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Characterization of fog water collection potential at Fort Ord and Glen Deven Ranch near Big Sur

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Abstract

Standard fog collectors (SFCs) that have been used all around were set up at two locations along the Monterey County coastline. The volume of water collected by the SFCs was measured periodically, either by hand or with a data logging tipping-bucket rain gauge. Measurements were carried out from June 26 until October 16 of 2005. The average collection rate at Fort Ord for the period of June 26 to July 22 was 0.08 $L/m^2/d$. The average amount of water collected per day for the period of July 22 to October 16 was 1.17 $L/m^2/d$ at Glen Deven Ranch and 0.37 $L/m^2/d$ on Fort Ord. From these data I have calculated that a set-up of fifty 48-m^2 large fog collectors (LFCs) at Glen Deven Ranch would produce 1,000,000 L a year. There is reason to believe that none of the collection rates obtain represents the maximum for this region as none of the collectors were at an elevation where moisture content of the air would be highest (397 m). Further study is needed.

Introduction

The amount of fresh water on Earth will never change, making it a non-renewable resource. However, it is constantly flowing through the hydrologic cycle, which has fostered the attitude among some that it is a renewable resource. Vapor condenses into clouds and precipitates as rain or snow, which then flows into rivers, lakes and swamps until it reaches the sea. Along the way, much of the water is taken up by plants or penetrates into aquifers. Ultimately water particles evaporate into the atmosphere, forming clouds and starting the cycle all over again (Olmsted 2004).

Humans have learned to manage water to their advantage by intervening in the cycle between the points where precipitation reaches the ground and fresh water empties into the sea. Over the millennia, humans have built dams to slow down the flow of the rivers to the sea, aqueducts to transport water to dry regions, irrigation systems to divert natural flows onto croplands, and myriad ways to collect and store rainwater and tap into aquifers (Cooper 2005).

In modern times, members of the non-profit humanitarian organization FogQuest have developed a new impediment to the hydrological cycle. Known as fog collection technology, it captures fog-water from the air before it precipitates into the ground or evaporates. Fog collection technology makes use of relatively simple devices called fog collectors. These are tautly erected nets facing oncoming winds that trap water particles in the air. The nets are connected by a transport system to a sufficient container where all the water collected is stored.

Fog forms when relative humidity of the air is high enough that water droplets can form around condensation particles. The relative humidity of an air parcel is the ratio of the amount of water the parcel is holding at its barometric pressure to the amount of water it could hold (saturation). Fog is the same thing as a cloud, a bunch of water droplets in proximity to each other. Relative humidity can rise if water vapor has been added to the air via evaporation or combustion, or if the air has cooled (Rosa 1984).

At any given barometric pressure, the dew point is the temperature at which the air will have 100% relative humidity. Water condenses on surfaces at this temperature. Fog forms when dew point and ambient temperature coincide. There is another condition necessary for the formation of fog water, which is small particles, called condensation nuclei, being present in the air. If there are not enough particles, fog will not form even if the ambient temperature is at the dew point and conversely, if there is an abundance of condensation nuclei in the air, fog will form at less than 100% relative humidity. Most fog forms around sea salt particles (Rosa 1984).

These particles form as water evaporates from the spume blown off the whitecaps in ocean waves. The amount of spume blown off is insubstantial and its moisture quickly evaporates. Additionally, bubbles rise from the ocean and break the surface. When this happens, the bubble creates a minute splash, which sends microdroplets of water into the air. These microdroplets of water evaporate very quickly. Both these processes leave behind airborne sea salt particles (Rosa 1984).

One of the conditions that results in fog formation is cool air moving over a wet surface that is warmer than the air. Bodies of water typically form fog because the heat capacity of water is much greater than that of air or land. Cool air is constantly being inundated with water vapor under such circumstances. Also if the night is clear, heat can quickly leave the regional atmosphere and fog forms (Rosa 1984).

In the case of the California coast, fog forms because the water inshore is cooler than the water offshore (Lerner 1992). Warm air moves over the cooler water and reaches its dew point. In the inshore of the California coast, there is substantial upwelling of cold water that wind must cross before blowing over land. In addition to this natural phenomenon, this area also experiences orographic fog, which is caused by wind moving up sloped landscapes. Rising air encounters lower pressure and expands to a larger volume, dispersing heat in a process known as adiabatic cooling. This is why there are often clouds along the coastal ranges disintegrating over the mountaintops.

The amount of water that can be collected from fog in any region is going to be influenced by many variables. Elevation, proximity to the ocean, and terrain are just some of the factors which will influence results (Schemenauer *et al.* 1994b). Such a place experiences wind consistently coming from one direction. It is necessary for the terrain to be mountainous so that the landscape fosters the development of advection and orographic fog. The ideal location would be between 400 and 1000 m (where 2/3 the height of a cloud usually is) because that is where the most liquid water is in stratus and stratocumulus clouds. These are the only clouds seen near the surface of the Earth (Schemenauer *et al.*

2005). Coastal regions along the entire coast of Monterey County experience foggy days, where fog occurs for at least part of the day, for 1/3 of the year (Ravn 2004).

How much water can be obtained at Monterey County locations with fog collection technology? To answer this question, I quantified the rate at which fog water collection occurs in selected portions of this region with the SFC described by Schemenauer and Cereceda (1994a). I used three of these devices throughout the entire study. They yielded measurements in volume of water per area of mesh per day ($L/m^2/d$). Many devices currently exist now that collect fog water, and they function with various degrees of success. However, the harvested water is usually not used for any purpose other than scientific study. Furthermore, the comparison of data obtained from different sites and/or time periods is complicated by the inconsistency of equipment utilized to collect fog (Schemenauer *et al.* 1994a). Making use of the SFC allows my data to be directly compared with that from other parts of the world.

For this study to be meaningful required that I find a location in Monterey County that met physical criteria that previous studies have determined are necessary for maximal collection. I tried to find locations that met all of the criteria described in the above paragraphs to perform this study. However due to constraints on access, time and mobility foggy locations were selected at lower elevations: initially only at Fort Ord, then also at Glen Deven Ranch near Big Sur. One collector was kept on Fort Ord after the other two were moved. From conversation with The Big Sur Land Trust employees, I was informed that Glen Deven Ranch was the foggiest location on any of the conservancy's properties. The measurements obtained on Fort Ord reflect the volume of water that came directly off the ocean in fog events, before significant advection occurred. The sites have been deemed Fort Ord 1, Fort Ord 2, Fort Ord 3, Glen Deven 1, and Glen Deven 2 to differentiate them throughout the rest of the report (see figure 1). The collector that was left behind when the other two were moved was stationed at site Fort Ord 3.

