THE DESALINATION POTENTIAL FOR SOUTHERN IRAN

ABSTRACT

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The Desalination Potential for Small Communities
in Southern Iran

Southern Iran is sparsely populated; much of the population is concentrated into small widely scattered communities, each of less than 1000 inhabitants.

These isolated communities face an acute shortage of fresh water. The existing sources of fresh water supply, such as rainwater, ground and surface water, are inadequate and often unsuitable. However, brackish or saline water is available which can be desalted. In view of the low daily fresh water demand in these communities, solar distillation appears to be a suitable desalination process.

In this thesis the possibility of using solar desalination for the isolated communities of Southern Iran has been considered from both technical and economic standpoints. Two alternates have been studied: one of building large-scale community solar stills and the other relating to the provision of small-scale family-size units. As a part of the investigation five small-scale experimental solar stills were built and tested in Montreal and the results extrapolated to Southern Iran.

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by

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Definitions of Terminology

In order to avoid possible confusion regarding the subject chosen for this study, the following terms have been defined:

Small Community: The southern coast of Iran is characterized by small and scattered concentrations of population. With the exception of a few cities and ports, the number of inhabitants living in a settlement ranges from about 100 to 1000. The supply of fresh water for these communities is either inadequate or unsuitable. However, a source of saline and/or brackish water is available which can be readily used for desalting. An increase in fresh water supply for these communities will contribute to a positive raising of their standard of living. It is hoped that the information presented here will be of value for such communities.

Saline Water: Any water source with a total dissolved solids content of over 1000 ppm (parts per million) is designated as being saline. Sea water generally contains about 35,000 ppm of total dissolved solids (1). However, the salinity of Persian Gulf waters is of the order of 39000 ppm (2).

Fresh Water: This is defined as water suitable for drinking purposes as set out by the United States Public Health Service (3) and the World Health Organization (4). The total allowable solids content should not exceed 500 ppm and the same criterion is chosen for this study. It is to be noted, however, that in certain cases water of higher salinity is considered acceptable.

Water Supply System: Includes the works and auxiliaries for collection, treatment, storage and distribution of water from the sources of supply to the houses. In this study, it does not include the internal piping leading to the free-flowing outlets of the ultimate consumers.

Solar Desalination: Refers to the process whereby solar radiation is used to distill saline water into fresh water inside a solar still.

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CHAPTER I

1.1 Introduction

The Iranian plateau is a triangle set between two depressions, the Caspian sea to the north and the Persian Gulf to the south. It is bounded on the north by the Soviet Union and the Caspian Sea, on the east by Afghanistan and Pakistan, on the south by the Persian Gulf and the Sea of Oman, and on the west by Iraq and Turkey (5).

Iran extends between 25° and 40° north latitude (6) and is, therefore, entirely in the temperate belt of the northern hemisphere. However, because the country is rimmed by mountains on all sides, it is shut off from surface climatic conditions that affect the neighbouring areas. The northern part of the triangle is formed by the mighty Alborz mountain range, of which the highest peak, Mt. Damavand, rises to over 19000 ft. Skirting the southern shore of the Caspian Sea, it forms a high and narrow barrier which separates the coastal area with its luxuriant vegetation from the desert regions of the interior.

Two great deserts, the Dasht-e-Lut and the Dasht-e-Kavir occupy a large part of the central plateau and together account for one-half of the desert area and one-sixth of the total area of Iran. These deserts are the most arid in the world, and, aside from an occasional oasis that may be found in the Kavir, the region is totally barren, supporting no life whatsoever.

The rest of the country, with the exception of the Caspian littoral, experiences mainly arid and dry weather accompanied by high temperatures, and wide daily and annual temperature variations. The temperatures during the year range from 32° to 122°F (0.0° to 50.0°C). The hottest part of Iran, and one of the hottest places on earth, is the hollow basin of Jezmorian in the south-east, where the average maximum daily temperature for four months in the summer does not fall below

133°F (56.1°C).

The scarcity of water for domestic and agricultural consuption constitutes a serious problem in Iran. The Caspian littoral in the north lies in the rainbelt of the Alborz mountain range, which extends from the north-west to the north-east of Iran along the Caspian Sea, and is consequently quite different from the rest of the country. It is characterized by moderate temperatures with low daily and annual variations, high humidity and heavy precipitation the year round. The great contrast between the climate of this area and the rest of Iran is also manifested in the population density, economic prosperity and agricultural potentiality. It may be noted that, based on a record of 6 years (1961-1967), the Caspian region has been found to have an average of 50 inches (1270mm) of precipitation a year (7,8,9,10,11,12)

In the central part, with the exception of the two aforementioned deserts, precipitation ranges from 6 to 10 inches (152.4 to 254.0 mm) per year and the water needed for domestic and agricultural purposes is provided by rainfall catchments and underground extraction. The climate of the southern Iranian Coast is hot and arid with only occasional rainfall. The annual precipitation is less than 6 inches (152.4 mm) and water is obtained from shallow lenses of fresh water floating above the underlying salt water zone (13). The quantity as well as the quality, therefore, depends on the amount of rainfall and the sea water level. The traditional systems of earth dam reservoirs, used to collect rainfall runoff, have frequently been a source of considerable bilharziasis infection, which normally results from untreated water.

The objective of this thesis is to determine the basic supply-demand characteristics for fresh water for small communities in Iran. In view of the traditional inadequacy of the natural water supplies (13), it is also proposed to ascertain the potential of desalination as a means of fresh water provision for the small communities of the southern Iranian coast to study the economics of the proposed desalination system.

Since the geographic conditions are very similar along the southern coast, it was decided that only two coastal stations, namely Bandar Abbas (latitude $27^{\circ}11'$, longitude $56^{\circ}70'$) and Gheshm Island (latitude $26^{\circ}57'$, longitude $56^{\circ}16'$) (13) be studied in detail and the results extrapolated along the entire coast. This has been done because more climatological data are available for these areas.

1.2 General Description of the Areas Selected for Study

Both the city of Bandar Abbas and Gheshm Island are located in the province of Ports and Islands (Banader Va Jazayer) in Iran; their location is shown in Figure (1).

These areas face a shortage of potable drinking water and are in need of water quality improvement(13).There is an available supply of saline or brackish water which can be used for desalination. Additionally, in both these areas some crops have been grown with highly saline water (13). Gheshm Island is located 20 kilometers south of Bandar Abbas and is one of the largest islands in the Persian Gulf. The island is about 144 kilometers long, having a maximum width of 35 kilometers with the mean width being 10 kilometers. The mean elevation of Gheshm Island above sea level is 30 meters. Bandar Abbas is one of the largest Persian Gulf ports. Its mean height above sea level is 6 meters.

1.3 Climate

The climatic variables for Gheshm Island and Bandar Abbas are listed in Tables (1,2,3,4,5,6).It is readily seen that the climate in Gheshm Island and Bandar Abbas is hot and very humid all year round. The yearly average temperature, based on the daily average temperature, for Gheshm Island was found to be 81.1 ^{o}F (27.3^{o}C). Similarly the annual average relative humidity is quite high--of the order of 70 percent. For the Bandar Abbas region, the annual temperature over a period of 7 years (1961-1967) has recorded to be 83.1 ^{o}F (28.4^{o}C). The corresponding value for relative humidity was 65.4 percent.

The precipitation comes in the form of rain and normally occurs in the late winter and early spring and is characteristically of a high intensity and short duration (13).

As shown in Tables (1) and (4), the average annual precipitation for Gheshm Island for a six year period (1961-1966) is of the order of 4.17 inches (105.9 mm). The corresponding figure for the Bandar Abbas is 4.37 inches (110.9 mm).

Tables (1) and (4) further indicate that no rainfall is experienced from June to October in Gheshm Island and Bandar Abbas. The winds are predominantly from the north and south, although surface winds blow from the northeast for a period of time during the summer. The principal effect of the prevailing winds, is to bring warm and humid air to the inland area and increase the humidity of the ambient air. The mean wind speed for Gheshm Island for the year 1966 is presented in Table (7).

1.4 Hydrology

As a result of the low precipitation and the presence of short water courses, and the low permeability of the soils (14) a good portion of the runoff on Gheshm Island and in the southern part of the Bandar Abbas region moves toward the Persian Gulf (13). To the north and north east of Bandar Abbas, there are some shallow fresh water aquifers located in the area known as Issin, having an average salt content of about 500 p.p.m. (13). This constitutes a portion of the water supply utilized in the Bandar Abbas city. The chemical analyses of the surface waters from the Gerrow River, Shemil River, Jamogh River and Niam River indicate a high level of salinity. The total dissolved solids are found to range from 1320 to 5200 p.p.m. The salinities of the surface waters in the Bandar Abbas region are presented in Tables (8) and (9). The existing aquifers on Gheshm Island are divided into two categories:

(1) Buoyant Fresh Water Aquifers

A portion of the precipitation infiltrates into permeable areas forming fresh water aquifers adjacent to the coastlines (13). Based on their investigations along the European coast, Aravin and Gunther (15 and 16) discovered that the fresh water aquifers of this type are generally in equilibrium with the salt water intruding from the sea; the salt water is located below the sea level at a depth of 40 λ, where λ is the corresponding height of fresh water above the mean sea level.

In Gheshm Island, because of the low precipitation and relatively high rate of surface evaporation, the amount of fresh ground water is almost negligible(13).The rates of evaporation for Gheshm Island are shown in Appendix A.

(2) Perched Fresh Water Aquifers

There are a few perched aquifers, located below the villages of Torion, Ramkan and Kaled, which are situated nearly in the centre of the island. It was observed by the author that these aquifers are not significantly affected by sea water intrusion. At present fresh water is supplied to these villages from shallow wells. Unfortunately no measurement of the salinity of these wells has been undertaken. The water was found to be reasonably acceptable by taste. It must be recognized that these perched water aquifers are dependent on the meager rainfalls experienced in this region(13).Hence their capacities are finite and seasonal. Both Bandar Abbas and Gheshm Island have ample supplies of saline and brackish water which might be rendered more suitable by means of desalination. Gheshm Island possesses highly brackish underground water intruded from the sea, in addition to sea water The Bandar Abbas region has three sources of saline water, namely, the brackish water of existing rivers with varying levels of salinity, underground brackish water and sea water(18)The salinity of sea water for this region is shown in Table (10).

1.5 Domestic Water Demand

The southern coast of Iran is characterized by small concentrations of population. In this study, it has been decided not to investigate the problems of water supply for the large towns but only that for the smaller communities.

The climatic characteristics of this area are given in Tables (1) to (7). The general aridity as indicated by this data means that the area cannot naturally support large populations. The population is generally scattered into small isolated rural communities; there are only a few large cities and ports such as Abadan, Bandar Abbas, and Bushehr. The total population of these coastal regions, including the offshore islands, was recorded in 1970 to be 254,000; this does not include the ports of Abadan and Bandar Abbas (13). This is equivalent to a population concentration of 9.2 persons per square kilometer (0.39 sq. miles)(18).

It is very difficult to determine the exact demand for fresh water in this area as almost no measurements have been taken. Investigations were made by the author in the libraries and files of numerous ministries of the Imperial Government of Iran in Tehran, but no specific data on water demand for the area under investigation was discovered. According to the authorities of the Ministry of Water and Power, specific data does not exist. As a result a twofold approach was taken:

(1) Earlier tests undertaken by the author in Iran were consolidated. An experiment was set up as part of this thesis in October, 1971, to measure the amount of water consumption on a per family basis in a rural community located in the central province of Iran. The village of Hezarjolfa, in the Ghazvin area (latitude 36^{o}N and longitude 50^{o}E) was selected and a water meter was installed on the main pipe supplying water to the village of approximately 100 families. The water is

supplied from an elevated water tank after being pumped from a deep well, of a depth of approximately 70 metres. The reason for choosing this village in the Ghazvin area was that at present there is no other region in Iran with an existing system of water supply in a rural area which has regular metering facilities. The author had acquired a considerable amount of data from this region during the period from 1968 to late 1970. This has nevertheless been included as no other data for rural areas was available for Iran. The results obtained are listed as follows:

Fresh Water Consumption for the Ghazvin Area, Central Province, Iran

Date - 1971	Water Consumption/family-day*	
	Litres	U.S. Gallons
16 Oct.	77.9	20.6
17	77.9	20.6
18	71.9	19.0
19	73.8	19.5
20	77.9	20.6
21	75.7	20.0
22	73.8	17.5
23	79.8	21.1
24	79.8	21.1
25	70.7	18.7
26	71.9	19.0
27	75.7	20.0
28	72.6	19.2
29	70.0	18.5
30	74.9	19.8

*In October, 1971, the village of Hezarjolfa had a population of 507 distributed among 101 families.

It can be seen that the approximate daily per family water consumption in this area at this particular season of the year is of the order of 20 gallons (75.7 litres). On a per capita basis this represents 4 gallons/day (15 litres/day). It should be noted that the water is piped only up to the village, and from then on it is moved by beasts of burden. It must nonetheless be stressed that this is representative of a village in Iran where pumped water is available and these consumption rates need not necessarily apply in a far more arid region where a regular piped supply is not available.

(2) Dutheil and Gaussens (19) have shown that in Iran and neighbouring Pakistan the per capita water consumption per day for localities having less than 20,000 inhabitants is of the order of 6.5 U.S. gallons (about 24 litres).

(3) The daily per capita consumption of water of cities in Iran can also serve as a guide for estimating the potential and existing water requirements in Gheshm Island, the Bandar Abbas area and other areas of the Persian Gulf region. The findings are listed below:

Name of City	Population	Water Consumption/capita-day	Reference No.
Shemiran	37710	(27.7 U.S. Gallons) 105 litres (piped in)	(20)
Ray	31160	(27.7 U.S. Gallons) 105 litres (piped in)	(20)
Boshehr	--	(31.7 U.S. Gallons) 120 litres (piped in)	(20)
Abadan	128000	(41.2 U.S. Gallons) 156 litres (piped in)	(20)

(4) It is also interesting to compare the above-mentioned figures to those for small communities in similarly arid areas in other parts of the world. These are listed in Table (11). It is, therefore, significant to note that the demand in a north central Iranian village with a piped well water supply is in the range of water consumption for small communities in arid areas of the world.

