WATER FOR PEACE

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WATER SUPPLY TECHNOLOGY

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Italy Water Conservation Techniques

UNCONVENTIONAL WATER SUPPLY SYSTEMS

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The problem of water supply is so different from place to place in the arid countries that no unique solution may be devised for all of them. In the present paper, a few of these unconventional water supply systems will be examined.

Although conventional water supply systems and water desalination represent the large scale solutions for the future, in particular areas, unconventional solutions may have a relevant role, being based on the use of local resources or particular local geographical conditions (1). We still know little about many aspects of the water problem, and the appropriate combination of ingenuity and engineering may develop new approaches of some importance for arid countries.

Water harvesting

Water harvesting may be defined as the technique of collecting rain water that falls on permeable ground, in which the permeability has been changed with artificial means. By this method it is possible to collect fresh water which otherwise would have been lost. An accurate analysis of the problem of water harvesting has been presented by Lloyd E. Myers of the U.S.Water Conservation Laboratory of Phoenix, Arizona (2)(3)(4)(5).

Fresh water collected in natural reservoirs was one of the first water supply systems used by man; nature offers instances of reservoirs - the natural lakes - formed where rain water and surface waters have found impermeable grounds.

Where the geography of an area does not offer narrow valleys with natural dams, it is possible to build artificial dams and create artificial reservoirs. This technique is quite widespread, and in Italy, for instance, various irrigation and water supply programs have been developed using this technique (6)(7).

The cost of the reservoirs so formed has been estimated in the order of \$0.1 per m^3/year of water collecting capacity, and the cost of water has been estimated to be about 0.01 \$/m^3 (0.04 \$/1000 U.S. gallons) (8).

In many arid countries, however, the ground is permeable. Although the rain may range from 100 to 500 mm. (4 to 20 inches) per year, the aridity is caused by the high surface evaporation and by the permeability of the ground which causes water to be lost.

Considering an average annual rainfall of about 300 mm. (12 inches), this means that 1 m^2 of ground receives 0.3 m^3/year (about 7 U. S. gallons/sq.ft. or 320,000 U. S. gallons/acre per year). Assuming that only one half of this quantity may be successfully collected, this means an available amount of water of 0.15 m^3/m^2 per year. If we say that the water needs are 30 m^3 (8000 U.S. gallons) per year per person, we know that that amount of water may be obtained from about 200 m^2 (2300 sq.ft.) of catchment. One acre may give enough fresh water for the needs of 3 families of 5 persons each.

The above considerations clearly indicate the usefulness of such a technique when applied where there is plenty of unused ground and where no other source of water exists. Since such conditions are rather common in inland arid areas, we shall examine the economics of water harvesting.

Let us assume that an acceptable cost for fresh water is 1 \$/1000 U.S. gallons (0.25 \$/m^3). Since 1 m^3 of water is collected in one year on a catchment of about 7 m^2, this means that the total yearly cost of the collecting system should not exceed 0.04 \$/m^2, not including the cost of the reservoir.

Water harvesting is not a new practice. Ancient civilizations in the Negev desert of Israel hand picked rocks from hillsides to increase runoff, built ditches to collect and convey water to lower lying fields, and then irrigated crops with it (9). Another ancient practice, common in arid countries, is the collection of rainfall on the roof of buildings or on concrete catchments. The Tremiti islands in Southern Italy and the town of Baux in Provence, among many others, have acres of such catchments which date back to Middle Ages.

In more recent times various experiments have been made for large scale water supply in arid countries through water harvesting. For example, in Lipari, an arid island in Southern Italy, a large concrete catchment has been built with a total surface of about 110,000 m^2 (28 acres). The water falling on the area is about 50,000 m^3/year (13 million U.S. gallons/year). The work has been described in several publications (9)(10)(11) in which the cost of the collected water is estimated to be 1.5 \$/m^3. Such a high figure is due to the high labor and materials cost in the islands, and also takes into account the cost of the reserviors (which have the capacity of the water collected during a whole year), i.e., about 30,000 m^3. Lower water costs may be obtained with cheaper construction materials and different designs.

The experiments conducted by Myers have shown that covering the ground with polyethylene films or aluminum films proved unsatisfactory Better results have been obtained (4)(5) by spraying the soil surface with asphaltic materials. The cost of the application was about 0.25 \$/m^2, but the collected water was discolored by the residue from asphalt oxidation.