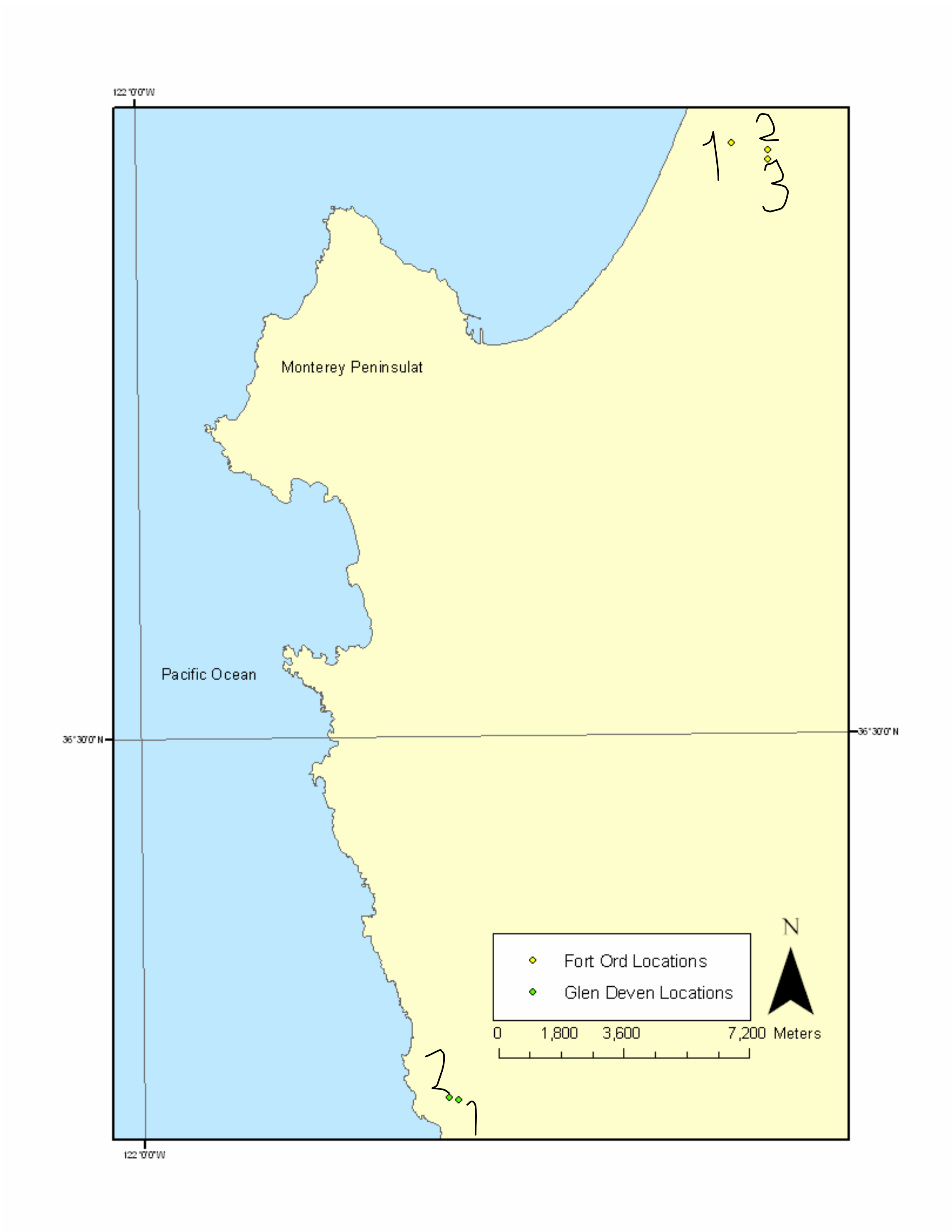

Figure 1. Map showing location of Glen Deven and Fort Ord Fog collectors relative to each other.

The number closest to a dot represents that site's number.

Methods

The SFC is composed of a 1- m^2 copper frame, a trough, and two steel posts. The copper frame is composed of four 1-m long sections of pipe connected with joints. A 2.15-m by 1.15-m piece should be cut out of 35% shade coefficient polypropylene mesh (obtained from Coresa in Chile). This piece should be cut so that the seams are parallel to small side of the rectangle and perpendicular to the other. This piece is folded across the top of the frame so that there are two layers of mesh wound around this structure extending about 7 cm over three of the sides (see figure 3)

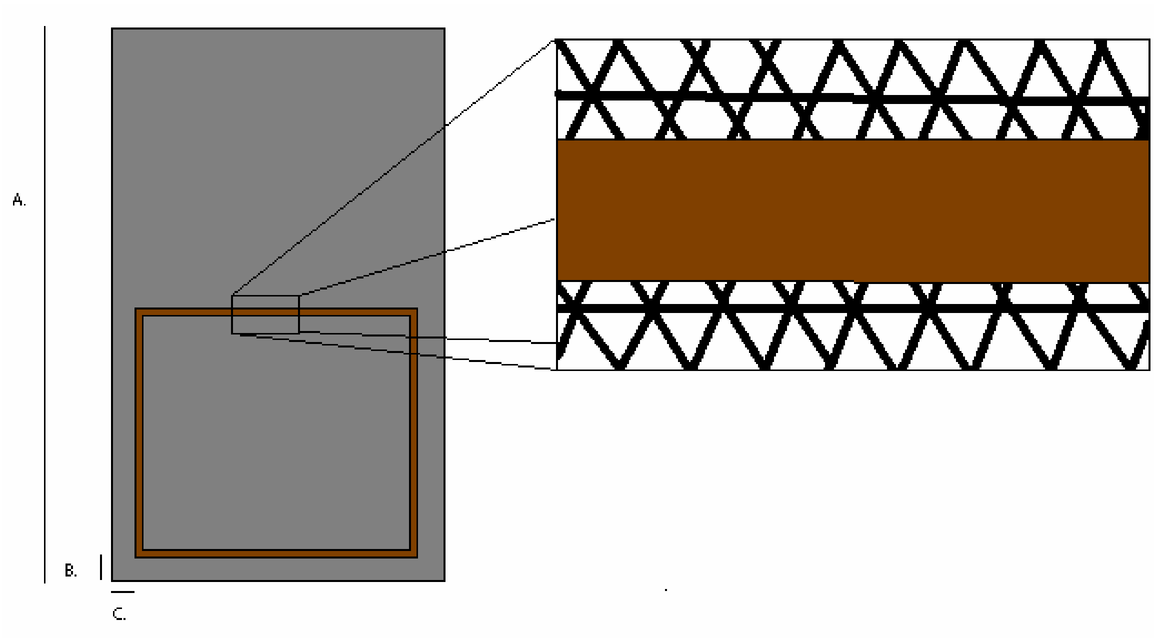

Figure 2. Properly cut mesh to be folded over copper frame across top pipe. Notice in close up how seem is horizontal to top pipe. Length of A.=2.15 m, B.=C.=7 cm.