Hence it would be reasonable to allow a consumption of 2 to 5 gallons per capita per day for Gheshm Island and the regions surrounding Bandar Abbas, bearing in mind the limitations of fresh water availability as outlined in the previous chapter.

1.6 Population Distribution and Potential for Desalination in the Areas under Study

The population in Gheshm Island and the Bandar Abbas area is spread over a series of villages, the details of which are given in Tables (12) and (13). These population levels are typical of the entire southern coast of Iran. It is clear that the population of villages in Gheshm Island and Bandar Abbas region range from 100 to 1000 inhabitants; the exceptions are Bandar Abbas City, Gheshm City, Dargahan, Sozad, and Laffet, which had, in 1970, populations of 35,000, 5,000, 2,155, 2,451 and 1,942 respectively. It seems reasonable that for villages of such size and considering a 2 to 5 gallons water consumption per capita per day, independent desalination units can be used. Solar distillation units appear to be the most attractive for desalination, because the amount of fresh water required for these villages would range from 200 to 5000 gallons per day. This is because solar desalination appears to be the most economical means of desalting sea water for up to 50,000 gallons per day (27).

CHAPTER II

Development of the Existing Sources of Water Supply

2.1 Rainfall Catchment

In Gheshm Island and in the Bandar Abbas area rainfall collection can be considered as a supplementary source of water supply. Rainfall can be collected either from natural drainage areas connected to storage ponds or from the roof tops. At present a number of ponds exist in the areas under consideration which provide a limited amount of fresh water. The following factors need to be considered with regard to the utilization of these ponds:

(1) The rainfall distribution is not really amenable to this type of collection system.

(2) The equipment required for preparing storage reservoirs must be brought from the mainland centres such as Bandar Abbas.

(3) The seepage from the ponds is relatively high as the deep underlying soil has a sandy texture (14).

(4) The rate of evaporation from the ponds is high. The evaporation rates were calculated, using the climatological data measured on Gheshm Island, and the results are presented in Appendix A. The total yearly evaporation is seen to be approximately 90 inches. Therefore, the storage of rainfall in natural reservoirs does not appear to be a practical solution. It is obvious that extremely large catchment areas would be required to overcome these high evaporation losses.

(5) The sizing of a suitable reservoir to effectively capture a significant portion of the high intensity short duration rainfalls also poses a major problem. Consequently this method of water provision is seen to be economically unfeasible.

In arid areas roofs of the buildings are commonly used as collection surfaces. The annual amount of water that can be collected in this manner is given by (28):

$$V_R = \eta \times A \times I$$

where η is the efficiency of rainfall collections, A is the total area available as collecting surface and I represents the average annual rainfall.

The area of roof surface per house in Gheshm Island and the Bandar Abbas region is assumed to approximate that measured by the author in the Ghazvin area (Central Province, Iran) which was about 200 square feet. Assuming an average annual rainfall collection efficiency of 80 per cent and average rainfall of 4.27 inches per year, the amount of rainwater collected is given as:

$$V_R = \eta \times A \times I$$

$$V_R = 0.8 \times 200 \times \frac{4.27}{12} = 56.9 \text{ ft}^3/\text{yr}.$$

In reality only about 80 to 90 percent of this amount can be collected because the low intensity rainfalls (below 0.05 inches) do not produce water especially from relatively porous surfaces (29).

This is, in fact, the case in Gheshm Island and the Bandar Abbas region where a special form of clay is used to seal the roofs ostensibly to make them weatherproof.

Consequently about 340 to 380 gallons of water can be collected off the roof tops per annum. Assuming a minimum requirement of 3.5 U.S. GPD/person and a family comprising of five persons, the collected water would be sufficient only for a period of about 20 days in a year. It is obvious, therefore, that other sources of supply must be secured in order to ensure survival in these areas.

2.2 Development of Ground and Surface Water Resources

The surface and ground fresh water supplies of this region are very limited (13). As discussed in Chapter I ground and surface water resources are neither reliable nor of a satisfactory quality. Currently a portion of the deficit in the fresh water supplies in Bandar Abbas area and other Persian Gulf Islands is often overcome through shipment from adjacent regions where supplies are generally more readily available. The cost of water from these sources is about $1.55 per cubic meter (13, 18). However, this is not satisfactory because adequate amounts of water are not provided for the inhabitants throughout the year (2). What is therefore needed is the development of a system of water provision which would offer these residents an independent source of supply. It is hoped that this system could be integrated within the structure of these communities. It must be borne in mind that these people are poor and cannot afford extensive expenditures. Therefore, it would appear to be the responsibility of the state to provide a means of fresh water provision for these areas. Although the importation of water is an alternative, this study investigates the potential of desalination as a possible solution.

2.3 Existing Desalination Installations in this Area

Within recent years, the Imperial Navy of Iran, commissioned Dr. H. Nohedani of the Institute of Water and Energy of Arya Mehr University of Technology, Tehran, to install a solar distillation plant on Hengam Island, which lies off the coast of Gheshm Island. This installation serves a naval facility, but unfortunately there are no published reports on its performance (30).

There are a number of other desalination plants in the area, but most appear to be large-scale. Some flash distillation units have been installed on Khark Island (30). Other installations are under consideration for Abadan and Bandar Abbas, but again these will be of a large size. Some small size units, mainly of the electrodyalysis type are in operation in Bahrein and in the other Gulf states (32).

As has been illustrated in Table No. 12, the distances between the capital of Gheshm Island and the outlying communities can be extensive. Hence it might prove expensive to install a central plant for the island with a fresh water distribution network. Therefore, this study will investigate solar distillation as a means of fresh water provision in that this process is sufficiently simple so that the local inhabitants can not only participate in the installation of the equipment, but also in its maintenance and operation. It has been effectively shown that other rural isolated and less developed communities in the world have also been able to operate this type of equipment (33 and 34). Also they would require neither the transportation of fuel supplies from the mainland, nor the stocking of specialized spare or replacement parts, whose installation demands the presence of skilled labour.

CHAPTER III

Solar Desalination

3.1 General Description

Solar desalination provides a simple and effective means of desalting sea and brackish water. The process which is schematically presented in Fig (2) is quite simple in principle. It involves the passage of solar radiation through a transparent cover which in turn heats up the saline water mass inside the still to a temperature above the ambient. For the system to reach a thermal equilibrium the transparent cover attains a temperature which--in general--lies between those of the ambient air and the water mass. The temperature differential between the water mass and the cover results in a corresponding vapour pressure differential and causes the water mass to evaporate. The vapors rise and condense on the cover as fresh water. By installing the cover in a sloping plane, the condensate is made to run down along its underside and is collected in troughs and transferred for subsequent storage.

3.2 Productivity (P)

The productivity of a solar still is a function of the brine surface temperature and the temperature differential between brine surface and the cover. Many factors influence the brine and cover temperatures and hence the productivity of a solar still. These factors are listed below:

(1) Solar Radiation Intensity. The most important parameter affecting the output of a still is the intensity of solar radiation. The productivity of a still usually increases exponentially with the intensity of total solar radiation. This is because higher intensity of radiation results in higher brine temperature; and even for the same temperature differential ($t_w - t_c$), a higher vapour pressure differential ($P_w - P_c$) is obtained. This results in a higher productivity for the

still.

The solar radiation incident on a still is composed of both direct and diffuse components. On clear or partly cloudy days approximately 10 to 40 percent of the total solar radiation consists of diffuse radiation (28). The percentage of diffuse radiation rises with increasing cloudiness; on completely overcast days diffuse radiation might be the only radiation reaching the ground surface. The apparent effective angle of incidence for the diffuse radiation on a horizontal surface is about 60 degrees (35).

The productivity (P) of a solar still has been found to be satisfactorily correlated by the intensity of total radiation incident of horizontal surface (I_H) and many empirical equations have been formulated by different authors. Amongst these Lawand (36) has suggested the following expression:

$$P = 5.53 \times 10^{-5} (I_H) - 0.041, \text{ gal/ft}^2\text{-day} \qquad (3.1)$$

Grune (37) has similarly developed a linear regression equation for a glass and plastic covered still as follows:

$$P = 2.74 \times 10^{-5} (I_H) + 0.0053, \text{ gal/ft}^2\text{-day} \qquad (3.2)$$

For the original deep-basin still at Daytona Beach (38) the following exponential relationship was obtained.

$$P = 6.17 \times 10^{-4} (I_H/100)^{1.64}, \text{ gal/ft}^2\text{-day}$$

A plot of the productivity of 10 large solar stills versus the intensity of radiation (I_H) is shown in Fig (3). Eibling (34) indicates that the productivity of the 9 lower curves is correlated well by the following equation:

$$P = 1.16(I_H/100)^{1.4} \times 10^{-3}, \text{ gal/ft}^2\text{-day} \qquad (3.3)$$

It is obvious that in order to predict the productivity of a solar still, a knowledge of the intensity of radiation (I_H) is mandatory. The methods used for estimating the annual variations in I_H for Southern Iran are discussed later in this chapter.

(2) Ambient Air Temperature. The second parameter affecting the productivity of a still is the ambient air temperature. Its effect, however, is of the second order of magnitude. In general, an increase in ambient air temperature results in an increase in the productivity of the still.

(3) Brine Depth. It is obvious that a shallow layer of water will reach a higher temperature during the day than a deep layer. This would result in higher rates of distillation during the daytime. However, owing to a low thermal capacity very little energy is left in a shallow layer of water after sunset to produce distillate. A deep layer, on the other hand, has a high thermal capacity and attains relatively lower temperatures during daytime. Although it results in lower rates of distillation during the daytime hours, the energy entrapped in the water layer enables the still to continue producing long after sunset. It has been found that other things being equal, a shallower layer of brine in a basin type still results, in general, in a higher productivity over a 24 hour period. This was experimentally verified by Bloemer (39) and Talkes (28); Löf (40) has verified this fact theoretically. The effect of brine depth on the productivity of the still is, however, of a second order of magnitude.

(4) Wind Velocity. An increase in wind velocity results in a lowering of cover temperature which instantaneously increases the rate of distillation. This is, however, followed by a subsequent drop in brine temperature and the rate of distillation generally drops. The overall effect of wind velocity on the productivity is not perfectly understood but is probably not too significant.

(5) Cover Slope and Shape. Löf et al (40), Baum (41) and Morse (42) reported that the effect of cover slope on productivity is quite small. The slopes as low as 6 degrees have been used successfully.

The two deep-basin stills built for the Office of Saline Water at Daytona Beach used 15 and 10 degrees covers. After experimenting with cover slopes of 10, 15 and 40 degrees at the Central Salt and Marine Chemicals Research Institute in Bhavnagar, India (43), they selected the 20 degree slope as being the most suitable for further development work. Baum and Bairamov (44) selected a 30 degree slope after investigating stills with 30, 35 and 40 degree slopes. Consequently the cover slopes between 10 and 20 degrees seem to be most practical for large solar stills. It is interesting to note that several attempts to reduce the cover slope have reported increase in productivity (45,46).

(6) Vapour Tightness and Distillate Leakage. Vapour tightness and distillate leakage have a considerable effect on the productivity. All solar stills should be designed to be completely vapour and distillate tight. Batelle (38) and Ahmed (43) reported that the vapour and distillate leakage reduced the productivity of the solar still by about 20 to 49 percent.

(7) Other Factors. Other factors affecting the solar still production, the effect of which have not been completely determined, are: the use of insulation beneath the basin and the orientation of the still. Obviously, if the use of insulation can effectively increase the brine temperature, then the productivity should be enhanced. Cooper (47) reported graphically the advantage of insulating the basin of a solar still. Materials such as straw and sawdust can be used for the insulation of the bottom of the basin. If such material is used the under side of the solar still basin must be kept dry, otherwise the insulating material will deteriorate if excessive moisture is present. Insulation can become wet from ground water or from leaks occurring in the basin liner.

It is evident that the productivity of a solar still is affected primarily by climatic and structural factors.

As has been indicated in Chapter I, the conditions in Iran tend to be conducive to solar desalination in that there is a good solar climate, the ambient temperatures are high and the major storms appear to be infrequent. The structural factors can be best determined by the selection of the optimum design features as outlined above, bearing in mind the whole question of economics.

3. Estimation of the Intensity of Solar Radiation for Southern Iran

To evaluate the performance of any type of solar still in a particular area, the records of solar radiation are needed. The still performance can be calculated on the basis of average monthly, weekly or daily records. Ideally speaking, the average hourly values of solar radiation based on 15 to 20 years of records should be used. In practice such data is seldom available and approximations are, therefore, needed.

For the southern coast of Iran no recorded data on solar intensity is available. The following methods were, therefore, used to estimate the intensity of total solar radiation on a horizontal surface (I_H) on a daily basis for Southern Iran. As would be expected, Bandar Abbas and Gheshm Island were chosen as representative areas for these estimations.

Method (1). The world distribution of solar radiation has been prepared in studies by Löf (48) and Black (49). The isopleths drawn in these maps record, on a monthly basis, the daily average of the intensity of total solar radiation (direct plus diffuse) on a horizontal surface (I_H). These charts were used to estimate the insolation in Southern Iran. Interpolations were made where necessary. The results are presented in Table (14).

Method (2). The empirical formula suggested by Reddy (Appendix B) was used to evaluate I_H. This method correlates geographical location and climatic variables in order to estimate I_H. The resulting values are recorded in the third column of Table (14).

Method (3). Although no recorded data on insolation is available for Southern Iran, the Meteorological Section of the Directorate General of Civil Aviation in the nearby Sheikhdom of Kuwait (located between latitudes $28^\circ.46'$ and $30^\circ.15'$ N) records some weather data. Although it is reported that solar radiation data has been recorded for some years there, only an indirect reference (51) was available.

In this reference the daily records of solar radiation intensity (I_H) for the year of 1964 have been tabulated. The resulting average monthly values for I_H are shown in the last column of Table (14).

Table (14) indicates that the solar radiation intensities given by Löf (48) are in close agreement with those recorded in Kuwait. The two sets of values differ by about 5 percent and the maximum variation is around 8 percent. This is very reasonable considering the method used to establish these charts.

