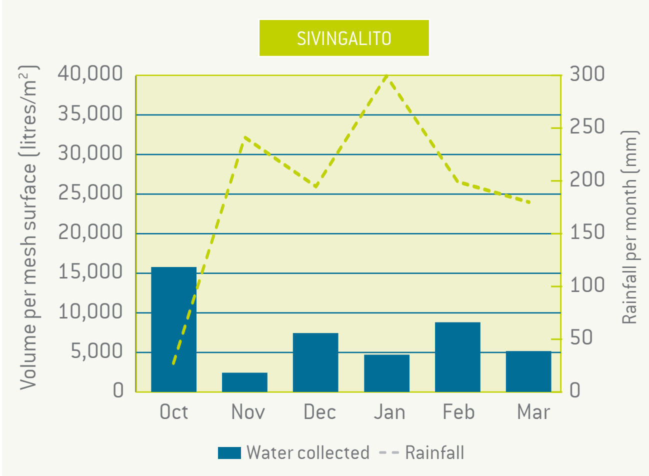


Figure 16. Total volume of water collected by the CloudFisher system, per month at the Sivingalito site



Figures 13, 14, 15 and 16 show the total accumulated volume for each month, measured by the flow meters located at the end of the set of CloudFishers at each site.

At the School, where there is a larger number of CloudFishers, **35,704 litres of water were collected during the month of October**, corresponding to 1,190 litres per day.

During the other months (November, December, January, February and March), large volumes of water were also collected, although it is important to bear in mind that those months typically receive considerable rainfall. Therefore, the volume collected does not solely reflect the fog water, but rather both fog and rain. As a result, the values for October are of greater interest.

With a total of 128 people attending the school, the CloudFishers were providing more than 9 litres of water per person per day.

In summary, large volumes of water, ranging from 3,000 to 35,000 litres per month, were collected at all the sites, and October was the month with the greatest fog water harvest, even though it was not the month with the greatest presence of fog or the highest levels of rainfall.

4.2. Performance

To compare the performance of the various sites, the volume of water per square metre of CloudFisher mesh was calculated.

