Reports

Condensation of Atmospheric Moisture from Tropical Maritime Air Masses as a Freshwater Resource

Abstract. *A method is proposed whereby potable water may be obtained by condensing moisture from the atmosphere in suitable seashore or island areas. Deep, cold, offshore seawater is used as a source of cold and is pumped to condensers set up on shore to intercept the flow of highly humid, tropical, maritime air masses. This air, when cooled, condenses moisture, which is conducted away and stored for use as a water supply. Windmill-driven generators would supply low-cost power for the operation. Side benefits are derived by using the nutritious deep water to support aquiculture in nearby lagoons or to enhance the productivity of the outfall area. Additional benefits are derived from the condenser as an air-conditioning device for nearby residents. The islands of the Caribbean are used as an example of a location in the trade-winds belt where nearly optimum conditions for the operation of this system can be found.*

Many islands and coastal continental regions of the world which lack adequate freshwater sources have, in fact, an enormous potential freshwater resource in the form of atmospheric moisture. The conditions necessary to utilize this resource are: (i) coastal location; (ii) situation in the regular path of movement of humid, maritime air masses; and (iii) offshore ocean depths which provide deep, cold ocean water close to the shore. The last condition does not necessarily require steep offshore slopes, but could be met by the presence of a submarine canyon bringing cold, deep ocean water close to shore across an otherwise shallow shelf.

In this scheme the cold, deep, offshore seawater used as a cold source is brought up through a large-diameter pipe and pumped through a condenser array located on shore to intercept the flow of humid, tropical maritime air masses. This air, when cooled, condenses much of its moisture, which is conducted away and stored for use as potable water. The seawater that is used as a coolant is brought up from a depth zone having the highest phosphate and nitrate content of the oceans. This water, if discharged into a nearby lagoon, could greatly increase the biological productivity, giving support to aquiculture. Air with lowered humidity and temperature would be available on the leeward side of the condenser, and advantages in comfort would accrue to those dwellings or communities suitably located to receive this modified air.

The trade-winds areas lend themselves particularly to the operation of this system. These zones, situated roughly between 10° and 20° latitude in both hemispheres, cover 31 percent of the ocean surface (*1*) and occupy the belts between the quasi-permanent subtropical, high-pressure areas and the equatorial low-pressure zone. Hare (*2*) states "the trade winds have the reputation of being the most reliable constant winds of the globe." These winds have the warm, humid characteristics of tropical maritime air masses.

While not notably deficient in rainfall, the trade-winds zones include many oceanic islands which, because of their small size and low elevation, lack conditions that would create local rainfall. Unfortunately, on many of the islands the water problem is compounded by high evaporation rates and geological and subsoil conditions that will not support a normal ground-water table.

Many of the smaller islands of the Caribbean are typical of islands in the trade-winds zone with insufficient freshwater resources. Faced with these problems, the Virgin Islands have led the way in trying to create new water sources, but additional sources are badly needed. St. Thomas, with ever-increasing numbers of visitors, now operates two 3790 m³ (1 million gallons) per day desalination plants to supplement natural water supplies. Not only is this system expensive to build and operate, but the outfall of brine from these plants [the equivalent of more than 226.8 metric tons (0.5 million pounds) of salt per day] represents an undesirable pollutant. St. Croix, for all of its attractions, has a difficult water situation. Fresh water is supplied from wells and rainfall catchment, and about 758 m³ (200,000 gallons) per day are presently produced as a by-product at an alumina processing plant. The cost of well water delivered by tank truck to certain areas of St. Croix is as high

Table 1. *Atlantis II*, cruise No. 14, hydrographic station No. 512, 9 December 1964, in the Virgin Island Basin, 17°57′N, 65°00′W, to depth 4453 m. Abbreviation: μgA, microgram-atoms.