In order to avoid bad taste in the water, it is possible to cover asphalt pavements with plastic film. The total cost for an installation of this type was about 0.35 \$/m^2. The cost of the reservoirs must be added to this figure. Reservoirs may also be lined with plastic films.

Assuming a reservoir cost of 0.35 \$/m^2, a surface ratio of pavement to reservoir of 10:1, a life of five years and a collection of 0.15 m^3/m^2 per year, the cost of the water will be in the order of 0.5 \$/m^3 (2 \$/1000 U.S. gallons). Further reductions of water costs may be expected with the advent of new knowledge and new materials.

Condensation of atmospheric water vapor

The earth is surrounded by water in the atmosphere in the vapor state. This water vapor is continuously moving, but the amount is fairly constant and is estimated to be about 13×10^{12} m^3 (about 3.5×10^{15} U.S. gallons), irregularly spread over about 510×10^{12} m^2 (5.5×10^{15} sq.ft.) of the earth's surface. This corresponds to an <u>average</u> of 25 liters/m^2 (0.6 U.S. gallons/sq.ft.), although the water vapor in the atmosphere is distributed very differently on the earth, depending on the geographical and seasonal conditions. On the whole, it is a realtively small amount of water; nevertheless, it may be used as a source of water supply in particular areas.

Fresh water may be obtained by condensation of the air humidity producing what might be called "reserve distillation;" i.e., it is necessary to dissipate the latent heat of evaporation in order to condense the water vapor to liquid water.

The condensation of atmospheric water vapor may be achieved in three ways: (a) by natural means; (b) artificially by using natural cooling systems; (c) by using artificial cooling systems.

Natural condensation gives rise to dew and may be used as a practical water supply in only a few cases, although it is possible that dew condensation can give rise to ground-water used by man.

Artificial devices for producing dew condensation have apparently been used as water supply systems in the past. In modern times, all experiments to reproduce such systems have proved unsuccessful. Such experiments have been reviewed in two papers (13)(14).

The principle is to bring warm humid air against a surface cooled by natural means, especially by nocturnal heat radiation. Small hills, filled with calcareous stones, have been built; the humid air during the night was caused by convection to enter the stone hill and to meet the cool surfaces and leave a part of its humidity. Small condensation or no condensation at all has been observed. The real mechanism of the process is far from being understood, and this has so far caused the failure of the various experiments.

A different solution, also based on the use of nocturnal radiation as a source of cooling for condensation, is "nocturnal distillation" (15)(16). If ocean water, the temperature of which is relatively constant, is slowly pumped through a solar still (a flat tray surrounded by a glass or plastic envelope, tightly closed), the cover temperature of the still being lowered by infrared radiation from the surface towards the clear night sky, evaporation takes place from the ocean water, and condensation occurs on the inner surface of the cover of the solar still. Water production as large as a few liters/m^2 per night has been observed.

Another solution for causing natural dew condensation, without recourse to artificial cooling systems, is the one devised in Chile (17) in which dew condensation from humid air takes place on this nylon thread, 4 ft. long. This system may be used only where stable fog or very humid air exists.

It is also possible to obtain water from the atmosphere by using artificial cooling systems such as mechanical and absorption refrigerators. A patent (18) is reported on such systems, and apparently one device has been presented in a Trade Fair. The same idea has been considered in a paper by Hickman (19) and suggested as an emergency water supply system.

The energy balance of the method seems attractive. If a refrigerating machine operated by a mechanical compressor is used, and the "figure-of-merit" (ratio of heat shifted by the engine to heat represented by the power input) of the machine is as favourable as 5 to 1, the power consumption of the process would be about 120 kcal/kg of condensed water (0.14 kwh/liter or 0.5 kwh/U.S. gallon). If the compressor were driven by a Diesel engine using fuel with a calorific value of 10,500 kcal/kg and a yield of 33 percent, a 1 H.P. refrigerating machine would require about $641/0.33 \times 10,500 = 0.18$ kg of fuel to produce 5.3 liters/hour of water. In other words, 1 kg of fuel would produce about 30 liters of fresh water.