There exist wider differences between Black's figures (49) and the data recorded in Kuwait. The variation is generally in the order of 8 percent and for one month the difference is as high as 18 percent.

Reddy's empirical formula, on the other hand, results in values which, in general, are substantially lower than the other three sets of data.

Since the discrepancy was fairly large, these latter results were not used for subsequent calculations. Lof's data was utilized instead of Black's as primarily the former showed a closer agreement with the data from Kuwait.

CHAPTER IV

Experimental Investigations

During the summer of 1971 five experimental solar stills were built at the Brace Research Institute and subjected to field tests. These stills have been designated as BR-1, S-1, A-1, L-1 and W-1, and are illustrated in Figs. (4) to (7).

These solar stills were constructed with--as much as possible--the materials which were likely to be available in the rural areas of Iran. A list of these materials outlining their specifications and costs is given in Appendix C. The details of these stills are given below:

(a) Solar Still BR-1: The basin of this still was lined with butyl rubber. The still had a single-slope glass gover (1/8 inch, i.e. 32 mm, window glass) inclined at an angle of 5 deg. to the horizontal. The glass was sandpapered lightly in the direction of flow of the distillate to permit the utilization of such a small angle of inclination. A 6 inch (15 cms) high brick wall was used to support the glass on one side and a 3½ inch (8.89 cms) high moulded, pre-cast concrete wall which contained the rainwater and distillate troughs was provided at the other side. The basin area of the still measured 32½" x 112½" (.83 m x 2.8 m). The nominal brine depth of this still was 2 inches (5.08 cms).

(b) Solar Still S-1: The frame of this still was built of soil cement blocks and the basin was lined with a thin bamboo mat rendered impermeable through impregnation with sulphur. The rear supporting wall was 8 inches (20.32 cms) in height while the lower wall was 3 inches (7.62 cms) high.

The still had a basin area of 31" x 98" (0.79 m x 2.49 m) and had a single-sloping glass cover (1/8" thick, i.e. 32 mm window glass) included at an angle of 9 deg. to the horizontal. The nominal water depth of this still was 2 inches (5.08 cms).

(c) Solar Still A-1: This solar still was built with an aluminum base which was covered by a black orlon mat. The supporting walls, which were 10½ inches (26.67 cms) and 2½ inches (6.35 cms) high, were made of bricks. An aluminum basin was fabricated to fit directly into this frame. The single-sloping glass cover (1/8", i.e. 32 mm, thick window glass) was inclined at an angle of 16 deg. to the horizontal. The basin area measured 28" x 96" (0.71 m x 2.44 m) and had a nominal water depth of 2 inches (5.08 cms).

(d) Solar Still L-1: This solar still was similar in construction to the others except that the basin was made up of lead sheet. It had brick walls. The angle of inclination of the cover to the horizontal was 17 degrees. The nominal water depth for this still was also 2 inches (5.08 cms)

The stills described up to this point were built rather late in the summer and consequently only a limited number of measurements were taken on them. All these stills, it may be mentioned, were built directly on the ground and except for a layer of dry sand no thermal insulation beneath the basin was used.

(e) Solar Still W-1: The fifth still which provided the bulk of the data for analysis in this thesis was the first one to be built and was operative for most of the summer months. The basin liner--a 3.0 mm thick butyl rubber sheet--was laid over a 2 inches (5.08 cms) thick sheet of styrofoam to provide insulation, and this in turn rested on 1 inch (2.54 cms) thick cedar planks. The sides were made up of a double thickness of wood which strengthened the structure and at the same time provided insulation. The still was covered by 1/8 inch (3.2 mm) thick single-sloping window glass inclined at an angle of 15 deg. to the horizontal.

The basin measured 143" x 28" (3.63 m x 0.71 m) and had a water depth of 1 inch (2.54 cms).

Whereas the preceding four stills were tested in an open field, the still W-1 was placed on 6 inch (15.24 cms) high concrete blocks and placed on the roof of Machinery Hall (Department of Agricultural Engineering) at Macdonald College, Ste. Anne de Bellevue, Quebec. The data for the still W-1 was collected for about 11 weeks, extending from June 15, 1971, to August 31, 1971.

All the five stills described in this section were aligned on an east-west axis. The distillate was measured twice a day, in graduated cylinders, at 09:00 hours and 16:00 hours. The daily water loss due to evaporation inside the still was replenished at 08:00 hours every day so that all the stills reached their respective nominal depths at this time.

It is to be noted that in all the stills tap water was used instead of brine. Murphy (52) has indicated that such a use does not affect the theoretical evaluation of the process perceptibly, because the vapour pressure of sea water having 30,000 ppm TDS (total dissolved solids) is only slightly less than that of fresh water.

Instrumentation: The intensity of total solar radiation on the horizontal surface (I_H) was measured utilizing a calibrated Eppley pyranometer No. 4400. The instrument had been recalibrated one month prior at the Radiation Labs of the Canadian Atmospheric Environment Service. The data was totalized using a Lintronic Mark IV integrator.

Ambient air temperatures were measured in a Stevenson screen, using standard maximum and minimum thermometers. The wind speed was measured using a Munro cup-counter anemometer.

CHAPTER V

Analysis, Results and Discussions

Two alternatives were considered in this thesis for desalting saline water by solar desalination. One of them pertains to the development of a large-scale solar still for the whole isolated community and the other refers to the provision of small scale solar stills for each family in the community. The data for these two alternatives were analysed separately and the details are given below:

5.1 Estimation of the Productivity of a Large-scale Solar Still

In order to use a large sized solar still for desalting sea water in the isolated communities in Southern Iran, it is imperative that its output be predicted. For this purpose use was made of eqn (3.3)viz:

$$P = 1.16(^{I_H}/100)^{1.4} \times 10^{-3}, \text{ gal/ft}^2\text{-day}$$

or equivalently

$$P = 0.293111(^{I_H}/100)^{1.4}, \qquad \text{litres/m}^2\text{-day}$$

The values of the intensity of total radiation on horizontal surface (I_H) were taken from Löf's charts. The resulting values have been listed in Table (14). The values of productivity of large scale solar stills obtained from eqn (3.3) are listed in Table (15). The last column on the right gives the monthly totals of the productivity of the still on a per unit area basis. Yearly totals are also listed.

5.2 Estimation of the Productivity of a Small-scale Solar Family-size Solar Still

As has been discussed in Chapter IV, a total of five experimental small-scale solar stills were built and tested as a part of this study. The daily productivities (expressed in litres/ sq. meters) were measured as a function of total intensity of solar radiation, I_H (cal/cm^2-day). The results are recorded in Table (16) and Table (17) and are graphically presented in fig (8). For the sake of clarity the experimental points are not shown and only the regression lines resulting from the data are plotted. Since only a limited number of measurements were available for the stills BR-1, S-1, A-1 and L-1, the regression lines resulting from them were not used for predicting the output of small-scale family-size stills in Southern Iran. The still W-1, which was tested for rather a longer period of time and which provided the bulk of experimental data, was used for this purpose.

The regression equation based on the experimental data of still W-1 was found to be:

$$P = 0.00003873(I_H) - 0.002054, \text{gal/ft}^2\text{-day} \tag{5.1}$$

where I_H is expressed in B.T.U.'s/sq. ft.-day

or equivalently in metric units:

$$P = 0.005807\ (I_H) - 0.083535, \text{litres/sq. meters-day} \tag{5.2}$$

I_H in this equation is expressed in cals./cm^2 -day.

The values of resulting productivities for a small-scale solar still are listed in Table (18). The monthly values and the yearly totals of the still productivity on a per sq. meter basis are also listed. The values of I_H used in eqn (3.3) were taken, as in the previous case, from Löf's charts.

Table (18) forms the basis for designing family-size solar stills in Southern Iran.

5.3 Efficiency (η) of the Small-scale Experimental Solar Still W-1

The performance of a solar still is often expressed in terms of operating efficiency (η). An expression which is often used for calculating efficiency (η) was given by Bloemer et al (53) as

$$\text{Efficiency } (\eta)\text{, percent} = \frac{(\text{Production, gal/ft}^2\text{-day})(8913 \text{ B.T.U./gal})(100)}{(\text{solar radiation intensity, } I_H\text{, B.T.U./ft}^2\text{-day})}$$

The resulting values for the efficiency (η) of the solar still W-1 are listed in Table (18A).

5.4 Estimation of the Reservoir Capacity for the Proposed Large-scale Solar Stills to be used in Southern Iran

In the most favourable circumstances the pattern of fresh water demand should match the pattern of production of a solar still in which case zero or negligible storage would be required. Thus the construction works would involve the solar still itself, a feed water supply system and a product water distribution system. However, the output of a solar still is dependent on solar radiation, and hence changes considerably during the year. Clearly then, unless an unusual fluctuation exists in demand, the use of solar desalination dictates the construction of storage facilities.

To calculate the storage capacities, the following cases were considered:

(1) Zero rain catchment from roof tops or solar still cover is assumed and a constant water demand of 3.5 GPD/capita (13.2 litres/capita-day) is assumed. The isolated community is supposed to be comprised of 1000 inhabitants. A large-scale single solar still is to meet the water demand of this community.

(2) Conditions are assumed to be the same as in case (1). Rain catchment off the roof tops of houses and the solar still covers are assumed to contribute to the water supplied to the community.

(3) The same conditions as in case (2) are assumed, except that the constant water demand of 3.5 GPD/capita (13.2 litres/capita-day) is substituted by a variable demand as specified below:

May 15 to September 15: Water demand of 4.5 GPD/capita (17.0 litres/capita-day)

Rest of the year: 3 GPD/capita (11.4 litres/capita-day)

(4) Same conditions as in case (2) are assumed to exist, except that a different constant water demand, viz 2.5 GPD/capita (9.5 litres), is assumed to exist.

(5) The same conditions as in case (4) exist. The demand

is variable and is as noted below:

May 15 to September 15: 3.5 GPD/capita (13.2 litres/capita-day)
Rest of the year: 2 GPD/capita (7.5 litres/capita-day)

The details of analyses leading to the estimation of storage capacities in the above-mentioned 5 cases are, as follows:

Case 1 - Based on a population of 1000 and a constant demand of 3.5 GPD/capita, the monthly demand is estimated. The annual total demand is then calculated. This demand is to be met fully by the solar still since it is assumed that the rainwater does not contribute to the water supply of the community.

The annual productivity of a large-scale solar still was calculated in Table (15) and found to be 1076.1 litres/sq. meter.

The total annual water demand was calculated to be 4835730 litres and is listed in Table (19). The area of the solar still required to meet this demand =

$$\frac{4835730}{1076.1} = 4493.8 \text{ sq. meters}$$

Assuming a bay to measure 150 ft x 7½ ft (45.73 m x 2.286 m), the total number of bays required =

$$\frac{4493.8}{45.73 \times 2.286} = 43.1$$

A total of 44 bays were assumed to form the solar stills.

Total area of the still =

$$44 \times 45.73 \times 2.286 = 4598.7 \text{ sq. meters}$$

The monthly productivities of a large-scale solar still on a per sq. meter basis are known (Table 15). These values were multiplied by the total still area (4598.7 meters) to determine the monthly output of the proposed large-scale solar still. The resulting figures are listed in the first column of Table (19). The still is seen to produce a yearly total of 4,950,386 litres of fresh water. The last two columns in Table (19) represent the monthly values of deficit or surplus in water supply. It can be noted that a total yearly deficit of 698653 litres and a total annual surplus of 813310 litres exists. It is readily seen that during the summer months (April to September) the solar still produces more than the demand, thereby producing a surplus of fresh water. In the fall and winter the productivity of the still goes down and the demand exceeds the supply resulting in a deficit. In order that the deficit in supply is met from October to March of the following year, the storage tank should have a supply of at least 698653 litres at the end of September. This figure is determined by totalizing the monthly figures whereby there is a water surplus during consecutive months of the year and taking the maximum figure that exists for any continuous stretch. By following a pattern on a month to month basis of relating supply and demand this figure can easily be determined. In this particular case it is reached by adding the surplus produced from April to September, month by month. The remaining surplus water (813310- 698653 =114657 litres) should be supplied to the inhabitants in the community during the summer months. By permitting an additional allowance of 15 percent* as a safety factor in the design of the storage tank, a total capacity of 69865 x 1.15 = 803451 litres = 803.5 m^3 is arrived at.

Case 2 - The analysis is similar to the one given under Case (1) except that rainwater collected off the roof tops and solar still covers meets part of the water demand.

To estimate the contribution of rainfall, the quantities of precipitation at Bandar Abbas (Table 1) and Gheshm Island (Table 4) were averaged and the resulting figures listed in Column 3 of Table (20). As described in Chapter II the amount of rainwater collected each month from the roof tops--and hence the total yearly contribution--is calculated. This was found to be 266024 litres.

*Standard practice followed in the Ministry of Water and Power, Iran

A total roof area of 40,000 sq. ft (3716 sq. meters) and an overall collection efficiency of 65 percent was assumed. This figure when subtracted from the total annual demand (4835730 litres) determines the amount of fresh water to be supplied by the solar still. It is seen to be 4835730 - 266024 = 4569706 litres per annum.

This amount of water has to be supplied by the solar still partly through the distillate produced inside the still and the remaining through rain catchment off its cover. The distillate and rainwater can either be mixed together in the system or collected separately.

Knowing the yearly distillate production of the still to be 1076.1 litres/sq meter and a total rainfall of 109.98 mm, and assuming an overall rainfall collection efficiency of 65 percent, the solar still area (A) is found to be:

$$A \doteq \frac{4569706}{1076.1 + 109.98\ (0.65)} = 3982 \text{ sq. meters}$$

A very low efficiency (65%) of rainfall collection has been utilized in order to allow for low intensity precipitation and the relatively high rates of evaporation in these areas. Assuming the bay size to be 150 ft x 7½ ft (45.73 m x 2.286 m), the number of bays in the solar still is found to be

$$= \frac{3982}{(45.73 \times 2.286} = 38.0$$

The solar still, therefore, will have an area of 3982 sq. meters. Based on this area the monthly supply of distillate (Column A, Table 20) and the monthly supply of rainfall collected off the still cover (Column B, Table 20) have been calculated. Their respective yearly totals are seen to equal 4275344 litres and 279920 litres respectively.