The seams should be horizontal when the frame stands up. The mesh is woven in a triangular pattern and, if the above instructions are followed, it will ensure that water will trickle down the fibers all through out the mesh. With the mesh drawn tightly around the frame, a UV-resistant polypropylene thread was used to sew one layer to the other. The mesh was held in place by winding tape around the pipes so that the sticky side was exposed and pressing the mesh against it. After sewing was complete, excess thread and mesh was cut away.

The frame with mesh is then attached to the steel post with 20-cm long bolts. The frame was affixed to both posts at two points each so that its bottoms would be 2 m off the ground when the posts were erected and its top is more or less aligned with the top of the posts. The bolts pass through 10 cm of copper tube (which holds the frame in front of the posts) and then through the 5 cm posts, leaving a small protrusion which a nut is wound around (see figure 4).

On the bolts connecting the bottom of the frame to the post hangs a trough with a 1.04 m x 0.15 m catchment area. This trough is held in place by the copper tubes and extends 12 cm behind the frame and 2 cm in front. The bottom is tilted so that all water collected in the trough will pass through a spout. This spout was connected by clear plastic tube to either a tipping bucket rain gauge or a container.

The steel posts are 5 cm in diameter and stand slightly less than 3 m high. At approximately 2.5 m height on a post it is attached to two cables via cable clamps. The cable is looped through the cable clamps using a thimble so that a 10 cm long section of it can be attached to the main length of the cable with u-bolt clamps. On the other end of each cable is a stake. The cable is looped through the eye of the stake exactly like it is looped through the cable clamp except no thimble is used.

The posts are placed 1 m apart and buried 15 cm into the ground. When the posts are erect the stakes are nailed into the ground so that the cables are tautly strung between the post and the stake. They stakes should be nailed so that the cables meet at 90 degree angles at the posts and make 135 degree angles with the frame. Afterwards the SFC is completely set up as in figure 5.

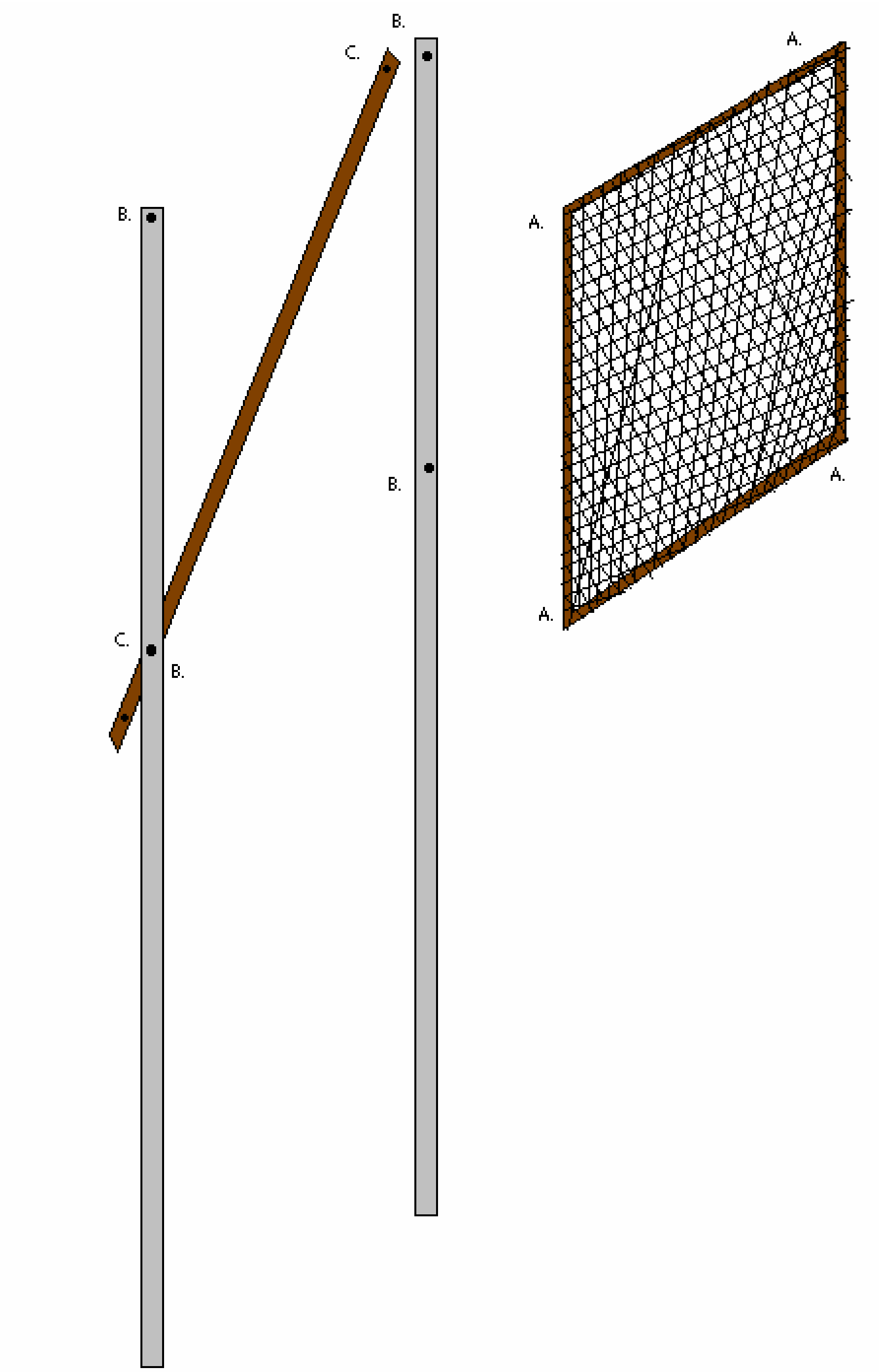

Figure 3. The 20-cm bolts go through the frame at all points labeled A. They pass through the steel posts at all points B. Additional support is provided by the copper pipe attached diagonally to the back. The bolts pass through points C. On the end of each bolt a nut is fastened.