In order to evaluate the real potential of the process, a series of experiments were made in 1959 (20)(21)(22) using an electrically operated mechanical dehumidifier. In the experimental unit the external air is introduced by a fan in the air duct, having a section of 24 cm x 20 cm. The air flows on the evaporator coil, perpendicular to the air flow. The air is thus cooled below its dew point, and water condenses on the evaporator surface. The cool saturated air is then blown on the condenser coil, at a distance of about 5 cm from the evaporator. The dehumified air is then discharged.

The unit is about 1/8 H.P. (about 95 watts). The actual power consumption and the condition of the inlet air have been measured and correlated with the amount of condensed water. After some years of operation, the following results were obtained:

(a) The electric power consumption of the device was about 110 ± 10 watt-hours/hour and was independent from the amount of condensed water.

(b) The amount of water separated from the air depends on the physical condition of the air itself; the water production was greater at higher relative humidity.

(c) With the particular experimental unit used in this work, water condensation was observed when the relative humidity was greater than 50 percent, independent from the dry-bulb air temperature.

(d) Usually the amount of water recovered from the air was about 10 to 20 liters per week, the specific power consumption in most weeks being from 1000 to 1500 kcal/liter of condensed water. Power consumption as low as 0.7 kwh/liter has been recorded.

(e) The electric power consumption per weight unit of condensed water usually resulted in 1.5 to 2 times the latent heat of condensation of water, therefore much greater than the calculated energy consumption in the most favourable mechanical devices, i.e., 120 kcal/liter of water. The greater energy consumption is due to the poor heat exchange between the cool air, at the outlet of the evaporator coil, and the surface of the condenser coil of the refrigerating machine. In the small dehumidifiers (less than 1 H.P.), in fact, the air speed is rather high, in the order of 200-400 m^3/hour (100-200 cu.ft./minute), and such high speeds do not permit a good heat exchange and a good recovery of the heat.

(f) When the dry-bulb temperature of the inlet air was lower than 10°C, ice formation was observed on the surface of the evaporator coil.

The above results suggest the following considerations:

(a) The power consumption in the extraction of water from the atmosphere seems to indicate that the system is convenient only in emergency conditions, where rather small amounts of water are needed by small groups of people and no local source of water is available. Water condensation from the air is possible if the air is rather high in relative humidity, at least in some hours of the day.

(b) In order to use this water supply system, it is necessary to design more efficient devices in which there would be a good heat exchange and a good recovery of heat from the dehumidified air.

(c) Attention must be paid to the sources of energy for the process. Waste power or the extra power of motor cars may be used for operating the mechanical dehumidifiers. Wind energy may be used as a source of mechanical energy. The Enfield Andreau wind motor should be studied for this purpose (23)(24) because the air draft operating the windmill may be brought into contact with the cooling system, powered by the windmill itself. Absorption refrigerators may also be used. If a fuel is burned directly in a thermally actuated refrigerant machine, the yield might be a little higher than if it were burned in a diesel engine driving a mechanical compressor. Solar energy may be used as a source of heat for absorption refrigerating machines (25)(26)(27).

Condensation of geothermal water vapor

In some arid areas of the world geothermal steam is available and may be used as a source of fresh water after condensation. So far this system has only been used on a very small scale in volcanic areas of Southern Italy. In 1930, in order to supply water to the Volcanologic Observatory of the University of Catania, at 2940 meters of altitude on the Etna volcano, a small tubing system was built to condense part of the vapor of the fumarols in the sides of the volcano. About 1 m^3/day of fresh water was thereby obtained (28)(29). The small plant was in operation until 1962.

More recently other experiments in this direction have been made on the island of Pantelleria, in the south of Sicily. Because of the high water permeability of the volcanic soil, no fresh water is available in the island, and the water supply for the 10,000 inhabitants is the rainfall collected in small reservoirs and the fresh water carried occasionally by tankers at a cost as high as 20 $/$m^3$ (11).