Total monthly supply (columns A+B+C) being known, the monthly deficit and surplus is readily calculated. The storage capacity can then be calculated as described in Case 1 and is found to be = 464 m^3.

Cases 3 to 5 - Storage capacities for these three cases are found in essentially the same way as in Case 2. The resulting storage capacities are found to be:

Case 3 - 309.6 cubic meters (Table 21)
Case 4 - 235.7 cubic meters (Table 22)
Case 5 - 248.4 cubic meters (Table 23)

5.5 Estimation of the Cistern Capacity for the Proposed Small-Scale Family Size Solar Still

The small-scale family size solar still is assumed to supply fresh water to a family of five. The still is proposed to be located on the roof top and hence the latter cannot be used for rain catchment. Except for this difference, calculations leading to the determination of the solar still area and cistern capacity are precisely the same as in the case of a large-scale solar still which has been discussed in the preceding section.

As mentioned in Chapter II, the roof area per house is assumed to equal 200 sq. ft (18.6 sq. meters). If the estimated area of a small-scale still exceeds this figure, one or two bays from the still will be transferred to ground level and placed inside the courtyard of the house located where they can readily receive solar radiation.

The following different cases were considered in this section:

Case 1: Constant water demand of 2 GPD/capita (7.5 litres)
Table (24)

Case 2: Constant water demand of 2.5 GPD/capita (9.5 litres/capita-day)
Table (25)

Case 3: Variable water demand as specified below:
May 15 - Sept. 15: 3.5 GPD/capita (13.2 litres/capita-day)
Rest of the year: 2 GPD/capita (7.5 litres/capita-day)
Table (26)

Case 4: Constant water demand of 3.5 GPD/capita (13.2 litres/capita-day)
Table (27)

Case 5: Variable water demand as outlined below:
May 15 - Sept. 15: 4.5 GPD/capita (17 litres/capita-day)
Rest of the year: 3 GPD/capita (11.4 litres/capita-day)
Table (28)

The cistern capacities for the above-mentioned five cases were calculated to be:

Case 1: 1.02 cubic meters
Case 2: 0.97 cubic meters
Case 3: 0.70 cubic meters
Case 4: 1.58 cubic meters
Case 5: 0.58 cubic meters

5.6 Economic Evaluation of the Large-scale, Community-size and Small-scale, Family-size Solar Stills in Gheshm Island and the Bandar Abbas Region

In order to be able to estimate the cost of installing family- and large-scale solar stills for use in Iran, it has been necessary to find out the cost of relevant building materials in Southern Iran. It must be appreciated that these figures will only be approximate. Representative building materials and labour costs are given in Appendix C. For this thesis the experimental investigations were carried out, as would be expected, on small scale units only. It is very difficult to extrapolate these costs to proposed large-scale units in Southern Iran. Nonetheless, working on a modular basis, approximate cost estimates have been given for small-scale equipment in Tables (33) and (34) and large-scale still in Tables (29) and (31). The annual operating costs for the large scale solar stills have been estimated in Tables (30) and (32). The equivalent annual cost basis has been used to estimate the annual charges. These differ according to the size of the demand and the required capacities of the cistern for small-scale and storage tank for large-scale solar still respectively. In estimating these costs, the following factors have been taken into account:

(1) The number of bricks required for the solar still frames have been calculated, using a double sloping roof type design. An extra allowance of 10% has been made for this factor.

(2) An extra allowance of 5% has been set for the glass required for the transparent covers.

(3) The sealant cost for the glass has been based on the experience of Lawand and Alward in Haiti (33), and amounts to 25 percent of the required glass costs.

(4) In estimating the cost of butyl rubber sheeting, 50 sq. feet (4.66 sq. meters) extra sheeting has been allowed for each basin.

The overall averaged figures representing the capital cost of the stills and the distillate produced from them are given below. These figures are based on various stills proposed earlier in this chapter.

	Average Capital Cost (Dollars/sq. meter of still)	Average Fresh Water Cost (Dollars/cu. meter of fresh water)
(1) Large-scale solar still for supplying water to 1000 inhabitants	8.97	1.32
(2) Small-scale solar still for supplying water to a family of five	7.81	1.16

5.7 Discussion

(1) Five experimental solar stills were built and tested as a part of this investigation. As mentioned earlier, only one (Still W-1) provided sufficient data. The other four provided a limited number of measurements as the experimental season is short due to climatic conditions in Canada. Based on these results, the regression lines were drawn (Fig. 3). It can be seen from Fig. 3 that these stills rank, in order of productivity, as follows:

Still A-1
Still L-1
Still BR-1
Still S-1

Owing to the limited amount of data, this order apparently cannot be treated as being conclusive.

(2) The productivities of a large basin-type solar still (Eqn 3.3) and a small experimental solar still W-1 (Eqn 5.2) are plotted in Fig. 9. It is obvious that, owing to the exponential nature of the curve, the large still produces more distillate at higher intensities of radiation. Even at lower levels of solar radiation, the productivity of a large solar still is only slightly less than that of a small still. Since these curves were used to predict the output of large- and small-scale stills in Southern Iran, where radiation intensities are generally high, the larger community-size stills were found to produce more distillate annually on a per unit area basis.

(3) Tests were run on small-scale stills only during the summer months. This is because the climatic conditions in Montreal, Canada are severe and testing of solar stills outside of the summer months is not possible.

It would have been preferable to conduct these tests in

Southern Iran. However, this was not possible.

(4) When a small-scale family-size solar still is to be installed on the roof, a maximum roof area of 10.9 sq. meters (200 sq. ft) is assumed to be available for this purpose. However, all of this area cannot be utilized and some allowance should be made for movement on the roof itself for maintaining the still. One or more bays of the still might have to be moved down into the courtyard.

(5) In case of small-scale stills, the saline water can be pumped by a hand pump or physically carried up into the basin. The distillate can flow under gravity directly into the collecting barrels. These are readily available in Iran and can be used for storing fresh water.

(6) As shown earlier, the cost of solar desalinated water is of the order of \$0.96 to \$1.41 per cubic meter. This figure appears to be reasonable, particularly if compared to the costs of transporting water to these areas, which is currently the only other source, however inadequate, of fresh water, and which, as noted earlier, costs about \$1.55 per cubic meter.

State responsibility in supplying fresh water to the arid areas is assumed in this discussion. Thus, cost figures quoted here indicate the relative costs to the government agencies supplying fresh water and not the costs to the local consumer. Historically, water supplies in the areas under consideration have cost the user nothing other than the time and energy to fetch the water. Recent government practise has been to augment insufficient water supplies, as for example shipping fresh water in, again at no direct cost to the consumer. It must be assumed that for the foreseeable future the burden of water costs will continue to fall on the government. Only at such time as these poor communities and their members attain an economic viability will the situation possibly change and the user be responsible for the direct costs of water supply.

It should be noted that most of the costs for building and maintaining solar stills will be channeled into the community, which will provide labour as well as the local materials for construction.

(7) Solar-desalination, in addition to being reasonable in cost for the size of communities existing in Southern Iran possesses several other advantages. Solar stills are easy to operate

and are readily absorbed into the infrastructure of the society. Repairs and maintenance do not need any special skills. Small-scale vapour-compression, reverse osmosis or flash distillation units which can be considered as alternative desalting processes, need a certain amount of skill for operation and maintenance which may not be readily available in Southern Iran. Moreover, even minor replacements or repairs might put the unit out of operation for rather long periods of time because a technician or a replacement part may have to be flown from a more developed centre such as Shiraz. The absence of electricity might impose a severe restriction on the use of such commercial units.

(8) The need for providing fresh water to these communities in Southern Iran cannot be overemphasized. The problem has human dimensions that attract immediate attention. The water presently used is unfit for human consumption in most cases, and has resulted in serious gastric troubles and diseases such as Bilharzia. The civilized world of today cannot remain indifferent to human problems of such magnitude.

(9) Owing to the lack of water, the people living in Southern Iran are gradually migrating to the cities which are already overcrowded. These people generally do not possess any skills and end up as a burden on the urban economies. Provision of fresh water will enable these people to stay in these coastal regions, engage in fishing and become an asset to the society.

SUMMARY AND CONCLUSIONS

(1) In this thesis the climate and hydrological conditions in Southern Iran were studied. The existing sources of water supply, namely groundwater, surface water and rainwater, were noted to be inadequate and unsatisfactory.

Underground water is limited to a few shallow and perched aquifers. This water is used to supply a small portion of the drinking water in Southern Iran. Accordingly, the contribution of ground water in meeting the fresh water demand has been neglected. Surface water that is obtainable from a few seasonal rivers was noted to be brackish. The rainfall catchment was found to meet only 20 days of fresh water demand on the southern coast.

(2) It was noted that the isolated communities in Southern Iran have an access to saline and brackish water and can be readily desalted and so produce fresh water for drinking.

(3) The daily demand of fresh water for each of these communities is well under 50,000 gallons per day (189,250 litres/day). As indicated in the literature review, solar desalination is often an economically feasible process in sizes less than this amount. Therefore, it appears to have potential in desalting saline and brackish water. Nonetheless, other desalting processes such as electrodialysis, vapour compression and reverse osmosis have not been investigated in this study.

(4) Two types of solar stills (viz, the large-scale community size and the small-scale family size) were considered for providing solar-desalinated water to the communities in Southern Iran.

(5) Different patterns of fresh water demand were considered. Some of these patterns assumed a constant water demand throughout the year, whereas the others assumed the water demand to be variable.

Based on these demand patterns, the costs of providing fresh water by large-scale and small-scale stills were calculated.

(6) The cost of providing fresh water by the large-scale still varied from \$1.24 to \$1.41 per cubic meter, whereas the corresponding range for the family size stills was found to be \$0.96 to \$1.37.

(7) These cost estimates are not supposed to determine as to which of the two stills is cheaper. The choice between a large- and small-scale still will be determined largely by the water demand pattern and this will have to be treated separately for each community where solar desalinated water is needed.

(8) These cost estimates, however, establish clearly that the cost of solar desalinated water is less than that of fresh water presently hauled ($1.55 per cu. m) from Boshehr and other locations. The latter being the only source of fresh water for isolated communities of Southern Iran at present, it seems reasonable to assume that solar-desalination can be used effectively as a means of desalting.

(9) Solar desalination appears to be one of the feasible processes for producing fresh water for the coastal settlements of southern Iran. The cost, nevertheless, is still prohibitively high. The inhabitants living in these communities are generally very poor and can not afford to buy even solar-desalinated water.

This, however, is not a deterrent because the Government of Iran has always supplied fresh water to these communities free of cost. The situation is not expected to change in the foreseeable future.

RECOMMENDATIONS

(1) A large-scale solar still be built in Southern Iran and tested for a reasonable length of time.

(2) A study be undertaken of various communities in Southern Iran in order to determine whether--at a particular location--a large-scale or a family-size solar still would be more suitable.

(3) Attention should be focussed on building small-scale family-size units with locally available materials. Detailed investigations of such materials should be undertaken.

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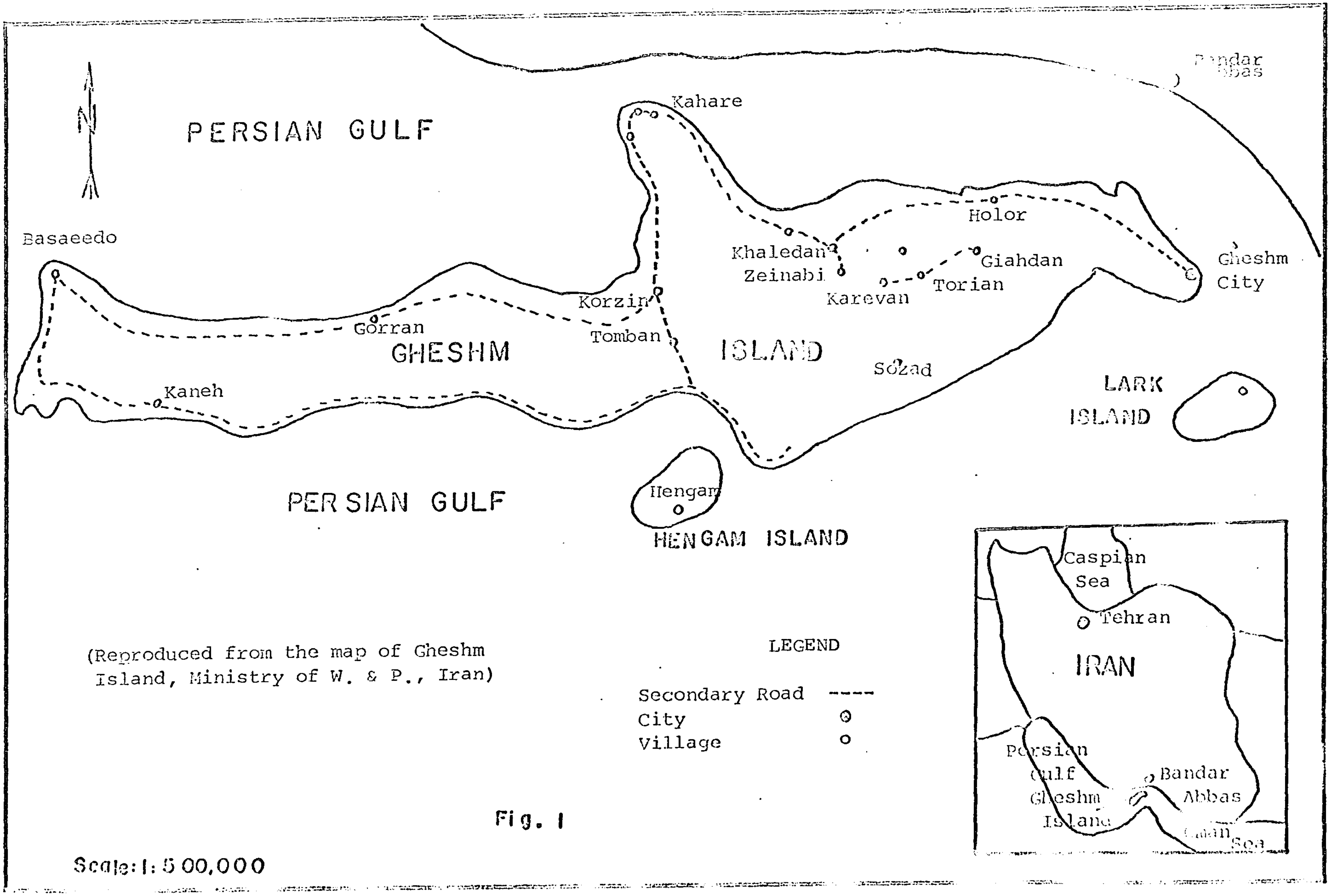