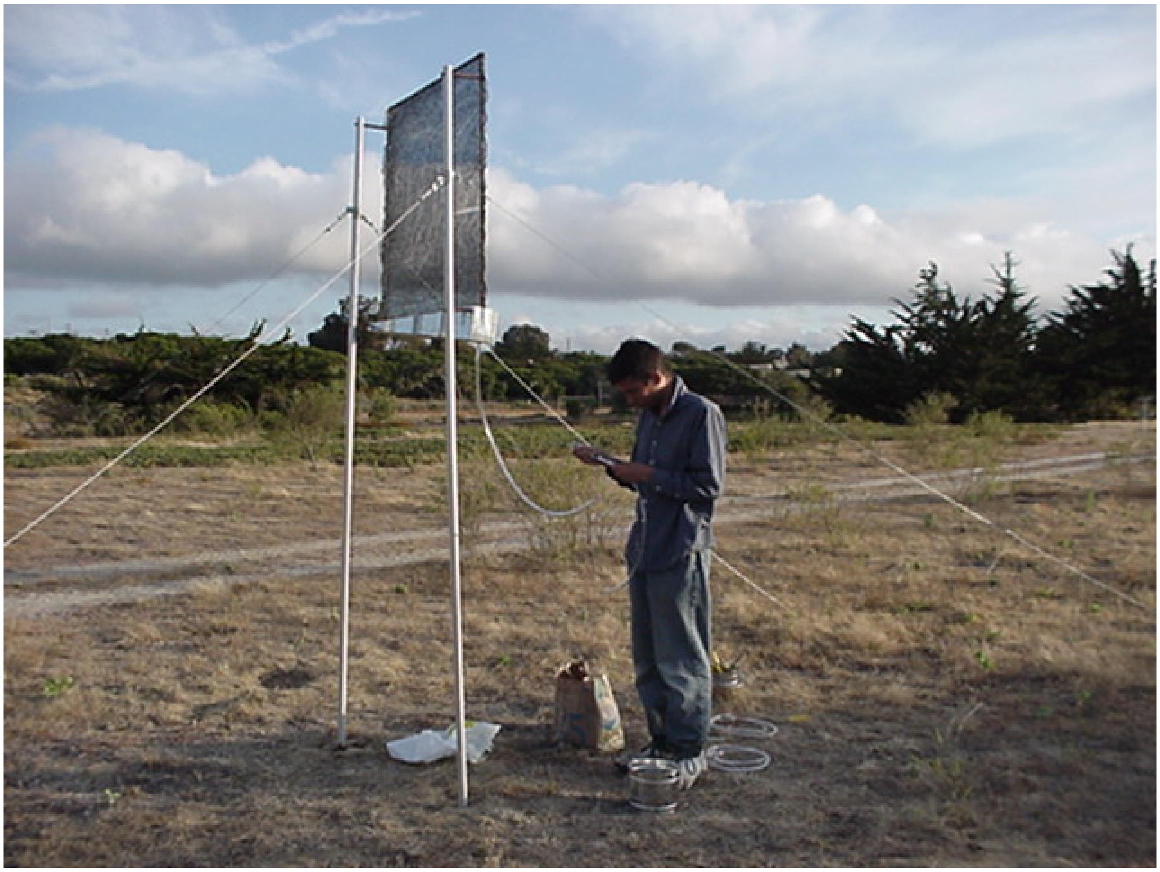

Figure 4. A completely erected fog collector.

SFCs were then set up at selected sites. Glen Deven is close to the ocean (see figure 5) and relatively mountainous (see figure 6). Fort Ord is flat but it is possible to find sites relatively free from obstructions (see figure 7). The exact parameters of the locations for each of the SFCs are listed in table 1. In each of the complete SFCs tubes lead from the spout on the trough to either a container or tipping-bucket rain gauge. Measurements obtained by the tipping-bucket rain gauge were recorded as precipitation (mm/h). These readings were converted to volume (L) by multiplying the precipitation measurement by the area of the tipping bucket rain gauge surface. Appropriate conversions were performed. When no tipping-bucket rain gauge was attached to an SFC, the tube was attached to a large container which was affixed to one of the steel post. The water was dumped into a graduated cylinder and the volume was recorded. This process was repeated many times if the volume collected was large. When it was found that the irregularly shaped 5-L containers was inadequate, 200-L cylindrical containers were used in their place which made it easy to calculate the volume of water that had been collected. All one had to do was measure the height of water in the cylindrical container and multiply it by the surface area of the top. It wasn't even necessary to empty that container as one could just subtract how much water volume there had been at the last measurement from the most recent measurement. The surface of the container was covered so evaporation was not a problem.

Table 1. Elevation and orientation of SFCs at locations throughout Monterey vicinity.

Location	Elevation (m)	Orientation (°)
Glen Deven 1	271	340
Glen Deven 2	292	310
Fort Ord 3	76	234
Fort Ord 2	55	270
Fort Ord 1	72	262

Figure 5. Behind SFC's at tip of Glen Deven.

Figure 6. Glen Deven from lookout point.

Figure 7. SFC is in center of picture behind cypress trees.

Whenever an SFC was not connected to a tipping-bucket rain gauge volume collected was measured by hand. From June 26 to July 22 all three collectors were located on Fort Ord. When there were SFCs at sites Fort Ord 1 and Fort Ord 2, they were never connected to a tipping-bucket rain gauge. At site Fort Ord 3 a tipping-bucket rain gauge was connected to the SFC from June 26 to July 10 and again from September 3 to October 16. In between this period measurements were taken manually and needless to say, no hourly data were obtained. From July 22 to October 16 a tipping-bucket rain gauge was connected to the SFC at site Glen Deven 2. Prior to this time the SFC had been on Fort Ord and measurements were taken manually. From September 3 to October 16 a tipping-bucket rain gauge was connected to the SFC at site Glen Deven 1. Initially the collector was on Fort Ord, and then it was moved but was still not connected to a tipping-bucket rain gauge.

Under those circumstances measurements were made manually. See figure 8 for more clarification.