During a study of the water supply problem on the island (12), attention was focused on the many small geothermal steam sources in the inner valleys of the island (Figure 1). Such steam

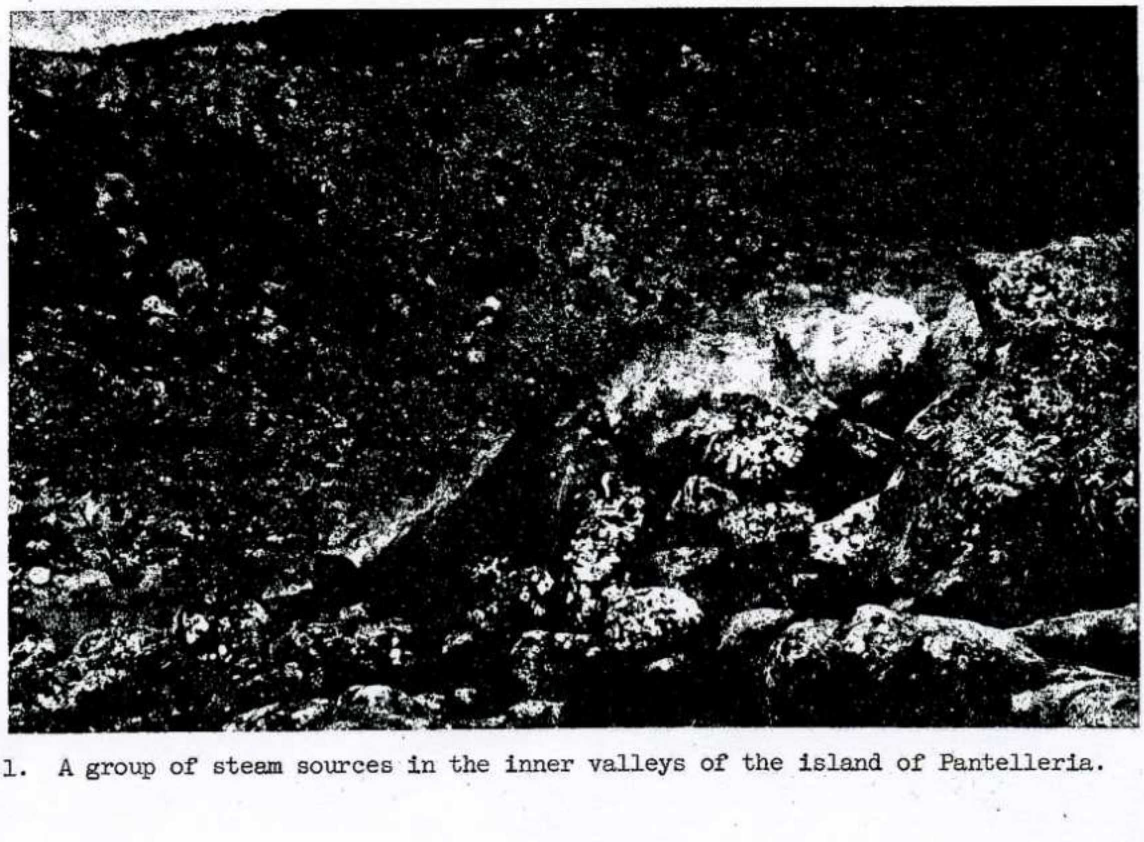

Figure 1. A group of steam sources in the inner valleys of the island of Pantelleria.

has been used in the past because a small amount of water was made to condense on branches placed in front of the sources (Figure 2).

Figure 2. Water condenses on branches placed in front of the steam sources. Such water has been used for years as a small water supply for the cattle.

The decision was made to build a better condensation system, and this was made by closing one of the many steam sources (Figure 3) and sending the vapor in a series of tubes, 6 to 10 inches in diameter, placed on the ground, having a total length of 60 meters (Figure 4). The tubes are connected to three reservoirs, 1 m^3 each, in which further condensation of the vapor takes place. The condensed water is sent to a small fountain.

The condensed water is about 1 m^3/day and depends on the air temperature. An average of 300-400 m^3/year (about 100,000 U.S. gallons/year) is collected. The total cost of the unit was about $300, and the unit has been continuously operating since 1963.

By condensing the vapor of a larger number of sources, it is possible to obtain at least ten times that of water, i.e., the amount of water necessary to supply one of the villages of the island. In the Eolie islands, also in Southern Italy, other volcanic vapor sources might be used for the same purpose. The geothermal and volcanic steam and heat may also be used as energy sources for water desalination.

Figure 3. One of the steam sources is closed. The emerging tube will be connected with the condensation system.