(Reproduced from the map of Gheshm Island, Ministry of W. & P., Iran)

Fig. 1

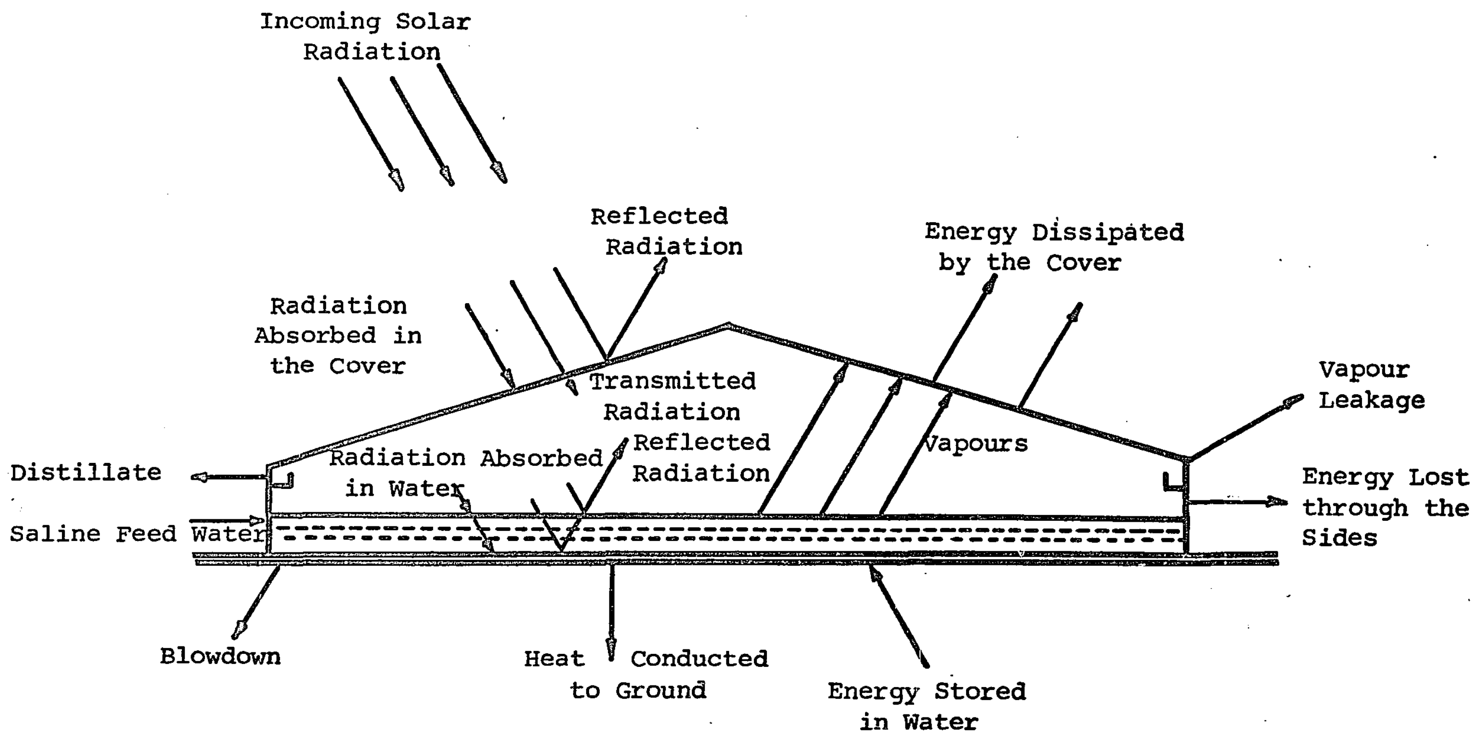


Fig. 2.-- Schematic Set-up of a Solar Still.

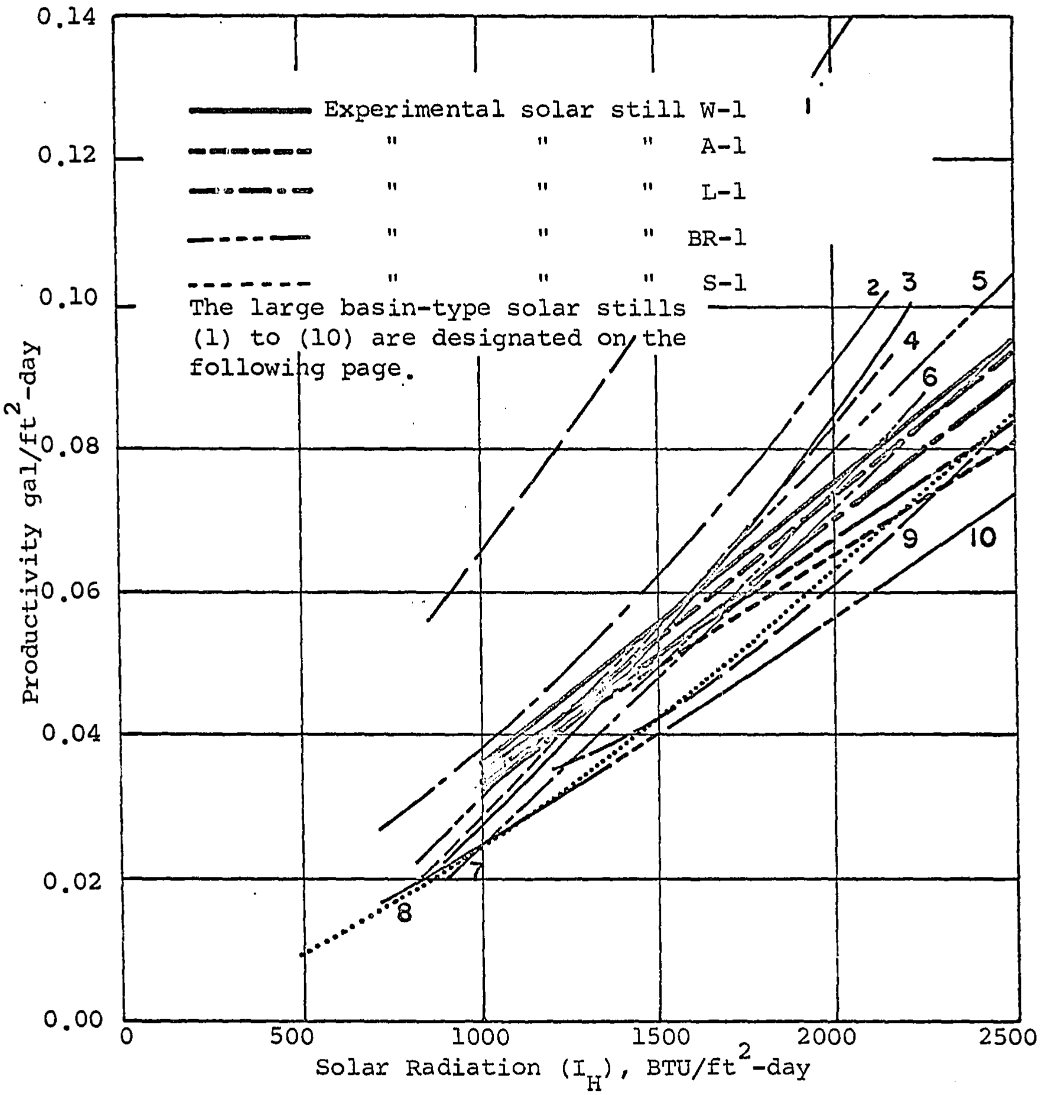


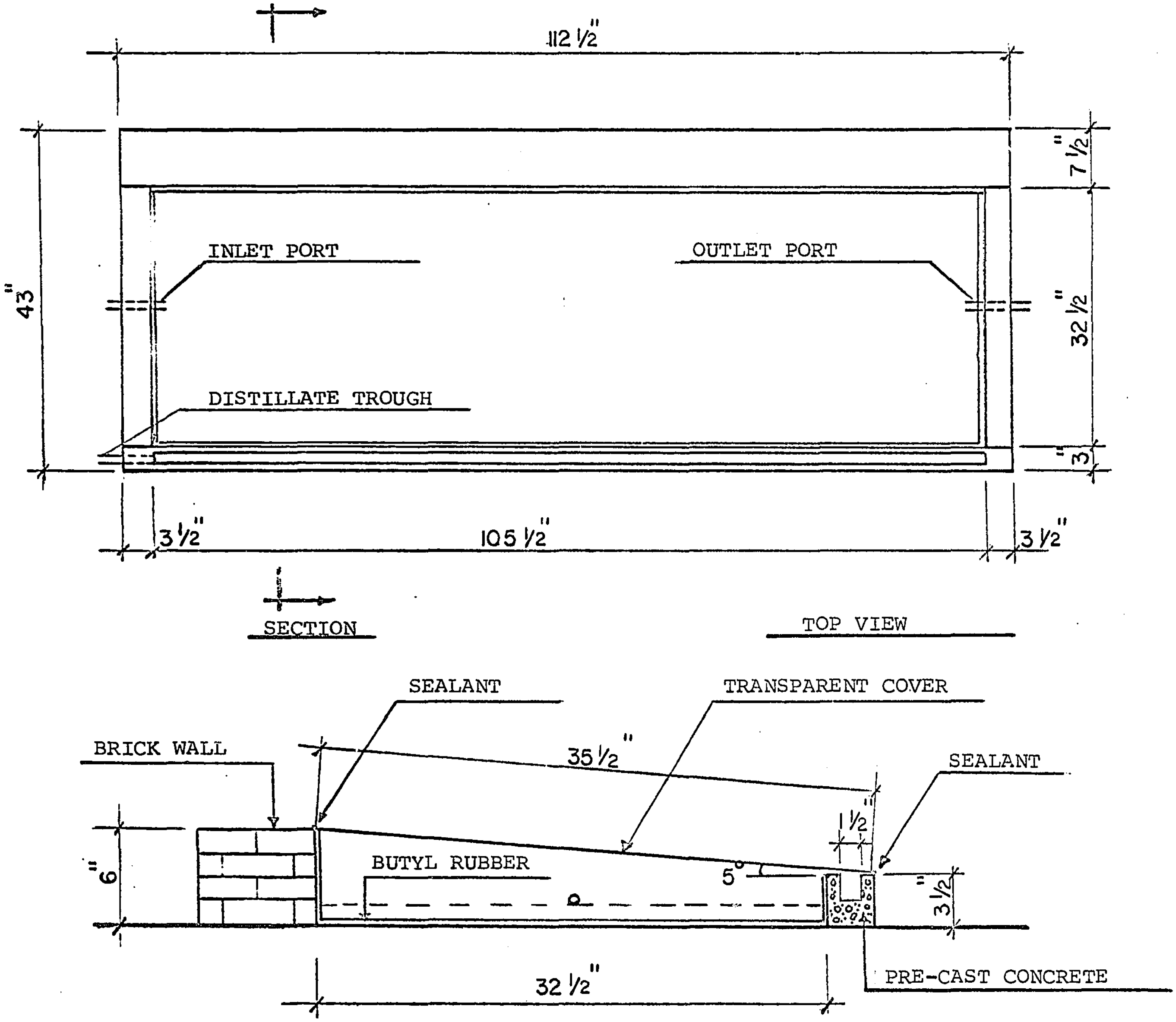
Fig. 3 Productivity of large basin-type Solar Still and small-scale experimental Solar Stills

(Reproduced from Manual on Solar Distillation of Saline Water, United States Department of Interior, Office of Saline Water Research and Development Progress Report No. 546 pp. 91)

Fig. 3 (cont'd)

1. Church World Service, Daytona Beach, 1600 ft^2, inflated Plastic, Insulated Basin
2. Church World Service, Symi, Greece, 28,920 ft^2, inflated Plastic
3. Battelle, Daytona Beach, 2450 ft^2 Original and 2650 ft^2 Second Deep Basin
4. Spain, Las Marinas, 9350 ft^2, Continuous Basin
5. University of California, 411 ft^2, Still No. 16, Insulated Tray
6. McGill University, Petit St. Vincent Island, 18,400 ft^2, inflated Plastic
7. University of California, 252 ft^2, Sawtooth-type Cover
8. CSIRO, Muresk, Australia, 4000 ft^2, Mark I and II Designs
9. CSMCRI, Bhavnagar, India, 4060 ft^2, 10 Bays
10. DuPont, Daytona Beach, 2330 ft^2, inflated Plastic

