Thematic week: Water and Land

Thematic axis: Land Use Planning, Forest Cover and Afforestation

Títle of the presentation: Fog: a sustainable source of water for people, forests and afforestation

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Abstract:

Fog is a natural part of the hydrologic cycle and, like precipitation, provides a vital water source for all life. Its contribution to water inputs at a particular location can vary from 0 % to nearly 100 % in some high-elevation desert environments. Fog is composed of tiny, water droplets from 1 to 40 µm in diameter. Typical droplet diameters are around 10 µm. Some types of trees are efficient at collecting these small, wind-blown fog droplets. They coalesce on the needles or leaves to form larger drops and then drip onto the ground. In high-elevation forested areas, in temperate latitudes, this process can provide 20 to 50 % of the water input to an ecosystem. FogQuest, a registered charity, uses specially chosen meshes to collect fog water in arid environments, to provide water to communities, for domestic, agricultural and forestry uses. The background to fog collection and some current applications will be presented in this paper.

Key words: Fog, fog collection, desert, forest hydrology

1. Introduction

In any discussion of the sustainability of forests it is important to understand that rain and snow are not the only sources of water in either arid or temperate environments. Substantial amounts of water enter watersheds through the interception of fog droplets by vegetation. This process of fog deposition is especially productive in mountainous areas. The combination of fog, with low visibilities, and moderate winds, leads to high fog fluxes that can be utilized by vegetation or collected by artificial fog collectors. Fog water has been shown to be responsible for 20 to 30% of the water inputs in high elevation forests in the Eastern US. The percentage may approach 100% in isolated forests on the west coast of South America. As well as being a significant water input, fog can be a source of nutrients for forests and also a wet deposition pathway for pollutants (e.g. Schemenauer et al. 1995). A registered charity, FogQuest, utilizes large fog collectors to provide clean water for villages in some of the world=s driest environments. Presently there are operational fog collection projects in countries such as Chile, Peru, Guatemala, Cape Verde Islands, Eritrea, South Africa and Nepal.

There have been a number of reviews of the history of projects to collect fog water, e.g. Nagel (1956), Kerfoot (1968). As early as the 1890s reports on fog drip from trees in California were being written and shortly after 1900 active projects to collect fog water took place in South Africa. In general, the water projects did not succeed due to a lack of understanding of the physics involved in the collection process. The modern era of fog collection research began in 1987 in Chile, with the cooperation of a team from Canada. Efficient, low-cost fog collectors were developed (Cereceda et al., 1992; Schemenauer et al., 1988) and are being used to provide water for communities in locations where conventional sources of water are unavailable. In Spain, work is presently being done to utilize fog water to restore degraded forest areas (Estrela et al. 2007; Valiente et al. 2007).

2. Properties of Fog

As well as being present at low elevations as radiation fog, or advection fog off the ocean, fog is even more frequent on hills and mountains. In these locations, fog is produced by both the movement of clouds over the terrain and by the effects of the topography, which forces the air upwards where it can condense on microscopic particulates in the air to form fog on the hills. In meteorology, fog is present when the visibility is less than 1 km. Fog is composed of tiny water droplets. The droplet diameters range from 1 µm to 40 µm. These are the same sizes as cloud droplets and, indeed, fog is simply a cloud with its base on the ground. Because of their small sizes, fog droplets have very low fall velocities, typically less than 1 cm s^{-1} but up to 5 cm s^{-1} for the largest sizes. They thus move essentially horizontally with the wind (Schemenauer and Cereceda, 1994a). Fog liquid water contents typically range from 0.05 to 0.2 g m^{-3} but can reach higher values when the bases of large convective clouds move over the terrain. The collection of fog droplets depends on the diameter of the droplets, the wind speed and the nature of the collecting surface. In places where fog is frequent, wind blown fog droplets are collected by vegetation in enormous quantities, large drops then form on the foliage, and these drops fall to the ground. This natural fog collection process sustains forests in the tropics (cloud forests) (Bruijnzeel et al., 2008), is an important water input to coastal forests in temperate latitudes and is the sole source of water for trees and plants in some desert regions of the world (Follmann, 1963).