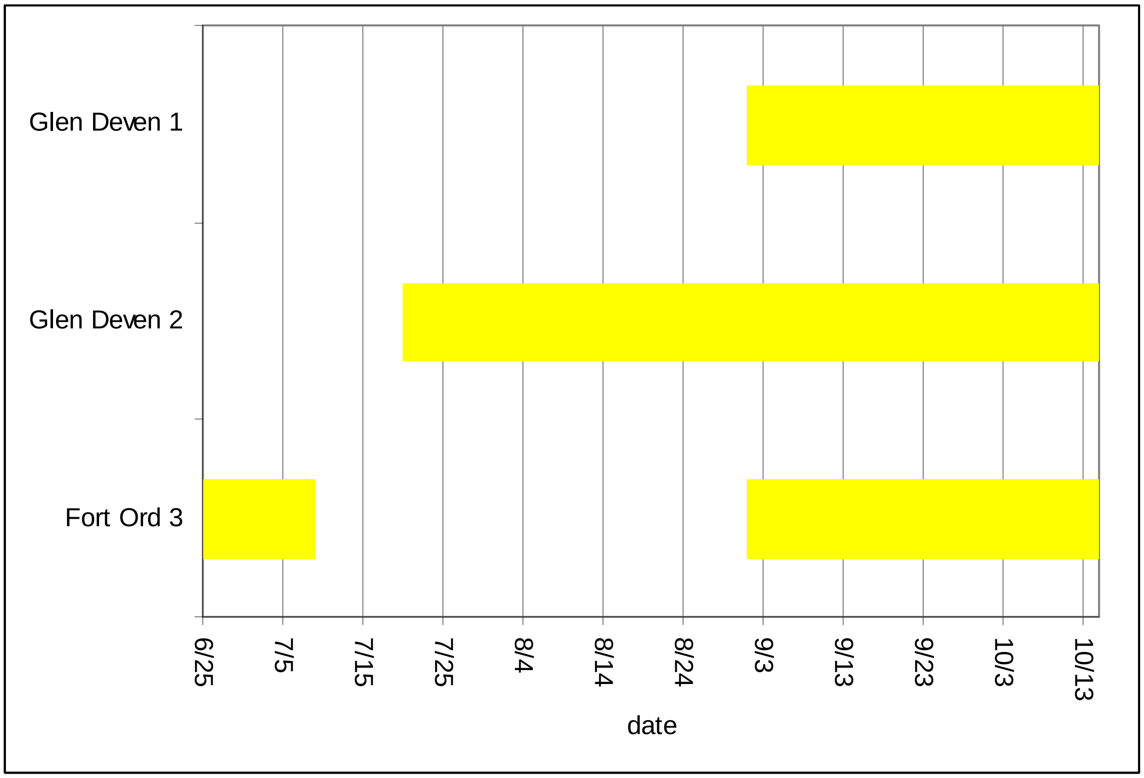

Figure 8. Bar represents time period when the SFC at a particular site was connected to a data logging tipping-bucket rain gauge.

Results

From June 26 to July 22, when all three SFCs were located on Fort Ord, the volumes of water collected were less than from July 23 to October 16, when two of the collectors were moved to Glen Deven Ranch (see figures 9 and 10). In one particular week more than 34.00 L were collected at one of the collectors at Glen Deven Ranch (see figure 10). On one of the days during that week, 7.12 L were collected.

Maximum hourly fog drip was experienced just prior to 6:00 A.M. at all three locales (See figures 11-13). Virtually no fog drip was collected in the afternoon. Note that only when an SFC was connected to a data logging tipping-bucket rain gauge could hourly measurements be obtained.

The volume of water collected at Glen Deven Ranch was between 2 and 30 times the volume collected on Fort Ord. The average amount per day at Fort Ord for the period of June 26 to July 22 (when all three collectors were at that site) was 0.08 $L/m^2/d$. The average amount of water collected per day for the period of July 22 to October 16 was 1.17 $L/m^2/d$ at Glen Deven Ranch and 0.37 $L/m^2/d$ on Fort Ord.

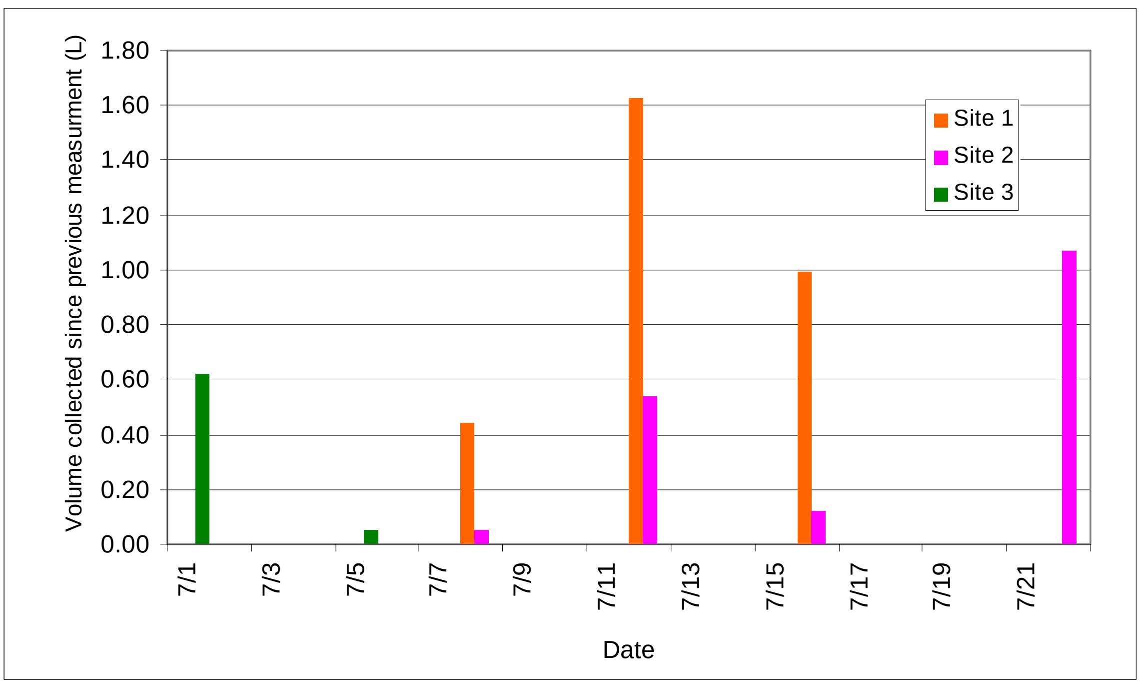

Figure 9. Volumes of water measured at each SFC on a specified date for the period when all three are on Fort Ord. Volumes collected represent collection that occurred on all days after last measurement but before specified date. Data collection started on 6/26.