BUTYL RUBBER SOLAR STILL NO. BR - 1



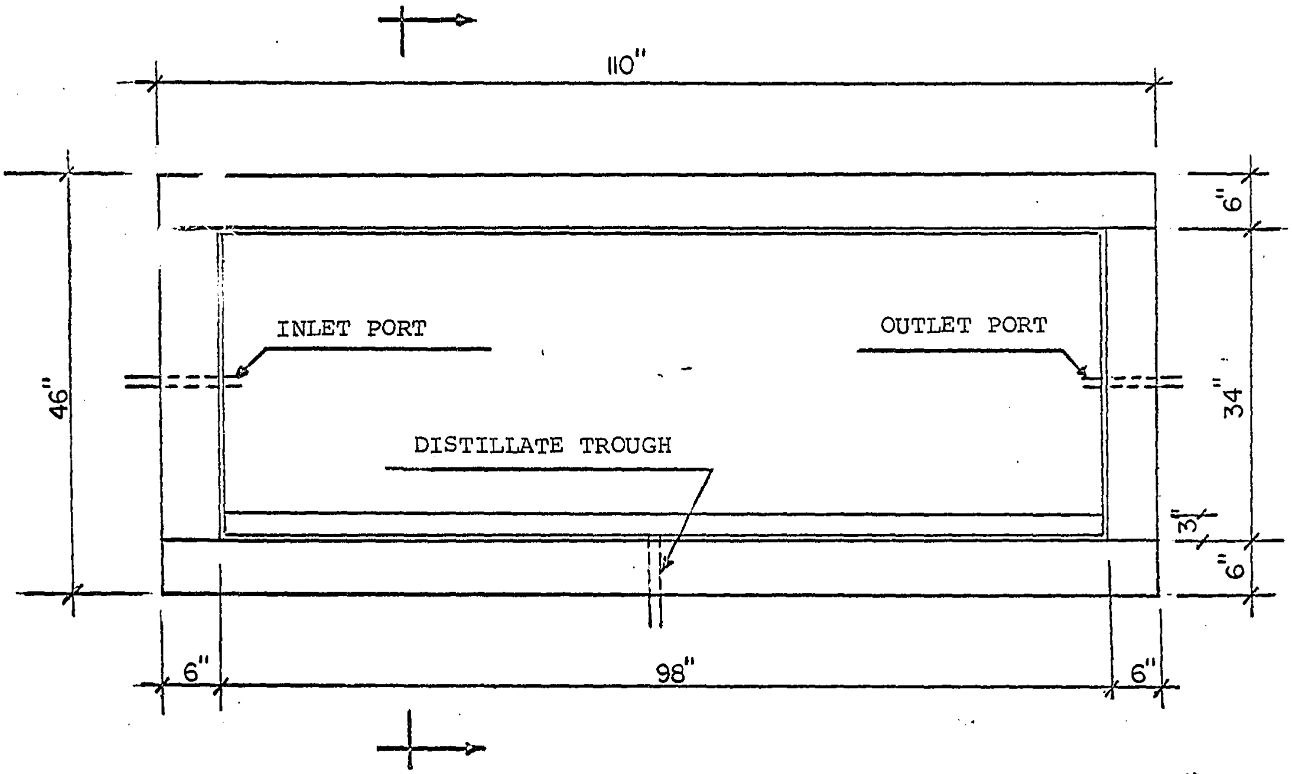
SECTION VIEW

SCALE:
Top view: 1" = 20"
Sec. view: 1" = 10"

BRACE RESEARCH INSTITUTE
Macdonald College of McGill University
Ste. Anne de Bellevue 800
Québec, Canada

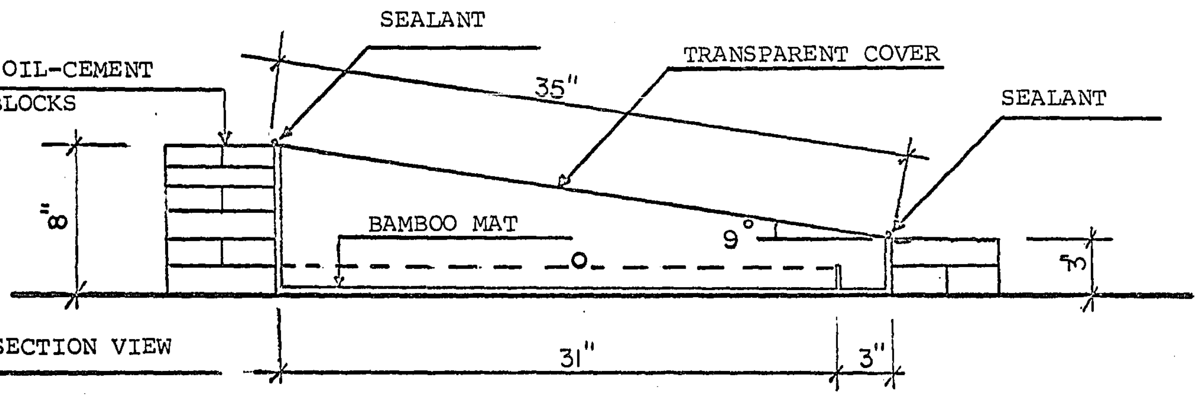
Fig. 4

SULPHUR SOLAR STILL NO. S-1



SECTION

TOP VIEW



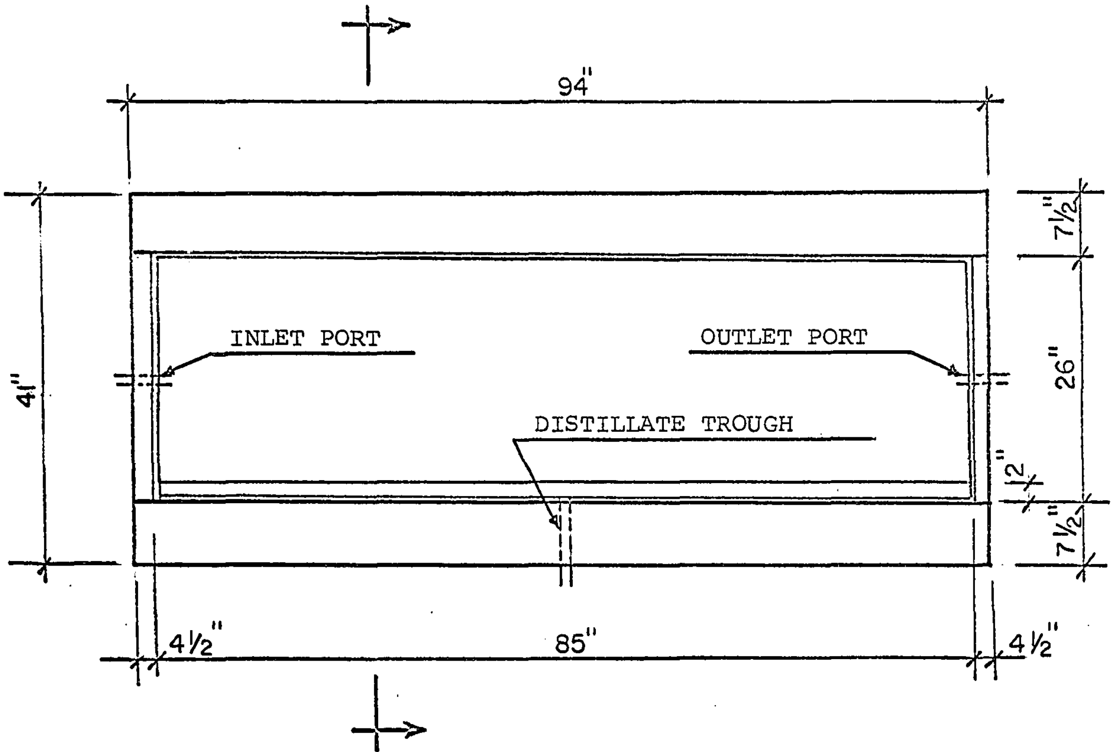
SECTION VIEW

THE BLOCKS AND THE BAMBOO MAT ARE IMPREGNATED WITH PLASTICISED SULPHUR

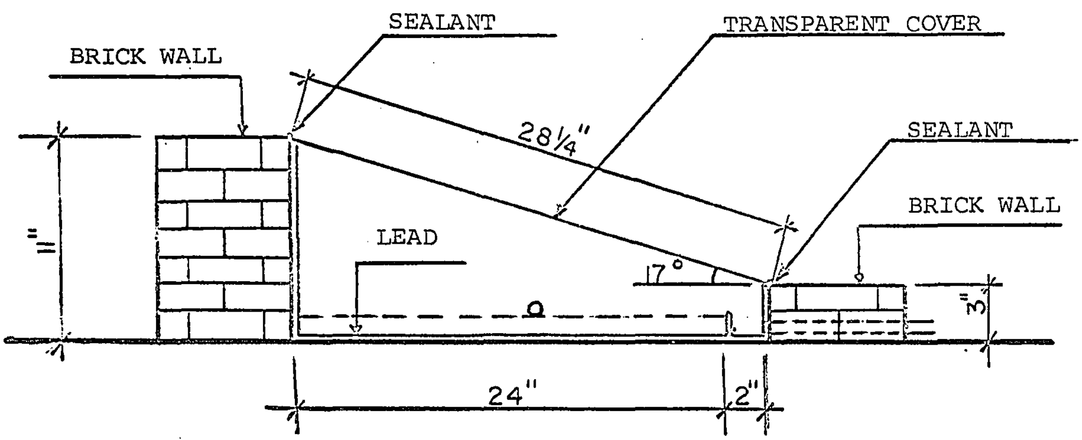
SCALE: Top View: 1" = 20"
Sec. View: 1" = 10"

Fig. 5

LEAD SOLAR STILL NO. L-1



TOP VIEW

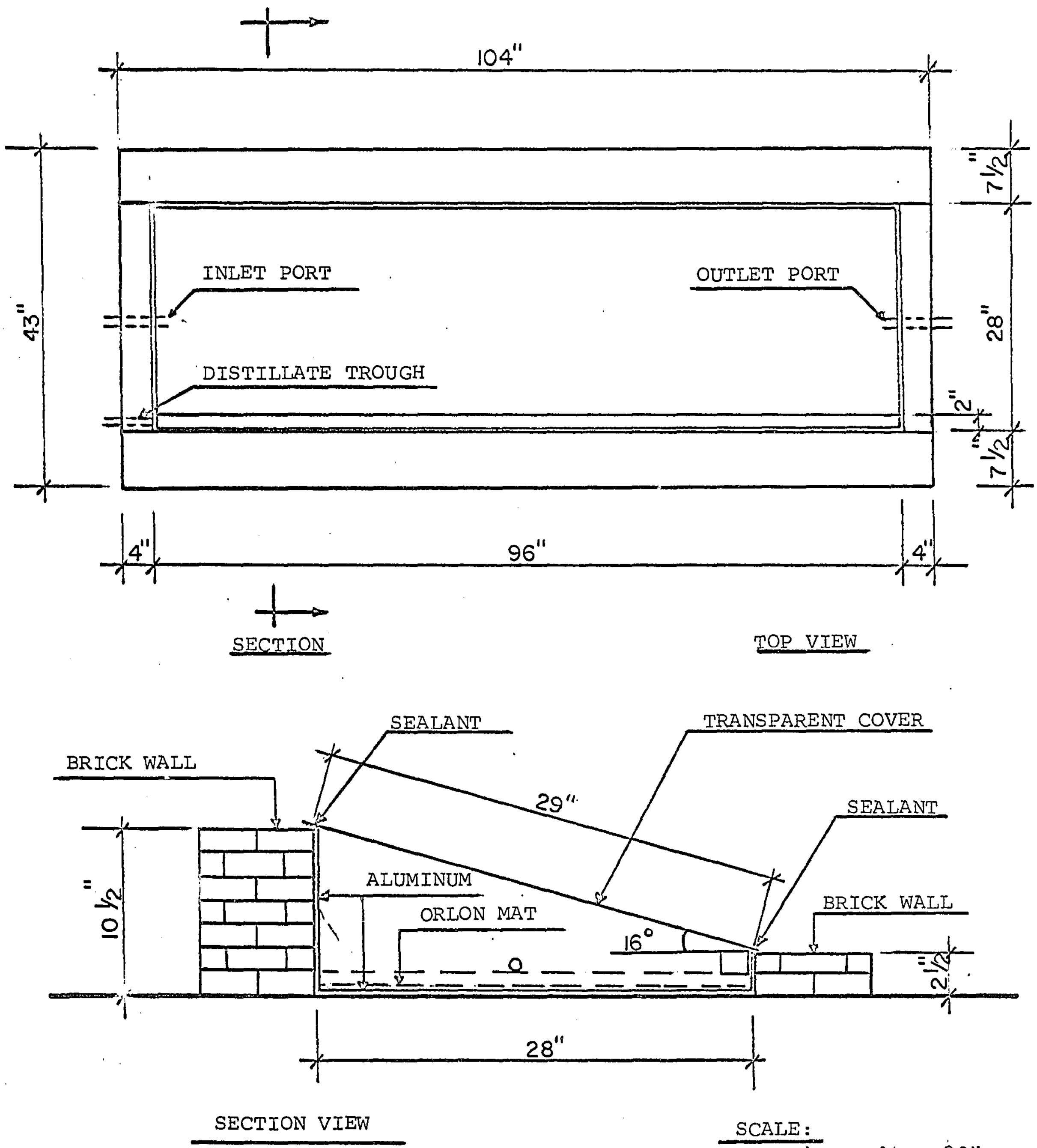


SECTION VIEW

SCALE Top View: 1" = 20"
Sec. View: 1" = 10"

Fig.6

ALUMINUM SOLAR STILL NO. A - 1



SCALE:
Top View: 1" = 20"
Sec. View: 1" = 10"