Figure 17. Performance of the CloudFisher at the Veladero School site

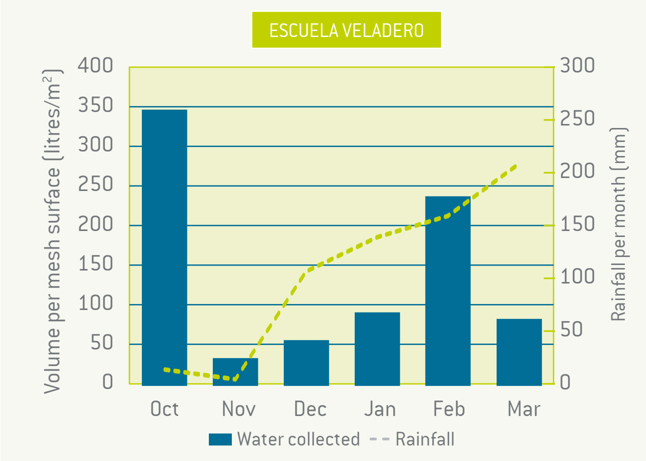


Figure 18. Performance of the CloudFisher at the Central site

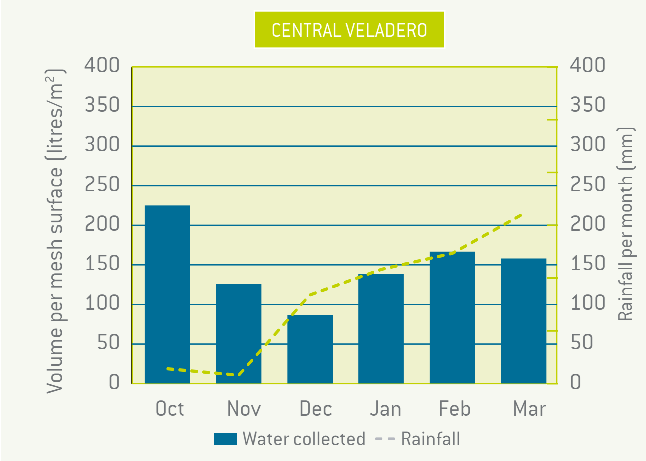


Figure 19. Performance of the CloudFisher at the Sahuintito site

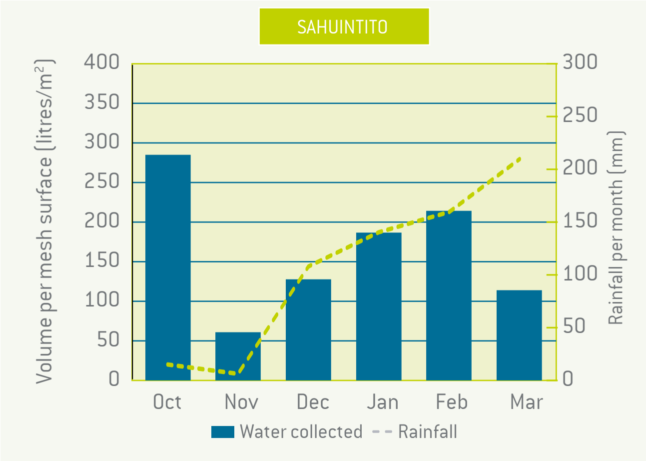
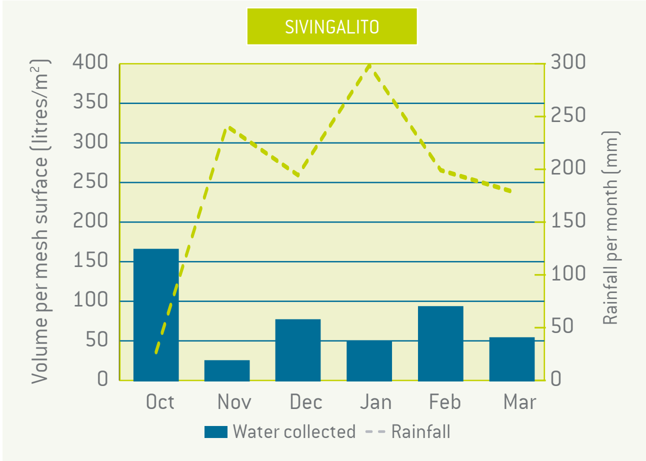


Figure 20. Performance of the CloudFisher at the Sivingalito site



One-inch flow meter to measure water volume harvested by the CloudFishers

The best performance was obtained at the School in October, with approximately 350 litres per square metre (figure 17), which translates to more than **11 litres of water per square metre per day**. This falls within the range of **6 - 22 litres per square metre per day** of other CloudFisher experiences in other places around the world[6].

In October, Sahuintito collected nearly 300 l/m2 (figure 19) and Central yielded 225 l/m2 (figure 18), corresponding to **10 and 7.3 l/m2 per day**, respectively. Sivingalito has remained at 150 l/m2 (figure 20), although this is still a very significant volume, considering that in the month of October the water reserves are scarce and there is hardly any rainfall; thus, any additional supply of water is highly valuable.

In the remaining months of the year, the performance was quite irregular and it is difficult to compare the different sites. This is because, as explained above, both the wind speed and particularly the wind direction may have significantly impacted the systems, making it more difficult for the CloudFisher systems to retain the small droplets of water from the fog.

4.2. Analysis of the water

The harvested fog water was intended for human consumption, and in order to ensure that the water was of sufficient quality, the water was tested. Specifically, samples were taken from the CloudFisher tanks at the 4 sites to measure physicochemical and microbiological parameters.

6 www.wasserstiftung.de/en/cloudfisher-extracting-clean-water-from-fog-with-innovative-technology

Table 6. Results of the tests carried out in the laboratory of the "Montes Claros" R.L. Public Services Cooperative, with water samples collected on 13 and 14 February 2023.