3. Amounts of Fog Water Available

A simple way to measure horizontal fog fluxes is with a standard 1 m^2 fog water collection device known as a Standard Fog Collector (SFC). The construction and use is described in detail in Schemenauer and Cereceda (1994b). Evaluations of fog fluxes using an SFC have shown that on mountains in the deserts of Chile, Yemen and Eritrea, average fluxes ranged from 3 to 8 liters of water per square meter of vertical mesh surface per day. Given the 50% efficiency of the SFCs, this means that in arid regions, in the driest times of the year, there was about 10 L m^{-2} day^{-1} of fresh water moving over the surface. In other countries, measurements of fog fluxes have shown average values as low as 1 L m^{-2} day^{-1} in Namibia and as high as 70 L m^{-2} day^{-1} in the Sultanate of Oman.

Fog collectors are made of an inexpensive, durable polypropylene or polyethylene mesh (Schemenauer and Joe, 1989). The mesh has fibers that efficiently collect the fog droplets and is woven to allow for rapid drainage of the collected water. The mesh is erected in vertical panels that are 4 m high by 10 or 12 m long. Depending on the location, each panel produces 150 to 750 liters of potable water per day during the fog season. The operational projects to date have used from 2 to 100 fog collectors. Projects have shown success even in locations with as little as 1 mm per year annual precipitation.

The total quantity of water produced by large (40 to 48 m2) fog collectors depends on the number of fog collectors installed and the collection rate at the site. The longest running site (Cereceda et al., 1992; Cereceda et al. 1997), in the coastal desert of Chile, supplied a village with clean water for ten years. At its maximum of 100 fog collectors, the fog collector array at this site produced an average of 15,000 L of clean water each day of the year, in an arid region with an annual precipitation of only 60 mm. In order to have a successful project, a social need for water must be present, the correct meteorological conditions must exist, and the topography on several scales must be suitable (Schemenauer and Cereceda, 1994a). Normally in countries like Chile or Eritrea, fog collectors are grouped together to provide water for a school or a community but FogQuest is now working in two villages in the western highlands of Guatemala where individual families have and maintain their own fog collectors. This has proven to be a good model for these villages. Two fog collectors produce about 400 L of potable water per day for a family.

4. Fog Water Chemistry

The chemistry of the fog droplets can be measured using several types of specialized collectors. Schemenauer and Cereceda (1992a) reported on the quality of both the fog water and the water from the fog collectors at the El Tofo site in Chile. They found that both sources of water met the WHO drinking water standards for ions and for 23 heavy metals. Schemenauer and Cereceda (1992b) measured the concentrations of ions and 23 heavy metals in fog water at Ashinhaib in the Dhofar Mountains in the Sultanate of Oman. At this site on the coast of the Arabian Sea, all concentrations of ions and heavy metals fell within the WHO limits. Eckardt and Schemenauer (1998) found that ion concentrations measured in fog water collected in the Namib Desert near Gobabeb, Namibia were well within the WHO limits and in fact were even lower than previously reported values for Chile and the Sultanate of Oman. These three examples from the Chilean Coastal Desert, the Arabian Desert and the Namib Desert, illustrate that fog water is a very suitable water supply for human consumption and thus for other uses as well.

5. Applications

There are two major applications for fog water collection in arid regions:

1) fog collectors can provide water meeting World Health Organization drinking water standards to rural communities and groups of homes; this water is inexpensive to produce and can be delivered to the homes by gravity flow;
2) fog collectors can provide water for reforestation of ridge lines and the upper parts of mountains where it is impractical to import water from conventional sources; the fog water can be delivered to drip irrigation systems by gravity flow and the resulting forests, if properly situated, can become self-sustaining by directly collecting fog water. A major experiment funded by the European Union took place in the late 1990s to investigate

techniques to reforest the hills in the Peruvian coastal desert. Another project is starting in northern Chile in 2008 to build a plantation at the Atacama Desert Center using fog collectors as the source of water.

6. Fog Deposition to Forests

The question of fog deposition rates to forests has received considerable attention. One reason for this is the importance of fog water for the sustainability for 'cloud' and 'rain' forests. Another is that because high-elevation fog in industrial regions normally has higher concentrations of both major ions and heavy metals than does rain (e.g. Schemenauer et al. 1995), the wet deposition of sulphate or nitrate, for example, can be dominated by fog even though only perhaps 30 % of the water input is from fog. This has led to a number of models of fog deposition to forests being developed. Some models assume a flat surface (Lovett 1984) others like that of Walmsley et al. 1996, deal with complex terrain. In general, the deposition rates are in the range from 0.1 to 0.7 mm per hour on the ground. Coupled with the long fog immersion times for high-elevation forests, this results in substantial total water inputs, and is responsible for the survivability of cloud forests in the tropics and of species like the California Redwoods on the west coast of the United States during rainless periods of the year.