Fig. 7

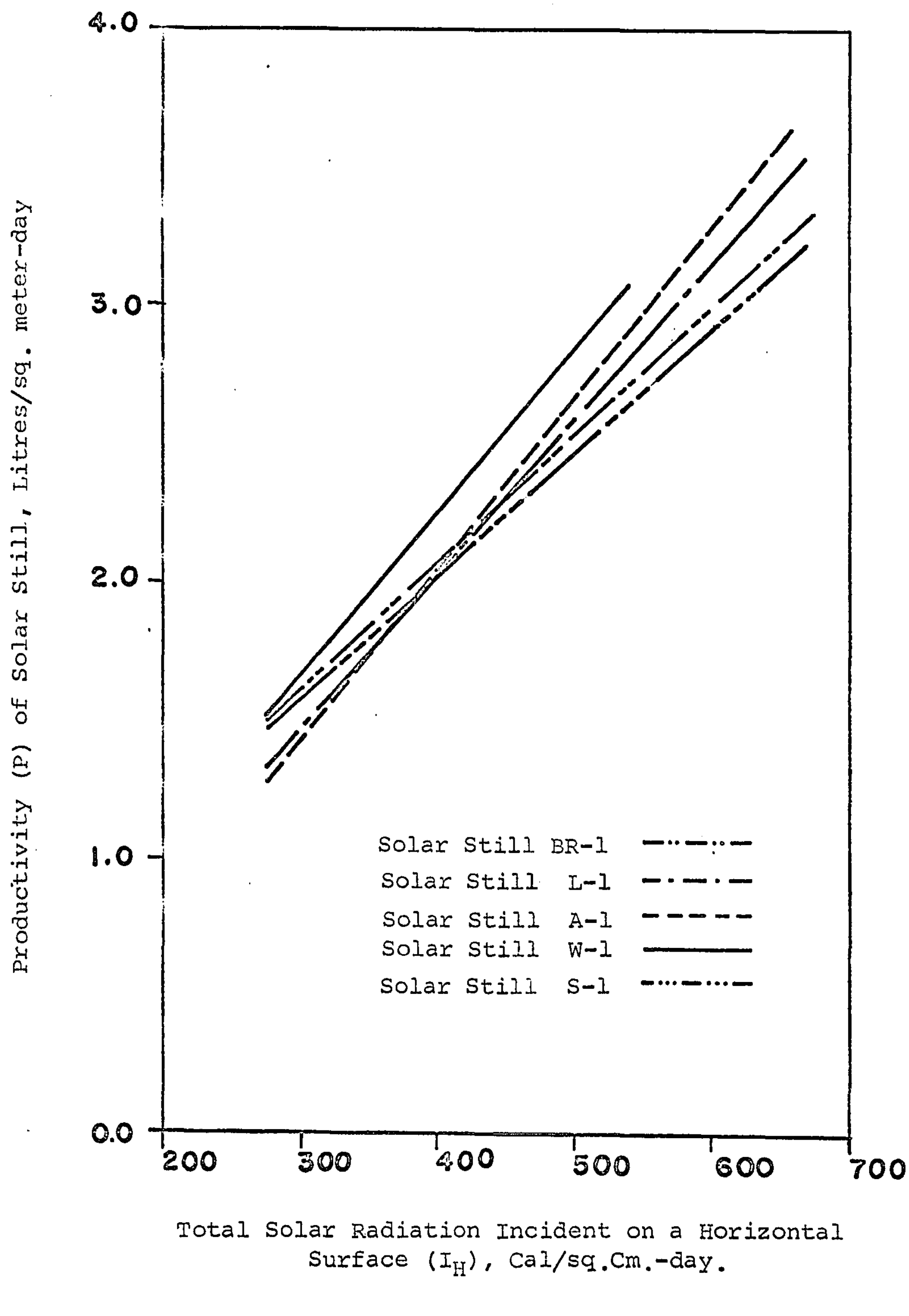


Fig. 8.-- Variation of Productivities of Experimental Solar Stills as a Function of Solar Radiation (I_H).

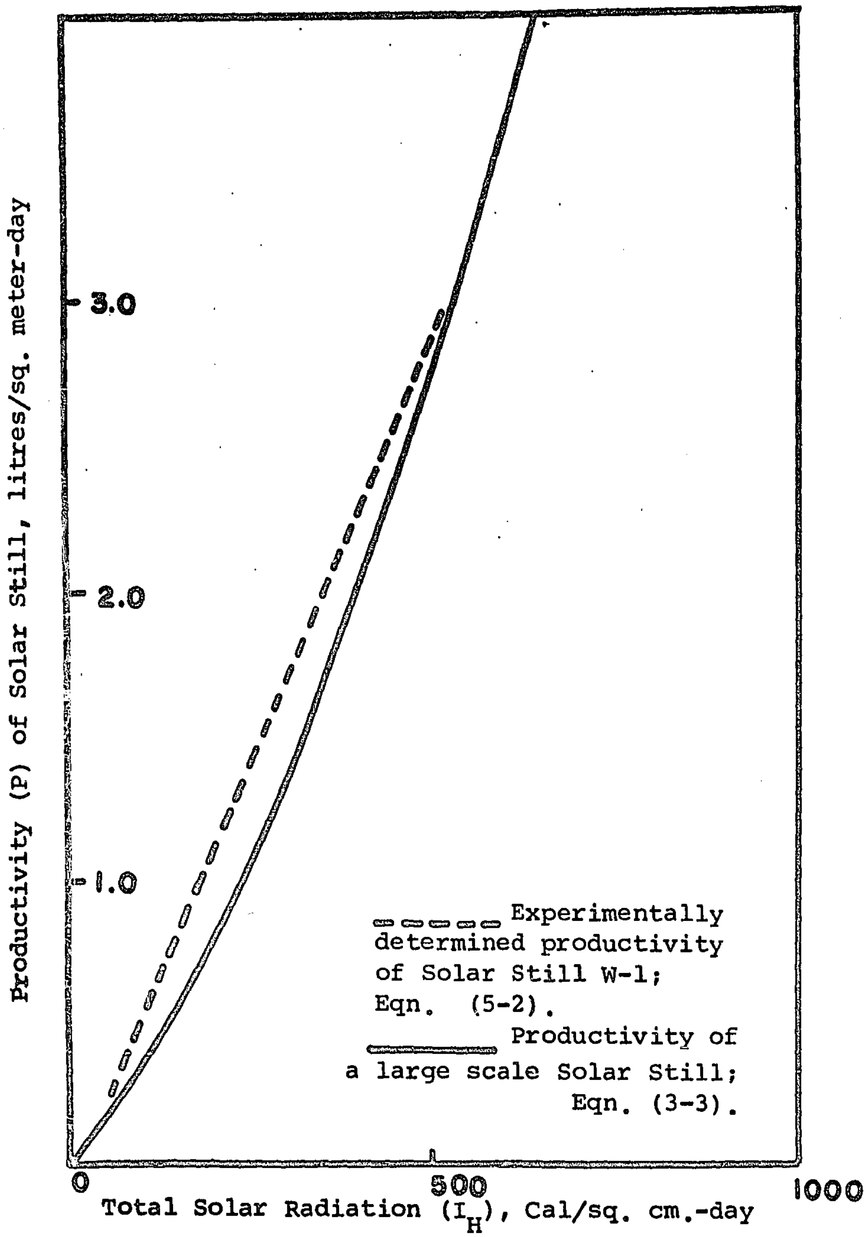


Fig. 9 Productivity of large basin-type Solar Still and Experimental Still W-1.

TABLE (1)

Average Monthly Precipitation for Gheshm Island, Iran (*)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1961	0.0	0.0	0.0	3.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.48	1.48
1962	0.0	0.0	0.0	1.04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.04
1963	0.0	0.04	0.3	0.0	0.41	0.0	0.0	0.0	0.0	0.0	2.48	1.2	4.43
1964	1.72	1.76	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.17	11.65
1965	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.06	0.0	0.14
1966	0.41	2.64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.05
Total	2.21	4.44	0.3	4.27	0.41	0.0	0.0	0.0	0.0	0.0	2.54	11.11	25.02
Avg.	0.36	0.74	0.05	0.76	0.07	0.0	0.0	0.0	0.0	0.0	0.42	1.85	4.17

All figures quoted are in inches.
*References (7) to (12).

TABLE (.2)

Precipitation in Gheshm Island (12), Iran, Year 1966

Month	Precipitation (mm)		Number of rainy days/month
	Total	Max. for 24:00 hours	
Jan.	10.41	8.89	2
Feb.	67.06	25.90	3
Mar.	0.0	0.0	0
Apr.	0.0	0.0	0
May	0.0	0.0	0
June	0.0	0.0	0
July	0.0	0.0	0
Aug.	0.0	0.0	0
Sept.	0.0	0.0	0
Oct.	0.0	0.0	0
Nov.	0.0	0.0	0
Dec.	0.0	0.0	0
Total	77.47	34.79	5

TABLE (3)

Climatic Data for Gheshm Island, Iran (12), Year 1966

Month	Ambient Air Temperature, deg. C: Monthly Average: Max. daily temperature	Min. daily temperature	Average daily temperature	Absolute max. temperature for the entire month	Absolute min. temperature for the entire month	Relative Humidity Percent: 06:00 hours (03 GMT)	18:30 hours (15 GMT)	Duration of sunshine hours
Jan.	24.5	17.4	21.0	29.0	15.0	83	65	256
Feb.	24.0	17.2	20.6	27.0	14.8	80	65	206
Mar.	26.3	17.8	22.0	29.0	15.0	74	60	239
Apr.	30.2	20.6	25.4	34.6	17.2	83	62	236
May	35.8	24.6	30.2	40.8	22.6	80	64	317
June	37.6	27.4	32.5	41.8	25.8	89	61	306
July	36.8	29.5	33.1	42.4	27.0	85	68	232
Aug.	37.0	30.5	33.7	43.0	29.0	80	72	271
Sept.	35.2	28.9	32.0	39.5	26.0	79	70	267
Oct.	33.9	26.3	30.1	36.0	23.4	80	66	279
Nov.	29.0	21.2	25.1	34.5	15.0	48	38	230
Dec.	24.8	17.7	21.2	27.4	16.0	69	54	241

TABLE (4)

Average Monthly and Annual Precipitation in the Bandar Abbas Region (13)Iran

1962 - 69

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1962	0.0	0.0	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05
1963	0.0	0.40	2.2	0.03	1.12	0.0	0.0	0.0	0.0	0.0	1.9	0.27	5.92
1964	1.85	5.32	1.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.30	9.60
1965	3.66	0.55	0.05	0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.86
1966	0.63	0.61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.24
1967	0.05	2.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.27	2.36
1968	0.07	3.66	0.02	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	5.95
1969	4.40	0.03	0.0	0.29	0.0	0.0	0.0	0.0	0.0	0.25	0.03	0.0	5.00
Avg.	1.33	1.57	0.42	0.13	0.14	0.0	0.0	0.0	0.0	0.03	0.24	0.49	4.37

Rainfall measured in inches

TABLE (5)

Average Monthly and Annual Ambient Air Temperatures* in Bandar Abbas (13), Iran
1961-1967

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Average
1961	19.1	19.1	23.1	25.2	31.4	33.1	34.7	35.0	33.4	29.6	23.8	21.6	27.4
1962	19.2	22.3	24.6	27.4	32.9	34.2	35.2	34.8	32.8	29.7	24.6	20.3	28.1
1963	19.9	22.5	25.2	27.1	28.4	33.3	34.6	33.7	32.5	30.3	24.9	18.9	27.6
1964	14.1	19.2	23.4	26.3	30.0	32.8	33.9	33.5	32.1	28.5	23.1	15.9	26.0
1965	19.2	22.6	25.0	26.8	33.5	35.8	36.1	35.7	35.6	33.7	28.4	22.8	29.6
1966	23.0	22.7	24.8	--	33.8	35.7	35.8	36.4	34.6	33.0	27.4	23.1	30.0
1967	21.5	23.7	25.6	27.8	33.6	35.3	36.1	34.4	32.4	29.8	--	--	29.9
Monthly Average	19.4	21.7	24.4	26.8	31.9	34.3	35.2	34.8	33.3	30.7	25.4	20.4	Overall Annual Average 28.4

*The temperatures are given in degrees centigrade

TABLE (6)

Average Monthly and Annual Relative Humidity* in Bandar Abbas(13), Iran
1962-1967

Month	1962		1963		1964		1965		1966		1967		Monthly Average
	06:00 hours	12:00 hours	06:00 hours	12:00 hours	06:00 hours	12:00 hours	06:00 hours	12:00 hours	06:00 hours	12:00 hours	06:00 hours	12:00 hours	
Jan.	70	49	83	63	73	53	75	60	84	58	69	48	65.5
Feb.	81	64	80	58	88	66	79	57	87	60	83	59	71.9
Mar.	78	59	79	53	83	61	73	50	77	52	69	48	65.2
Apr.	68	56	80	60	75	57	74	51	73	50	77	55	64.7
May	67	59	76	56	73	60	68	44	71	48	73	53	62.4
June	74	61	76	61	74	59	71	52	74	56	80	57	66.3
July	72	62	81	64	76	61	73	55	80	62	78	59	68.6
Aug.	65	61	83	68	79	62	73	56	82	61	81	61	69.4
Sept.	71	54	82	62	75	52	77	54	79	60	84	67	68.1
Oct.	80	59	86	59	60	38	84	56	81	55	79	55	66.0
Nov.	58	41	82	57	59	40	77	52	48	32	--	--	54.6
Dec.	75	56	74	55	60	38	65	41	69	47	--	--	58.0
Annual Average	71.6	56.8	80.2	59.7	73.0	54.0	74.1	52.4	75.5	53.5	77.3	56.2	Overall Annual Average 64.5

* Unit for relative humidity: percent

TABLE (7)

Mean Wind Speed* for Gheshm Island(12), Iran

Year: 1966

Month	N**	NE	E	SE	S	SW	W	NW
Jan.	7.4	7.4	11.2	9.3	18.6	9.3	9.3	11.2
Feb.	7.4	5.6	13.0	18.6	9.3	9.3	9.3	14.9
Mar.	14.9	9.3	18.6	24.1	18.6	9.3	11.2	13.0
Apr.	9.3	13.0	16.7	16.7	13.0	9.3	14.9	14.9
May	18.6	9.3	11.2	18.6	11.2	11.2	13.0	22.3
June	0	0	0	7.4	0	11.2	14.9	22.3
July	3.7	0	9.3	7.4	11.2	7.4	13.0	16.7
Aug.	0	0	0	9.3	9.3	7.4	13.0	16.7
Sept.	7.4	3.7	11.2	7.4	11.2	9.3	13.0	13.0
Oct.	14.9	14.9	16.7	14.9	11.2	7.4	9.3	18.6
Nov.	5.6	7.4	11.2	7.4	7.4	9.3	9.3	9.3
Dec.	9.3	9.3	11.2	13.0	13.0	9.3	11.2	13.0

*The wind speeds are given in kilometers per hour.