Parameters	Units	Maximum admissible values*	Fog water at VELADERO SCHOOL	Fog water at CENTRAL VELADERO	Fog water at SAHUINTITO VELADERO	Fog water at SIVINGALITO
pH	-	6.5-9.0	6.41	6.21	6.49	6.48
Temperature	°C	....	21.4	21.8	21.3	24.1
Specific conductivity	µS/cm	1500	21.8	7	16.7	11.6
Turbidity	NTU	5.00	2.56	4.44	3.59	2.63
Total coliforms	CFU/100ml	<1CFU/100ml	8	9	6	8
Faecal coliforms	CFU/100ml	<1CFU/100ml	2	3	3	3
Nitrites	mg/l	0.1	0.000	0.000	0.000	0.000
Nitrates	mg/l	45	0.02	0.03	0.01	0.07

*according to Norma Boliviana NB 512:2016 Agua potable - Requisitos

All the parameters showed values within the admissible maximums (table 6). A low level of coliforms was detected, although this is not a cause for concern, as it may be due to the presence of certain residues that can remain inside the storage tanks. To prevent this from occurring, it is advisable to ensure that the tank is free of plant debris and any other types of residues, and the tank should be cleaned regularly. To be sure of the water quality, the fog water supplied to the school was tested again some months later and no coliforms were detected.

In addition to analysing the usual parameters for water for human consumption, more complete tests were run to rule out the presence of any other microorganisms or chemical elements that might be present in the environment and carried along by the fog. Specifically, the water was tested for the presence of microorganisms other than coliforms (streptococci, clostridium, pseudomonas, etc.) and metals such as aluminium, arsenic, copper, chromium, zinc and fluorides, among others. The results were satisfactory.

The physicochemical and microbiological tests have confirmed that the fog water is suitable for human consumption.

Apart from the water from the fog collectors, tests were run on the water from the natural springs that currently feed the main supply network of the communities and the water that supplies the households, which is ultimately a mixture of fog water and spring water. The values for the physicochemical and microbiological parameters were good, although they were slightly worse than those of the water from the CloudFishers. Total coliform values between 5 and 30 CFU[7] and some levels of turbidity were recorded. Turbidity in springs is common, and it is easily removed via the use of the solids filters and settling systems in the communities' water supply and distribution systems. In addition to the analysis of the water, it is strongly advised to keep animals out of the springs and to clean the water supply system regularly, to lower the presence of coliforms.

7 UFC, Unidad Formadora de Colonias que es una medida para contabilizar el número de microorganismos viables en una muestra líquida o sólida.

5 Skills Building and Environmental Education

Members of the Veladero Water Committee speaking with ICO workers Limber Cruz and Adalid Salazar.

Projects such as this one, which contribute directly to improving access to water, an essential aspect for the well-being of rural families and a basic human right, and which are also innovative, are enormously inspiring for the local communities and provide an opportunity to develop new knowledge and skills.

In these remote rural communities, there are very few opportunities for technical training; access is further limited due to a lack of financial resources, limited education background, geographical isolation and family responsibilities (which are typically shouldered by the women), among others. For this reason, ICO staff implemented the project activities in constant coordination with the representatives from the participating communities, primarily the members of the Water Committees. The idea was to keep them well informed and to ensure that they had in-depth knowledge of the systems and the project work plan, so that they could contribute ideas and participate in the decision-making process.

Through the project activities, the Water Committees and community members received practical training in new construction techniques with anchoring and levelling, how to use weather stations, how to read and interpret data on rainfall, humidity, wind speed and direction, and the dynamics of fog and rainfall, among other skills.

Environmental education session at Veladero School

In fact, this understanding of the local climatic conditions based on specific parameters, their trends and variations due to climate change, and their impact on water availability and agricultural activities, is extremely useful information to help the local authorities and municipalities to make appropriate decisions to reduce environmental impacts and to adapt to climate change.

As part of this project, project staff also provided environmental education sessions at Veladero School. Finding new ways to provide water is as important as using it responsibly and efficiently, and to promote these practices it was necessary to build an awareness of environmental issues.

6 Practical Learnings and Conclusions from the Experience

Fog on the mountaintops in the Valles Cruceños area

The experiences of Zabalketa and ICO in the application of the fog water harvesting techniques in Bolivia between 2012 and the present day have resulted in numerous practical insights that may be useful when implementing this technique in other places.

From a technical perspective, Zabalketa and ICO have defined several **suitability criteria** for the identification of new sites for fog collection:

Although the priority has been to satisfy the population's drinking water needs, fog water can also be used can also be used for other purposes such as irrigation of crops or reforestation.