Depth (m)	Temp. (°C)	Salinity (per mil)	Phosphorus			Nitrate N (μgA/lit.)	Silicate Si (μgA/lit.)
			PO_4 (μgA/lit.)	Partial (μgA/lit.)	Total (μgA/lit.)		
1	26.97	35.162	0.02	0.03	0.15	0.08	1.66
25	26.97	35.158	0.02	0.02	0.11	0.11	2.18
39	26.93	35.152	0.01	0.03	0.13	0.11	1.66
89	25.26	36.957	0.01	0.01	0.12	0.26	0.90
99	24.67	36.938	0.03	0.01	0.08	0.40	0.90
138	22.47	36.928	0.04	0.00	0.45	0.76	0.83
197	19.54	36.686	0.12	0.01	0.16	2.53	1.09
296	17.34	36.381	0.33		0.35	6.15	2.18
395	14.85	35.969	0.76		0.79	11.98	5.31
494	12.55	35.611	1.18		1.17	13.97	9.41
592	9.62	35.189	1.65		1.66	23.01	16.13
691	8.02	35.008	1.87		1.83	26.98	21.06
790	7.02	34.956	1.95		1.95	9.94	22.27
987	5.56	34.957	1.71		1.70	17.31	24.19
1184	4.51	34.970	1.61		1.61	18.58	26.62
1382	4.19	34.978	1.50		1.52	19.66	26.62
1678	4.05	34.989	1.36		1.38	15.37	20.41
1974	4.00	34.994	1.27		0.26	17.76	16.96
2270	3.80	34.985	1.26		1.25	18.85	14.14
2759	3.82	34.992	1.31		1.28	18.44	16.58
3257	3.83	34.983	1.26		1.26	18.13	16.82
3751	3.88	34.981	1.26		1.27	14.01	17.09
4244	3.95	34.985	1.24			17.76	18.62

as $14 per 1000 gallons. Fortunately, like many other Caribbean islands, St. Croix has a nearly ideal environment for the system of atmospheric moisture recovery that we propose. More than 758,000 m³ (200 million gallons) of fresh water per day, contained as vapor in the lower 100 m of air, sweep across every kilometer of the windward shores of the island. Let us examine a typical installation as it might be set up on St. Croix to recover a portion of this resource.

First of all, we will require a pipe leading outward from the shore to depths where cold water can be found. In the Virgin Island Basin, water of 5°C is encountered at depths of about 900 m (2700 feet) (Table 1) (*3*) in places as close as 1 mile (1.6 km) northward of St. Croix (Fig. 1) (*4*). Therefore, a pipe of about 1 mile in length, possibly requiring insulation around the upper 300 m, will suffice.

Before choosing the pipe diameter, we need to know something of the capacity of our plant. Let us assume that we require a plant producing 3790 m³ (1 million gallons) of fresh water per day. Maritime tropical air masses continually sweeping across this island have temperatures that stay within a few degrees of 25°C (*5*) at all seasons. If this air, with a relative humidity of 70 to 80 percent (*6*), were cooled to 10°C and 100 percent humidity, about 16 g of water could be recovered per cubic meter of air (*7*). We may estimate roughly (with much uncertaintly about the efficiency of various components in our system) that 25 to 30 units of seawater must be pumped through the condenser for each unit of fresh water condensed. Our 1-mile-long pipe, therefore, must deliver 114,000 m³ (30 million gallons) of seawater per day, taking into account pipe friction and differences in water density inside and outside the pipe. This requirement is met by a pipe 0.9 m in diameter, terminating at our pump located in a chamber 6 m below sea level to provide sufficient head for flow to the pump (*8*). The effective head from the pump to the condenser would be about 18 m, which, at the volume we require, indicates a work load of about 300 horsepower. Some of our head requirement could be reduced through siphoning action, by returning the salt water from the condenser to the sea surface in a closed system. Since the seawater pump represents our principal power consumption, the total plant power requirement is small indeed.