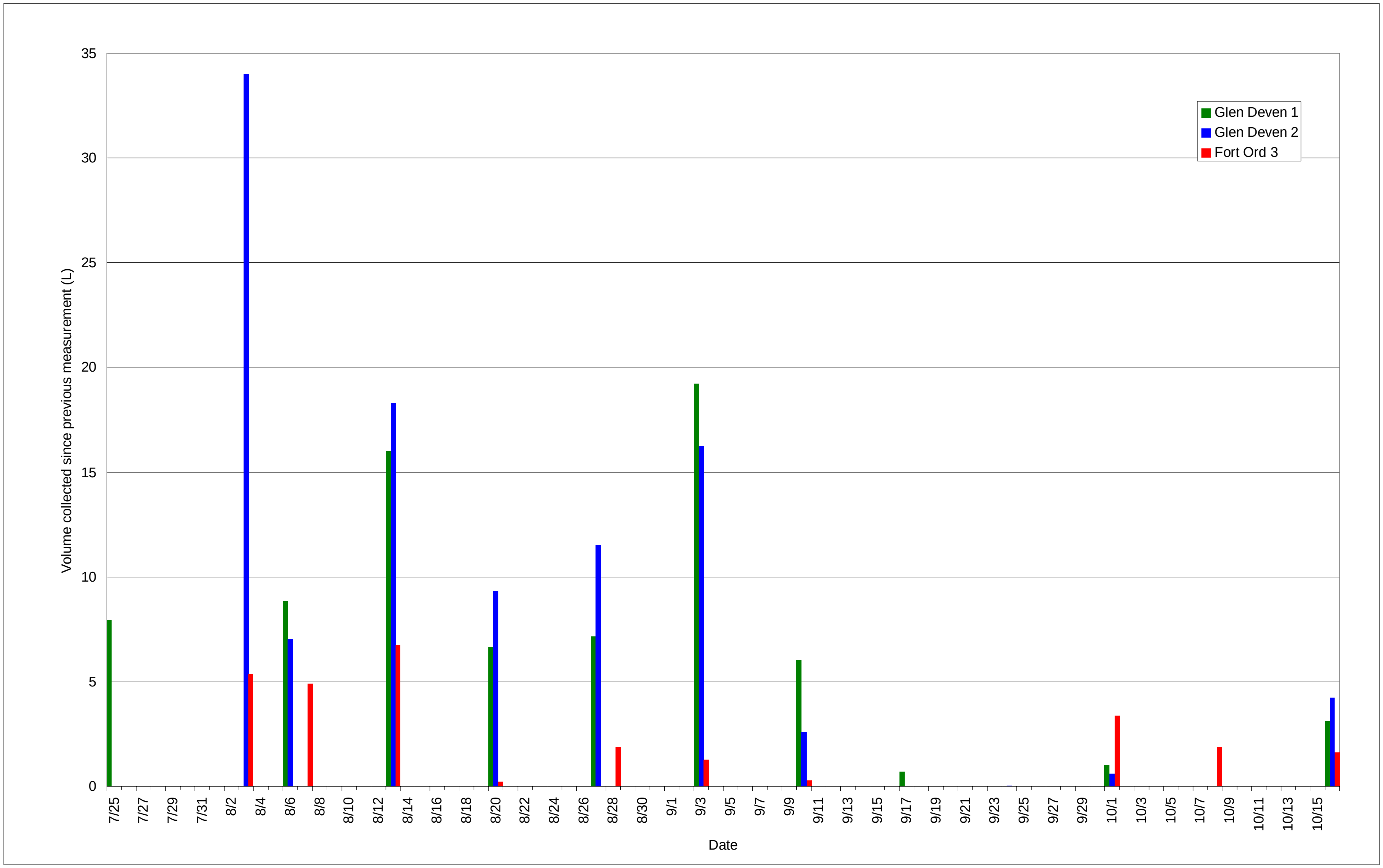

Figure 10. Volume of water measured at each SFC on a specified date when two were at Glen Deven and one was at Fort Ord. All volumes measured represent collection that occurred after last measurement and up until specified date. Data Collection started on 7/22.

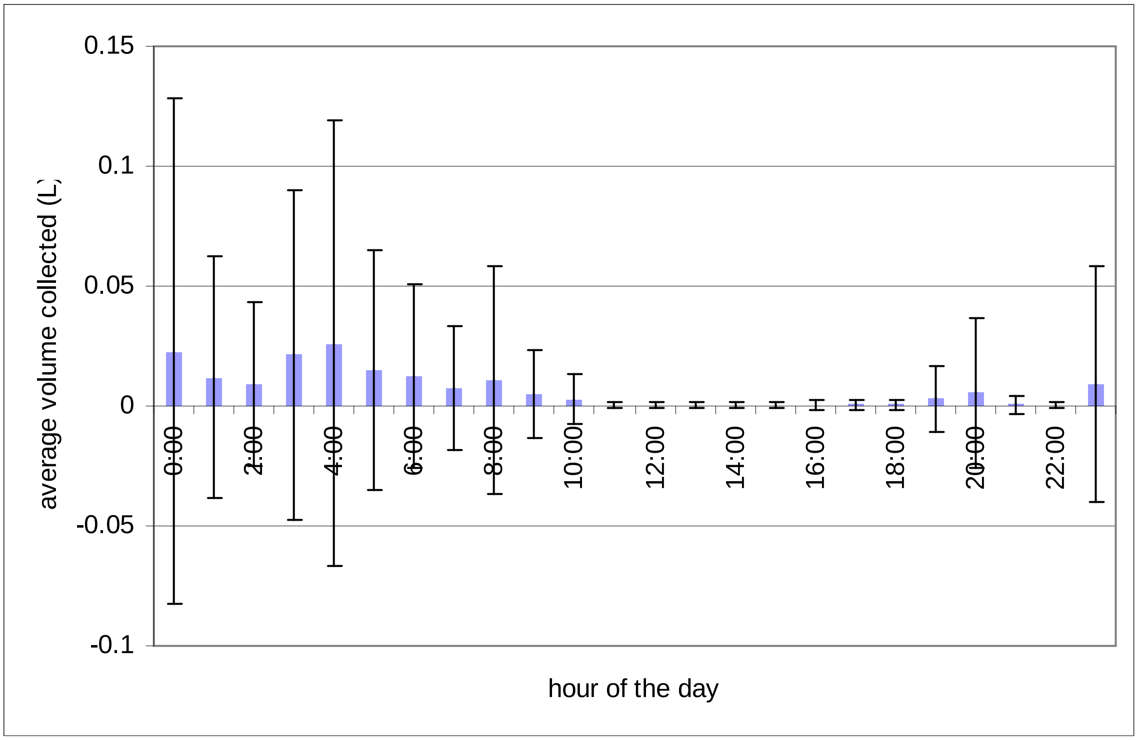

Figure 11. Average volume of water collected during a specified hour of the day for period when an SFC was stationed at Fort Ord 3. Only data logged by tipping-bucket rain gauge could be used to calculate the hourly means.