- **The need for water, whether for human consumption or for other uses**. Priority has typically been placed on meeting the drinking water needs of the local community. Nevertheless, water obtained from fog can also be used for other purposes, such as the irrigation of household vegetable gardens and reforestation.
- **Frequent presence of fog accompanied by moderate wind**. Geographically, the Valles Cruceños area is a transition zone between the rainforest (the edge of the jungle to the east) and the high peaks of the Andes (to the west). **The fogs that form here are orographic** and come from warmer and more humid areas. The mass of moist air moves up the mountain slopes and gradually cools until it reaches the dew point, where it condenses into small water

The fog water that supplies the Veladero School is also being used to produce vegetables for school lunches.

droplets that form fog. This phenomenon is known as the Föhn effect. Unlike the advection fogs that occur in coastal areas, this type of fog usually occurs all year round, making it of particular interest.

Although it is difficult to define a minimum percentage of days with fog to justify the installation of collector panels, in general, Zabalketa and ICO have worked with ratios of over 20% for all the months of the year and with a minimum annual average of 40%.

Regarding the wind, the movement of the fog facilitates greater water harvesting yields, although the wind speed must not be so high as to blow the droplets of water out of the fog collector meshes or collection trough; it also must not endanger the stability of the structure. These studies worked with wind speeds ranging from between 5 and 30 km/ (1.4 and 9.7 m/s) and the company Aqualonis estimates the optimum speed to be between 4 and 10 m/s.

↗ **Proximity to homes or to the residential water distribution network**. Fog collectors are placed high up in the mountains in order to capture the fog. At the same time, however, the sites must be strategically located so that the collected water can be channelled easily (by the force of gravity) and economically to the homes or to the place where the water is to be used.

All in all, fog collection is an immensely valuable technique for water supply in places where water is scarce, as it provides the following advantages:

- **FUNCTIONAL, as it provides large volumes of water even in dry months.**
- **SIMPLE, as its installation does not require any machinery or sophisticated technology.**
- **ACCESSIBLE, as the collector panels can be built with local materials. While the CloudFisher mesh offers the advantage of high yields and durability, the Raschel mesh panels have also displayed good performance.**
- **MODULAR, given that it is possible to install as many panels as may be necessary. Moreover, the number of panels can be adapted to the dimensions of the land where they are to be installed.**
- **COMPLEMENTARY, as the harvested fog serves as an additional source of water when the flow volumes of springs or other surface water sources decrease.**
- **ENVIRONMENTALLY SUSTAINABLE, as the water is naturally condensed and conducted via gravity to the point where it is to be consumed. Hence, it does not require any source of energy. It is 100% green technology.**
- **SOCIALLY SUSTAINABLE, because the local community has quickly adopted this technique, the maintenance of which is also straightforward and inexpensive. Moreover, private land has been assigned for this purpose, for the benefit of the entire community.**
- **FAIR AND EQUITABLE, as it contributes to lessening the inequalities of water access among the planet's least favoured communities.**

Representatives of ICO, the municipal government of Pampagrande and villagers of Sivingalito

This experience is a joint achievement of **Asociación Zabalketa** and **Instituto de Capacitación del Oriente**, the **German foundations WaterFoundation** and **Munich Re Foundation** and, above all, the women and men of the communities of **Alto Veladero** (municipality of Moro Moro) and **Sivingalito** (municipality of Pampagrande). Thanks to their efforts, enthusiasm, commitment and collaboration, it has been possible to guarantee access to safe water for all.

In this way, it contributes to progress in the Sustainable Development Goals proposed by the **2030 Agenda for Sustainable Development**, such as:

- ↗ SDG 6, by offering an alternative technique for obtaining clean water for human consumption.
- ↗ SDG 3, by contributing to reducing diseases related to water scarcity or poor water quality and promoting well-being for all at all ages.
- ↗ SGD 9, by promoting resilient infrastructures and encouraging the search for innovative solutions.
- ↗ SGD 10 and 11, by improving water services for communities in a clean, affordable manner and providing coverage for all.
- ↗ SGD 17, by learning, sharing, supporting and advancing collaboratively towards a common goal, between community organisations, local government and NGDOs and international entities.

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