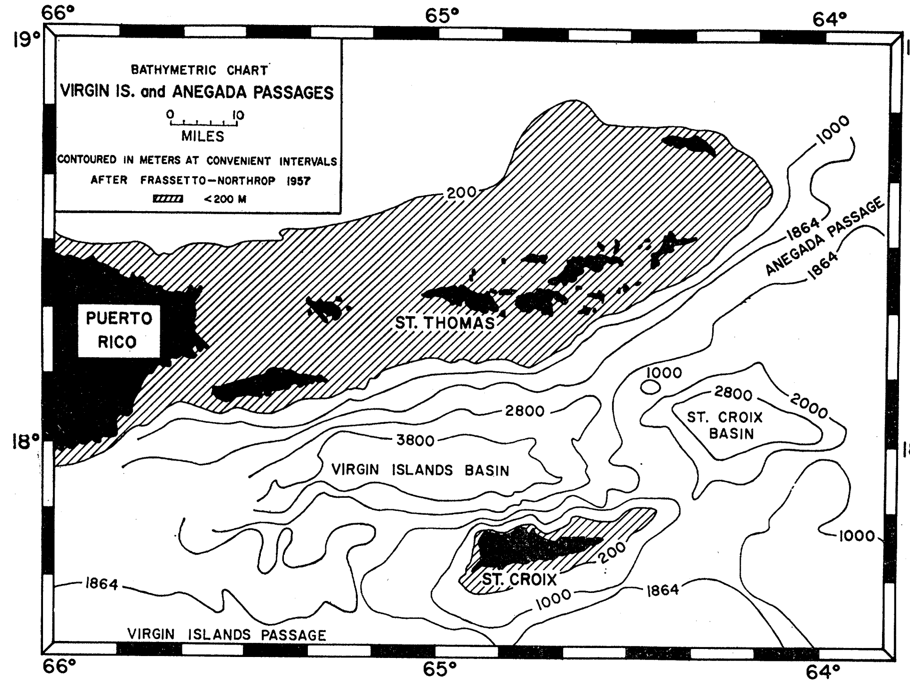

Fig. 1. Bathymetric chart, Virgin Islands and Anegada Passages.

Looking about the picturesque landscape of the Caribbean islands, one frequently sees the remains of towerlike structures which are the ruins of old windmills once used in sugar cane processing (*9*). These were patterned after the efficient Dutch windmills of the 17th and 18th centuries. Polder mills of South Holland (*10*), although lacking the constant winds of the Caribbean, developed up to 90 water horsepower and were capable of raising water nearly 2 m at a rate of 56 m³ (2000 ft³) per minute. What better source of power need we seek in this region of faithful winds? On St. Croix, for example, wind speeds average Force 4 (5.5 to 8 m/sec) (11 to 16 knots) from northeast to southeast for all months except September and October, when the average wind is Force 3 (3.4 to 5.4 m/sec) (7 to 10 knots). Calms average about 2 percent of all reported wind readings (*11*). St. Croix, while having a high potential for wind-generated power, is atypical in that it also has an oil refinery which may enable more economic diesel-generated power. On the less developed, more remote islands modern windmill electric generators would be an economical power source.

The general nature of our proposed plant is shown schematically in Fig. 2. Some of the features of this plant, such

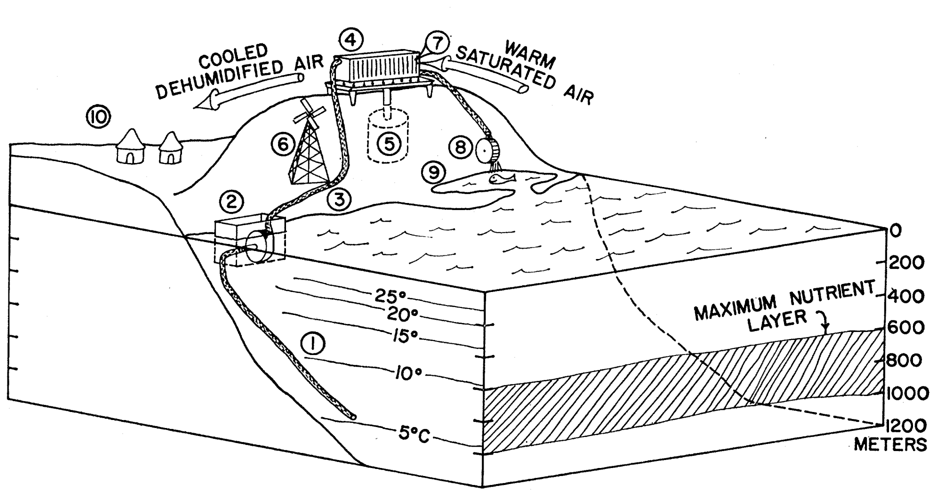

Fig. 2. Proposed water-recovery plant. (1) Large-diameter pipe to deep water; (2) pump; (3) connecting pipe; (4) condenser; (5) freshwater reservoir; (6) windmill electric generator; (7) baffles to direct wind; (8) small turbine to recover water power; (9) lagoon receiving nutrient-rich water for aquiculture; (10) community enjoying cooled dehumidified air.

as the size and construction of the condenser, will be difficult to specify until a pilot plant can be built. Much progress has been made in recent years in heat-exchange technology. The use of surfaces plated with a noble metal to promote dropwise condensation, for example, might greatly reduce the required condenser area below that of conventional equipment (*12*). A condenser 200 m long and 10 m high would intercept about 1 billion (10^9) m^3 of air (moving at 6 m/sec) per day. With perfect efficiency our condenser might recover about 8000 m^3 of water per day. Realistically, we might recover half this amount, giving us the desired 3790 m^3 (1 million gallons).