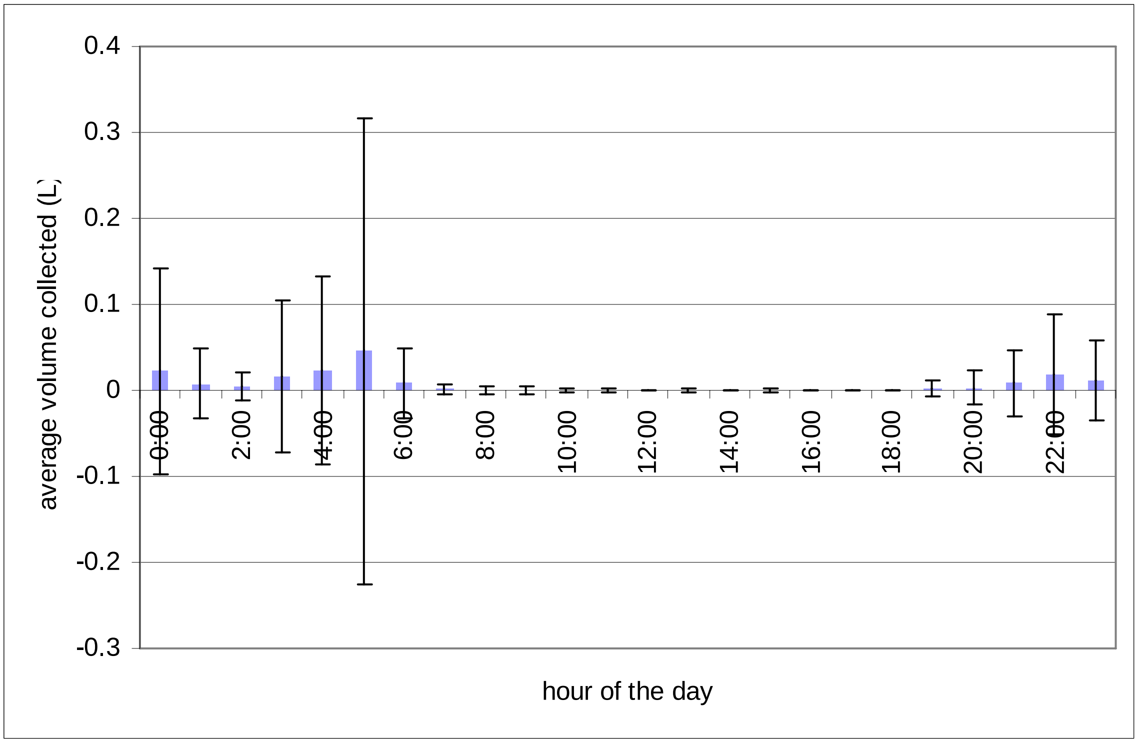

Figure 12. Average volume of water collected during a specified hour of the day for period when an SFC was stationed at Glen Deven 1. Only data logged by tipping-bucket rain gauge could be used to calculate the hourly means.

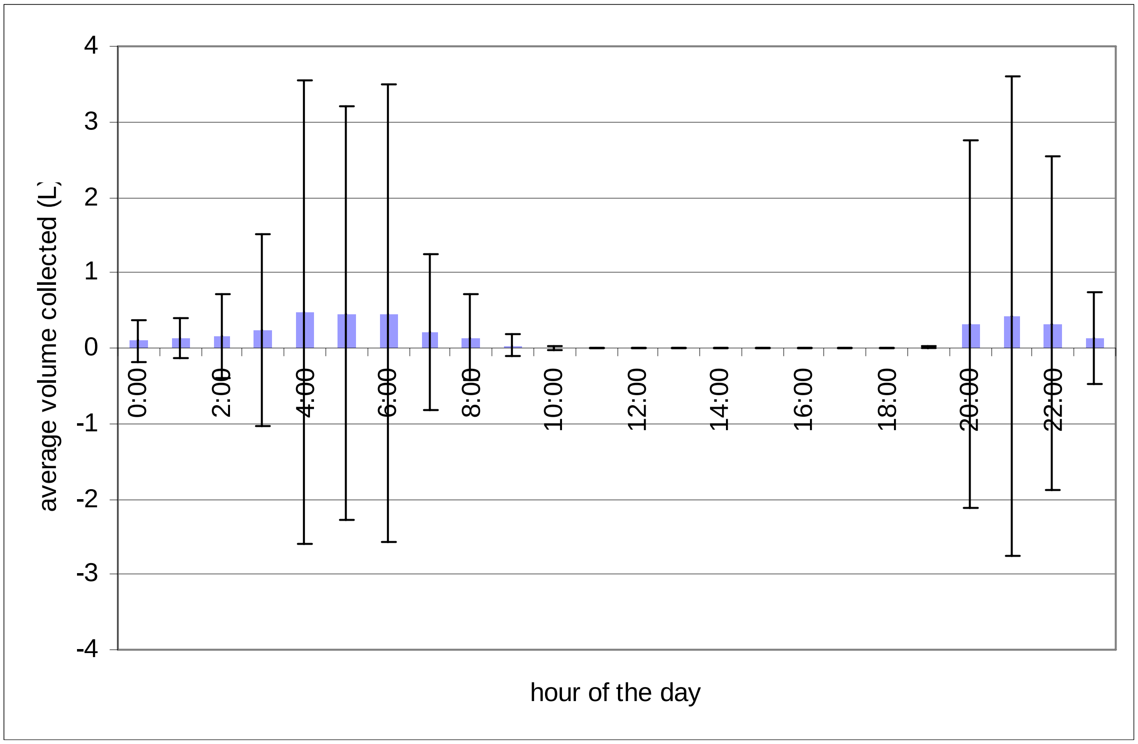

Figure 13. Average volume of water collected during a specified hour of the day for period when an SFC was stationed at Glen Deven 2. Only data logged by tipping-bucket rain gauge could be used to calculate the hourly means.