Figure 4. General view of the system for condensing the water vapor from one of the steam sources of Pantelleria. The steam source is at left, near the reservoir at the far left. Sixty meters of tubing are placed on the ground and part of the vapor condenses in them. Further condensation takes place in the three reservoirs. From each reservoir the condensed water (about 1 m^3/day) is carried to the fountain (at the center, below the reservoirs).

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SYSTEMES INEDITS D'ADDUCTION D'EAU

Résumé

Une ingéniosité opportune et l'application de nouveaux principes, de nouveaux matériaux de construction et de nouvelles techniques pourraient avoir pour résultat la mise au point de systèmes inédits d'approvisionnement en eau dont plusieurs sont examinés à la lumière de l'expérience acquise.

Captage de l'eau

L'eau de pluie peut être recueillie dans de grands réservoirs naturels et artificiels là où les conditions géologiques sont favorables. Toutefois, lorsque le sol est perméable, l'eau filtre à travers la terre et est souvent perdue.

On pourrait diminuer la perméabilité du sol au moyen de différents systèmes dont la technique et la rentabilité sont encore peu connues.

Dans une île aride des îles Lipari, en Italie méridionale, on a recouvert partiellement le côté d'une colline d'un pavage en béton d'une superficie de 110.000 m^2; environ 50.000 m^3 d'eau potable y sont recueillis chaque année.

De meilleurs résultats seraient possibles en utilisant des matériaux de pavage différents et meilleur marché; en outre, l'aspect économique du système pourrait devenir plus attrayant.

Condensation de vapeur d'eau atmosphérique

L'humidité atmosphérique constitue une réserve latente d'environ 13 x 10^{12} m^3 d'eau toujours disponible et réintégrée continuellement, soit une moyenne de 25 litres d'eau par m^2 de surface terrestre. Cette vapeur d'eau atmosphérique peut être utilisée comme source d'eau si l'on met au point des systèmes de condensation rationnels et rentables, en appliquant un principe que l'on peut appeler une "distillation inverse".

Dans le passé, on a mentionné la condensation de la rosée comme une autre méthode possible d'approvisionnement en eau pour les petites agglomérations; toutefois, aucun essai pratique n'a pu reproduire jusqu'à présent une telle condensation sur une vaste échelle.

La condensation de la rosée pourrait être utilisée pour l'approvisionnement en eau si l'on pouvait mettre au point des systèmes de refroidissement rentables. Le refroidissement artificiel du sol après une augmentation artificielle du rayonnement nocturne pourrait produire une plus forte condensation de la rosée.

La "distillation nocturne" dans des appareils analogues aux appareils de distillation solaire mais ne fonctionnant que la nuit, constitue un aspect particulier de cette méthode appliquée sur une échelle réduite. Le rapport examine de façon approfondie le phénomène lié au rayonnement nocturne du sol et de diverses surfaces.

On peut obtenir de l'eau par condensation en refroidissant l'air au moyen de dispositifs analogues à des appareils de climatisation et de déshydratation, conçus de façon à produire une quantité maximum d'eau et à assurer une consommation minimum d'énergie spécifique.

Des recherches expérimentales faites à l'Université de Bari ont montré que cette méthode offre des possibilités; en utilisant des déshydratants de 100 watts à effet unique (sans récupérat: de chaleur) il a été possible de tirer de l'air 2 litres d'eau par jour avec une consommation d'én gie de 0,7 kWh par litre.

Une telle consommation élevée d'énergie ne permet l'emploi de la méthode que dans des circonstances exceptionnelles. On pourrait obtenir de meilleurs résultats avec des dispositifs plus efficaces en tenant compte de la récupération de la chaleur et en utilisant des sources d'énergie mécaniques, notamment l'énergie éolienne.

Condensation de la vapeur d'eau géothermique

Dans certaines zones arides du monde, on peut utiliser la vapeur ou la chaleur géothermiques. Dans une île aride de l'Italie méridionale, Pantellaria, il a été procédé à la condensation de vapeur géothermique à basse température et une nouvelle source d'eau est ainsi devenue accessible

La condensation a lieu dans des tubes refroidis par air, et une source de vapeur fournit 1 m^3 d'eau douce par jour.

L'aspect économique du système semble attrayant et la vapeur d'eau géothermique pourrait être considérée comme une source d'eau douce lorsqu'elle est condensée sur une vaste échelle.