7. Discussion

Fog is present in almost every country on Earth. It is composed of droplets of water and these droplets when combined by the billions upon billions become a major water source for vegetation and can be a managed water supply for small communities. Reforesting clear-cut areas on mountains, especially if they are in zones with frequent fog, can result in a sustainable forest, lead to increased runoff and provide more water in aquifers. Forests created on foggy desert hilltops can sequester carbon from the atmosphere and help address the buildup of greenhouse gases. These are the large scale applications for fog collection. They are also longer term applications. On shorter time scales, villages that lack either adequate amounts of water, or potable water due to contamination of the aquifers, can be given clean water with simple, passive, fog collectors.

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9. Figures and tables

Figure 1: High elevation fog is normally caused by the movement of clouds over the terrain (Kamloops, Canada).

Figure 2: Orographic clouds are produced by the flow of wind over the terrain. These can result in thick fog and moderate to high wind speeds (Chile).

Figure 3: Large scale fog collectors generate water when the visibility is less than about 300 meters (Chile).

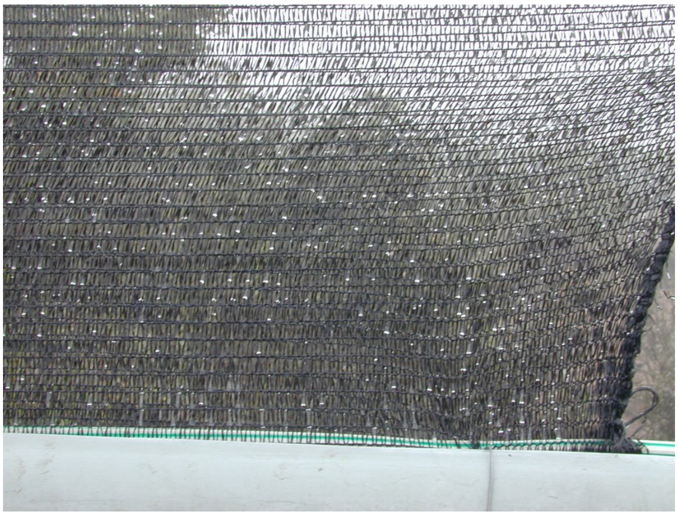

Figure 4: A double layer of a specially chosen polyethylene mesh is used to collect the fog droplets.

Figure 5: FogQuest Project, Tojquia, Guatemala, October 2006. Two large fog collectors and one 3000 liter tank provide water for one or two families.

Figure 6: A 1300 liter water tank and fog-water pipeline, Alto Patache, Atacama Desert, Chile.

Figure 7: Aloe vera being grown with fog water and a drip irrigation system at Falda Verde, Chile,

Figure 8: Some trees are good collectors of fog droplets. The droplets then coalesce to form the big drops seen here.

Figure 9: There are five 3000 liter tanks for fog water at Arberobue, Eritrea (2007).

Figure 10: Fog water is provided for school children at Arberobue, Eritrea (2007).

Table 1: Water production and costs.

WATER PRODUCTION AND COSTS
One square meter of mesh can produce from 1 to 30 liters of water per day : 5 L m-2 day-1 is a typical production rate
One large fog collector (LFC) produces an average of about 200 L of clean water a day : enough for eight people in arid climates
Twenty-five LFCs can supply 5000 L per day for a village
One LFC costs from $600 to $1000 US
A village water supply can cost from $10,000 to $20,000 US depending on access, pipelines, tanks, etc.
The fog water meets WHO drinking water standards

Table 2: Conclusions

CONCLUSIONS
There are Applications in all Parts of the World
Fog Water is New Potable Water in a Watershed
It is an Environmentally Friendly Way to Produce Water
Sustainable – Over periods of hundreds of years – There are seasonal & annual variations as for rain
Complementary to Rain Catchment – Fog collection is effective even if rainfall is negligible – Rain is also collected if present
Fog is a Natural Source of Water for Forests and can be Managed to Generate New Forests