Discussion

August was the foggiest month of the year thus far on Fort Ord. It is reasonable to assume that this was also the foggiest month for Glen Deven Ranch because they are close enough to experience the same weather throughout the year. Thus they would be subject the same dominant weather patterns for the summer, which in the case of the central California coast is a semi-permanent subtropical high pressure zone (Lerner 1992). Furthermore, although there were differences of scale for the volumes of water collected hourly at the three sites, a general pattern can be seen (figures 11-13) at all three locations where collection does not start until the evening, reaches its highest level right before dawn and ceases to occur before noon. That this pattern is so similar at all three sites in spite of the differences in elevation and/or time of observation also suggests that Glen Deven Ranch and Fort Ord experience the same weather pattern.

The reason that site Fort Ord 3 experienced the least amount of hourly collection (see figure 11) is that significantly more condensation had occurred when fog encountered the SFCs at Glen Deven Ranch due to those sites' higher elevations. The difference between the two Glen Deven sites is due to the fact that at site Glen Deven 2 (see figure 12), the fog collector had been attached to a tipping-bucket rain gauge through the prime fog collection months (July and August) while at site Glen Deven 1 (see figure 13), the fog collector was only attached to the tipping-bucket rain gauge for September and October.

As noted in the methods, the elevation of the sites limited the collection rate. Usually, cloud bases along the central California coast are 150 m above ground and cloud tops are 500 m above sea level (Goodman 1982). The maximum amount of water in a cloud is approximately 2/3 the distance to the top of the cloud, a height of 397 m along the California coast. Further study is needed to determine the maximum amount of water that can be collected from fog.

Additionally, SFCs would get blown over and containers would overflow throughout the study. While there were periods of time when data were not being collected at one particular site, at no point during the study were data lost from all three fog collectors at the same time. At least one collector was producing quality data at any point during the study. The conditions which usually sabotaged a collector for a period of time were either high winds or particular dense fog causing a container to overflow. Both of these occurrences are associated with high collection rates near the ocean. Therefore, the statistics obtained for average collection rates at Fort Ord and Glen Deven Ranch are probably underestimates.

A large fog collector (LFC) measures 4 m by 12 m and thus would be capable of producing 48 times the volume produced by an SFC. Communities that used fog collection as their primary water resource typically set up 50 of these devices to obtain their water supply (Schemenauer *et al* 20005). Supposing that 50 of the LFCs were strung up on Glen Deven Ranch the amount of water produced would be 1,000,000 L (assuming that the average rate of collection is about the same throughout the year). Currently the average household in Monterey County uses 424,000 L per year (530,000 L if it is a suburban household) (WACMC n.d.). A set of fifty (LFC) could support 2.5 households using water at current rates.

Communities that rely on fog collection as a water resource all have higher rates than the 1.17 L/m^2/d observed at Glen Deven Ranch. Comparable fog collection rates from around the world are as follows: Chile, 3.0 L/m^2/d; Peru, 9.0 L/m^2/d; Oman, 30.0 L/m^2/d and Madeira Islands 21.3 L/m^2/d (Prada *et al.* 2001). While the rates obtained for this region are lowest, it must be remembered that the SFCs were not optimally placed.

There are other uses for fog collection technology besides for human consumption. It can be used for restoration of cleared forests in mountains. The devices provide water to young seedlings until they are large enough that they can get provide their own water through fog drip. Fog water can also be used to irrigate crops. It is important for fruit and vegetable gardens in arid regions.

The quality of fog water I collected was affected by bird defecation. Droppings were persistently deposited on the mesh and within the trough. Water collected in other regions met World Health Organization drinking standards, but I believe water collected from this region would need to be treated if it was to be used for human consumption.

Chungungo had been the most famous case of a community whose water problems had been solved by the implementation of fog collection technology. However, Chungungo has recently decided to discontinue the use of LFCs, instead opting to have their water brought in via truck from 40 km away. The reasons for the failure of fog collection to become a fixture of this town are a myriad. The residents were not adequately involved in the implementation of the project and tended to see it as a gift. The fact that they had to pay as well as perform work to upkeep it was largely seen as an annoyance. There were a multitude of agencies involved in the project; however no agency ultimately took on the responsibility of overseeing its success. Historically, residents had received free water and electricity from a local mine and many still feel that is the ideal way to be supplied (Nef n.d.).

Another problem was the lack of engineering input into this project. The design of the nets and frames is ideal, being cheap, efficient and easy to put together. But the distribution of the water was never addressed by project planners and future project managers need to figure out how the fog water will get to people beforehand. Initially the project started as a means to reforest cleared slopes. The people involved had a background in science. The development of the project into a water supply for human consumption occurred only after it was realized how much water could be collected from fog. In the end, the project had endless scientific data suggesting that it would be a success but not enough sociological research was done to identify how the community would receive the project (Nef n.d.).

There are many factors besides how much water is available that affect the success of fog collection in a given locale. Communities whose members choose to undertake the development of a fog collection project needs to make a commitment of several years to see it truly take off. Significant time and effort must be invested to secure funds. Field investigations are necessary to determine optimal placement and require the purchase of equipment that will not necessarily be used to build the water system (Schemenauer *et al.* 2005).

The community must want the water and be willing to pay for and maintain the equipment. Conditions in the community must allow for some risk to adapt to the new technology. If the community is severely depressed, then it should not undertake a project to bring in an alternative water source. There needs to be people with knowledge and ability to maintain the equipment among the community (Schemenauer *et al.* 2005). It cannot be overemphasized that malfunctions will occur. In fact it is important to determine if local weather patterns might be particularly harsh to any erected edifice. If that is the case, it might be possible to only have the fog collector up for part of the year, or to take it down when weather is particularly violent (Schemenauer *et al.* 2005).

I feel that more research is needed before it can be determined if this possible alternative water resource for coastal Monterey County locales. Future scientific inquiries need to find a higher elevation location and to set up additional meteorological equipment besides a tipping-bucket rain gauge to determine if certain weather conditions are particularly conducive to fog water collection in this region. Additionally, our local community needs to be surveyed to see if they will be willing and able to accept fog collection technology as their water resource.

Acknowledgements

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