Figure 2 also indicates some additional benefits that would accrue through the use of this system. The depth of 900 m from which seawater would be pumped corresponds (in this and many other ocean areas) to the depth of maximum nutrient salt concentration (Table 1). The content of dissolved phosphate and nitrate essential in biological productivity in the ocean is 10 to 20 times greater in this level than at the surface. Ryther (*13*) has shown that tropical seas have consistently low productivity owing to the paucity of nutrients from deeper levels. By contrast, the most productive waters in the world result in areas where upwelling of nutrients from deeper levels takes place. These considerations led Pinchot (*14*) to suggest chemical fertilizing and the pumping of deep, nutrient-rich water into circular atoll lagoons in order to culture captive whales. This proposal, which has been termed the "Coral Corral," would take advantage of the baleen whale's high efficiency in turning zooplankton into usable protein. Seawater flowing out from the condenser of our plant (unlike the harmful brine of a desalination plant) would thus be a valuable asset. Water in the zone of maximum nutrients contains about 2.0 μg-atoms of phosphorus per liter (*3*), or about 62 μg/liter. Our 114,000 m^3 (30 million gallon) per day input, containing 7200 g of phosphorus, would be delivered to a small lagoon where highly productive aquiculture experiments could be conducted. With a four-times-larger input of nutritious deep water providing 5 g of food per square meter per day, Pinchot calculates (*14*, pp. 37–38) that a lagoon 1.6 km (1 mile) in diameter could produce about 1 ton per week of food fish, or ten times this amount of plankton protein at the second trophic level.

Although many engineering problems require solution, the system outlined appears economically attractive, with the expectation of modest construction costs and very low operational costs. Its numerous advantages over desalination processes include low operating cost and simplified equipment and procedures. The proposed system may have important economies related to scale and location: a small island with a limited technology is not a likely place to install an atomic-powered desalination plant but might readily use the atmospheric water recovery method. We believe a detailed study will confirm the soundness of this plan. The best way to test these ideas is to construct a pilot plant. Preliminary tests might consist of setting up, in different areas, small, portable condensers using refrigerated water. Later phases of the program could use actual deep, cold seawater after a pipe line has been laid. Once the system has been refined, it might be feasible to make a ship-mounted system available, to be moved to a coastal area where an emergency develops. A large tanker could be a combined platform, storage vessel, and pumping station.

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Ionospherically Propagated Sea Scatter

Abstract. *Measurements of the spectrum of high-frequency radio waves scattered from the sea surface and propagated by the ionosphere show that the expected split-spectrum characteristic of scatter from the sea is preserved and suggests the possible use of high-frequency backscatter with a high-resolution receiving system to monitor varying sea state over wide areas.*

Several theoretical and experimental investigations of high-radio-frequency backscatter from the sea surface have shown that the scattering takes place by virtue of coherent addition of contributions from sea waves of length $L = \lambda/2$ moving radially from the transmitter-receiver, where λ is the wavelength of the observing frequency. The phase velocity of sea waves of length L is $(gL/2\pi)^{1/2}$. Thus, the Doppler shift of energy scattered by sea waves is given by

$$\Delta f \cong (g/\pi\lambda)^{\frac{1}{2}} \quad (1)$$

where g is acceleration of gravity (*1*).

If sea waves are moving toward the transmitter, a positive Doppler shift is encountered, and a negative shift is associated with waves moving away. Over a region of several thousand square kilometers, waves moving in opposite directions may be encountered, and thus the spectrum of the signal would be of a double side-band nature. Characteristics of this type have been seen by direct scatter observations (*2*) and have been suspected in ionospherically propagated sea scatter (*3*). A resonant scattering depending upon standing sea waves has been suggested to explain fading of sea scatter and sea scatter