La chaleur géothermique a été également considérée comme une source d'énergie pour le dessalement de l'eau.

SISTEMAS NO CONVENCIONALES DE ABASTECIMIENTO DE AGUA

Resumen

El uso conveniente del ingenio y la aplicación de nuevos principios, materiales de construcción y tecnologías pueden conducir a sistemas de abastecimiento de agua nuevos no convencionales, algunos de los cuales se examinan sobre la base de la experiencia disponible.

Explotación del Agua

El acopio de agua de lluvia se puede hacer y se hace en grandes reservorios naturales y artificiales, donde las condiciones geológicas son favorables. Sin embargo, en lugares donde el suelo es permeable, el agua penetra en éste y a menudo se pierde.

La permeabilidad del suelo puede reducirse mediante diversos sistemas, los cuales son aún muy imperfectos en sus aspectos técnicos y económicos.

En Lipari, una árida isla de Italia meridional, parte de la ladera de una montaña se ha cubierto con pavimento de hormigón en una superficie de 110.000 m^2 (28 acres); alrededor de 50.000 m^3 (13 millones de galones norteamericanos) por año de agua dulce se acopian en esta zona.

Pueden encontrarse soluciones más eficientes con el empleo de otros materiales de pavimentación más baratos; de esta forma, el aspecto económico también será más atractivo.

Condensación de Vapor de Agua de la Atmósfera

La humedad atmosférica constituye una reserva con una potencialidad de alrededor de 13 . 10^{12} m^3 (3,5 . 10^{15} galones norteamericanos) de agua que está siempre disponible y se reintegra continuamente, que equivale a 25 litros de agua por m^2 de superficie terrestre (0,6 galones norteamericanos/pie cuadrado). Dicho vapor de agua atmosférico puede emplearse como fuente de agua si se desarrollan sistemas de condensación adecuados y económicos, de acuerdo con un principio que puede considerarse de "destilación inversa".

En el pasado se ha informado que la condensación de rocío podía ser un posible sistema de abastecimiento de agua aun para pequeñas poblaciones, pero hasta ahora no ha habido ningún ensayo tecnológico que haya podido reproducir tal pretendida condensación en gran escala.

La condensación de rocío puede utilizarse como fuente de abastecimiento de agua si se logra encontrar un sistema económico de enfriamiento. El enfriamiento artificial del suelo, a continuación de un incremento artificial de la radiación nocturna, puede ocasionar un aumento en la condensación de rocío.

La así llamada "destilación nocturna" realizada en aparatos similares a los alambiques solares, pero trabajando durante la noche, es un caso particular de este proceso, llevado a cabo en pequeña escala. Se está tratando de lograr un mejor entendimiento de los fenómenos relacionados con la radiación nocturna desde el suelo y desde distintas superficies.

La condensación de agua puede lograrse enfriando el aire con dispositivos similares a los acondicionadores y deshumidificadores de aire, debidamente diseñados a fin de obtener la mayor cantidad de agua y el menor consumo de energía específica.

En la Universidad de Bari se han llevado a cabo experimentos que demuestran la posibilidad del proceso; utilizando deshumidificadores de 100 vatios (sin recuperación de calor) de efecto simple, ha sido posible obtener 2 litros de agua por día a partir del aire con un consumo de energía de 0,7 kWh/litro.

Tan alto consumo de energía limita la aplicación del proceso a condiciones de emergencia. Pueden obtenerse mejores resultados con unidades más eficientes que permitan la recuperación de calor, y que empleen fuentes de energía mecánica tales como la energía del viento.

Condensación del Vapor de Agua Geotérmico

En algunas regiones áridas del mundo se dispone de vapor o calor geotérmico. En una árida isla de Italia meridional, Pantellería, se ha logrado condensar vapor geotérmico de baja temperatura, en una escala reducida, poniéndose así al alcance una nueva fuente de agua.

La condensación tiene lugar en tubos enfriados por aire siendo la producción de una sola fuente de vapor de 1 m^3/día de agua dulce.

El aspecto económico del sistema parece atractivo pudiéndose considerar que el vapor de agua geotérmico es una fuente de agua dulce, cuando se lo condensa en gran escala.

El calor geotérmico también ha sido considerado como fuente de energia para la desalinización de agua.