**The wind speeds are given according to the directions of the compass as indicated.

TABLE (8)

Chemical Analysis of Surface Water
in the Bandar Abbas Region (13) Iran
Year, 1969

Chemical Components	Gerrow River		Shemil River		
	Oct. 11	Dec. 4	July 4	Sept. 10	Oct. 4
Total dissolved solids (p.p.m.)	1360	1320	1240	1500	1320
Electrical conductivity (milli-mohs/cm)	2246	2213	2068	2213	2257
Bicarbonate - HCo_3 (p.p.m.)	158	158	171	189	225
Chloride - Cl (p.p.m.)	532	487	439	505	531
Sulphate - So_4 (p.p.m.)	197	244	288	281	247
Calcium - Ca (p.p.m.)	65	62	64	51	41
Magnesium - Mg (p.p.m.)	59	55	30	41	39
Sodium - Na (p.p.m.)	326	322	367	391	377
Potassium - K (p.p.m.)	8	16	43	23	7
Percent sodium - Na	63	63	76	72	75
Sodium Absorption Ratio (p.p.m.)	7.05	7.18	11.2	9.9	10.17
Hardness - $CaCo_3$ (p.p.m.)	404	380	217	294	260

p.p.m. = part per million by weight

TABLE (9)

Chemical Analysis of Surface Water
in the Bandar Abbas Region (13) Iran
Year, 1969

Chemical Components	Jamogh River		Niam Spring	
	July 4	Oct. 11	July 4	Oct. 11
Total dissolved solids (p.p.m.)	--	5200	2836	2680
Electrical conductivity (milli-mhos/cm)	6767	8636	4250	4492
pH	6.9	--	7.6	--
Bicarbonate - HCo_3 (p.p.m.)	97.6	165	201	250
Chloride - Cl (p.p.m.)	2552	2862	1170	1240
Sulphate - So_4 (p.p.m.)	753	782	557	451
Calcium - Ca (p.p.m.)	354	213	188	168
Magnesium - Mg (p.p.m.)	175	247	66	121
Sodium - Na (p.p.m.)	--	1955	674	851
Potassium - K (p.p.m.)	--	47	62	3.5
Percent Sodium - Na	--	80	63	73
Sodium Absorption Ratio (p.p.m.)	--	26.3	10.7	14.3
Hardness - $CaCo_3$ (p.p.m.)	1250	1050	605	672

p.p.m. = parts per million by weight

TABLE (10)

Chemical Analysis of Sea Water from the Persian Gulf
in the Bandar Abbas Region(2) year, 1971
Iran.

Chemical Component	Quantity (p.p.m.)
Calcium Carbonate - $CaCO_3$	--
Calcium Bicarbonate - $Ca(HCO_3)_2$	283
Magnesium Bicarbonate - $Mg(HCO_3)_2$	--
Calcium Sulphate - $CaSO_4$	1066
Magnesium Sulphate - $MgSO_4$	2986
Magnesium Chloride - $MgCl_2$	3484
Sodium Sulphate - Na_2SO_4	--
Sodium Chloride - NaCl	30352
Potassium Chloride - KCl	1178
Potassium Nitrate - KNO_3	--
Total Dissolved Solids	39347

p.p.m. = parts per million by weight

TABLE (11)

Variation of Water Consumption per Capita

Location	Water Consumption per capita-day	Reference Number
South Pacific	5 litres (1.3 U.S. GPD)	(21)
Algeria	3 to 5 litres (0.8-1.3 U.S. GPD)	(22)
Spain	11 to 13 litres (2.9-3.4 U.S.GPD)	(23)
U.S. Navy (field requirements)	10 U.S.GPD (bivouacs)	(24)
United States of America (domestic, rural arid areas)	2 U.S.GPD (hauled in) 30 U.S.GPD (piped in)	(25)
U.S. Virgin Islands	2 U.S.GPD	(26)

TABLE (12)

Population Distribution in Gheshm Island
Iran(13)

Name of village	Distance from the administrative centre of Gheshm City (kilometers)	Population (estimated)
Gheshm City	--	5000
Damchah	18	1122
Hellow	18	1192
Dargahan	21	2155
Giahdan	24	856
Korehei	24	926
Risank	30	371
Ramkan	36	1135
Sozad	36	2451
Torian	36	526
Kosheh	38	319
Karvan	40	132
Massan	40	519
Zamin	44	527
Gurbehdaran	42	475
Direstan	46	1072
Pypesht	48	452
Laffet	48	1942
Korzin	72	850
Hengam Kohneh	75	723
Sahal	75	853
Tabal	84	1357
Gorran	96	547
Dollab	120	1079
Gorry	129	368
Dorostkoh	143	308
Basaeed	144	684
Total		27,931

TABLE (13)

Typical Population Distribution in Some of the Villages in the Bandar Abbas Region (13), Iran

Name of Village	Estimated Population
Kashko	551
Niam	163
Zehoki	248
Saeed Abad	271
Sarkam	129
Shamil	748
Abkahour	218
Zaminsang	546
Hasanlangy	574
Chahali	110
Paklaton	633
Sohrangy	693

TABLE (14)

The Estimation of Solar Radiation for Gheshm Island and the Bandar Abbas Region, Iran

Month	Total Solar Radiation on Horizontal Surface (I_H) cal/cm^2 - day			
	Lőf's charts	Black's charts	Calculation based on Reddy formula (50)	Reccrded value in Kuwait (51)
Jan.	350	400	349	354
Feb.	415	450	329	420
Mar.	490	475	455	462
Apr.	600	650	433	561
May	650	700	481	679
June	650	725	473	690
July	680	675	429	626
Aug.	625	650	465	574
Sept.	560	600	472	586
Oct.	475	525	452	516
Nov.	375	450	474	366
Dec.	300	350	364	308
Avg.	514	554	431	512

TABLE (15)

Estimation of the Productivity of a Large Solar Still for Gheshm Island and Bandar Abbas, Iran

Month	Intensity of total Solar Radiation (I_H) cal/cm^2-day	Productivity (P) * litres/m^2-day	Solar Still Productivity for the Month litres/m^2
Jan.	350	1.695	52.56
Feb.	415	2.083	58.27
Mar.	490	2.716	84.34
Apr.	600	3.607	108.38
May	650	4.035	124.68
June	650	4.035	121.42
July	680	4.296	133.24
Aug.	625	3.819	118.16
Sept.	560	3.274	98.20
Oct.	475	2.602	80.68
Nov.	375	1.808	54.19
Dec.	300	1.367	42.38
Avg.		2.945	
Yearly Total			1076.50

* Productivity calculated from the expression

$P = 0.293111\ (I_H/100)^{1.4}$ litres/m^2-day; I_H is expressed in cal/cm^2-day

TABLE (16)

Productivity of the Test Solar Still
and the Related Climatological Data

Date	Total Solar Radiation		Productivity of Solar Still		Ambient air Temperature deg. F.		Wind Speed mph
	cal/cm^2-day	B.T.U/ft^2-day	litres/m^2	gallons/ft^2	Max.	Min.	
15 June	612	2256	--	--	76.0	58.0	1.1
16	717	2643	3.10	0.0760	82.0	62.0	1.8
17	438	1614	3.87	0.0950	82.0	64.0	2.5
18	650	2396	4.10	0.1007	87.0	67.0	2.6
19	606	2234	3.87	0.0950	86.0	64.0	2.6
20	603	2223	3.87	0.0950	90.0	64.0	1.0
21	260	958	1.93	0.0475	84.0	68.0	0.7
22	629	2310	3.83	0.0940	80.0	65.5	2.5
23	693	2555	4.7	0.1154	81.5	62.5	2.0
24	388	1430	2.5	0.0635	78.0	65.5	1.8
25	157	568	--	--	73.5	57.5	1.3
26	721	2658	3.48	0.0855	76.0	74.0	3.0
27	579	2135	4.26	0.1045	80.0	58.0	2.7
28	308	1136	3.87	0.0950	78.5	62.0	2.6
29	402	1482	2.32	0.0570	82.5	54.7	1.0
30	681	2511	4.45	0.0570	96.0	72.5	3.3
7 July	577	2127	3.48	0.0855	80.0	62.0	3.3
8	642	2366	3.87	0.0950	85.0	68.0	2.4
9	549	2033	3.79	0.0931	85.5	77.0	2.0
10	650	2396	4.45	0.1093	86.0	60.0	4.0
11	688	2536	4.45	0.1093	84.0	54.0	2.6
12	728	2684	3.10	0.0760	75.0	61.0	3.0
17	309	1139	1.35	0.0330	84.0	63.0	2.6
18	449	1655	2.32	0.0570	76.0	52.0	3.3
19	287	1058	0.92	0.0240	74.0	63.0	1.7
20	532	1961	3.10	0.0760	72.0	59.5	3.3
21	631	2326	3.29	0.0810	68.5	67.5	2.2
22	688	2536	4.07	0.1000	85.0	64.5	1.7
23	551	2031	2.9	0.0710	88.0	71.5	2.2
24	329	1213	2.13	0.0520	89.0	68.0	2.1
25	552	2035	2.05	0.0500	86.0	64.0	0.8
1 August	586	2160	3.68	0.0900	80.0	60.0	2.9
2	505	1862	3.10	0.0760	83.7	64.0	0.9
3	234	863	0.96	0.0240	84.0	71.0	1.3
4	501	1847	2.09	0.0510	74.0	72.0	3.4
5	414	1526	2.32	0.0570	76.0	58.0	3.0

TABLE (16)(continued)

Date	Total Solar Radiation		Productivity of Solar Still		Ambient air Temperature deg. F		Wind Speed mph
	cal/cm^2-day	B.T.U./ft^2-day	litres/m^2	gallons/ft^2	Max.	Min.	
6 August	539	1987	2.94	0.0720	81.0	64.0	3.6
7	591	2179	3.68	0.0900	85.0	60.0	4.1
8	518	1910	3.10	0.0760	89.0	61.0	--
9	548	2020	3.87	0.0950	89.5	69.5	--
10	429	1582	3.10	0.0760	88.0	66.0	3.0
11	393	1449	--	--	89.0	66.0	3.6
12	586	2160	3.68	0.0900	77.5	56.0	4.7
13	300	1106	1.16	0.0270	76.0	62.0	--
14	508	1873	3.10	0.0760	84.0	56.0	--
17	549	2024	3.37	0.0830	82.0	58.0	2.9
18	504	1858	3.29	0.0810	85.0	63.0	2.0
19	539	1987	3.48	0.0500	87.0	66.0	0.9
20	300	1106	2.05	0.0500	86.5	70.0	2.6
21	300	1106	1.35	0.0330	82.0	58.0	2.5
24	536	1976	1.55	0.0380	64.0	46.0	2.0
25	452	1666	1.55	0.0380	65.5	43.5	1.5
26	321	1183	1.16	0.0280	54.5	59.4	1.3
27	221	815	--	--	71.5	57.5	2.0
30	184	678	--	--	74.5	65.0	--
31	--	--	1.74	0.0510	--	--	2.5

TABLE (17)

Comparison of the Productivities of Different Experimental Solar Stills

Date	Total Solar Radiation (I_H) cal/cm^2 - day	Productivity - Litres/sq. meter - day				
		test still (W - 1)	sulphur still (S - 1)	lead still (L - 1)	rubber still (BR - 1)	aluminum still (A - 1)
6 August	539	2.94	2.55	2.70	2.38	2.92
12	586	3.68	2.88	2.97	3.02	3.12
17	549	3.37	2.73	2.88	2.77	2.92
18	504	3.29	2.48	2.63	2.55	2.65
19	539	3.48	2.65	2.82	2.79	3.05
20	300	2.05	1.66	1.25	1.88	1.37
24	536	1.55	2.52	2.77	2.70	2.97
25	452	1.55	2.17	2.75	2.02	2.33

These solar stills were tested at Macdonald College, Ste. Anne de Bellevue, Montreal, Canada.

TABLE (18)

Estimation of the Productivity of a Small-scale Solar Still for Gheshm Island and the Bandar Abbas Region, Iran

Month	Intensity of total Solar Radiation (I_H) cal/cm^2-day	Productivity (P)* litres/m^2-day	Solar Still Productivity for the Month litres/m^2
Jan.	350	1.95	60.45
Feb.	415	2.33	65.24
Mar.	490	2.77	85.87
Apr.	600	3.41	102.30
May	650	3.70	114.70
June	650	3.70	111.00
July	680	3.87	119.97
Aug.	625	3.55	110.05
Sept.	560	3.17	95.10
Oct.	475	2.68	83.08
Nov.	375	2.10	63.00
Dec.	300	1.66	51.46
Avg.		2.907	
Total			1062.22

*Productivity calculated from the expression:

$P = 0.005807\ (I_H) - 0.083535$--litres/$m^2$-day; I_H is expressed in cal/cm^2-day

TABLE (18A)

Efficiency of the Experimental Test Solar Still (percent)
(Solar Still W-1)

Date	Based on the Solar Radiation Data from Ste. Anne de Bellevue
15 June	--
16	25.6
17	--
18	37.5
19	37.9
20	38.1
21	44.2
22	36.2
23	40.3
24	39.6
25	--
26	28.7
27	43.6
28	--
29	34.3
30	38.8

Average efficiency in June = 37.1%

Date	Based on the Solar Radiation Data from Ste. Anne de Bellevue
7 July	35.8
8	35.8
9	41.0
10	40.7
11	38.4
12	25.2
17	25.8
18	30.7
19	20.2
20	34.5
21	31.0
22	35.2
23	31.2
24	38.2
25	21.9

Average efficiency in July = [illegible].0%

TABLE (18A) cont'd

Date	Based on the Solar Radiation Data from Ste. Anne de Bellevue
1 August	37.1
2	36.4
3	24.8
4	24.6
5	33.3
6	32.2
7	36.8
8	35.5
9	41.9
10	42.8
12	37.1
13	21.8
14	36.2
17	36.6
18	38.9
19	38.1
20	40.3
21	26.6
25	20.3
26	21.1

Average efficiency in August = 31.5%

Overall average efficiency for the entire period from June 15 to August 26, 1971 is 33.9%.

TABLE (19)

Variation in Monthly Fresh Water Supply and Demand for a Large-scale Solar Still Without Rainwater Collection to Supply Water for a Population of 1000, based on a Constant Water Demand of 3.5 GPD (13.2 litres)/capita

Month	Distillate Produced by the Still (litres)	Monthly Demand (litres)	Monthly Deficit in Supplies (litres)	Surplus Water Available (litres)
Jan.	241711	410706	168995	0
Feb.	267743	370960	103017	0
Mar.	387861	410706	22844	0
Apr.	498411	397457	0	100954
May	573360	410706	0	162654
June	558370	397457	0	160913
July	612709	410706	0	202003
Aug.	543381	410706	0	132675
Sept.	451568	377457	0	54111
Oct.	370998	410706	39708	0
Nov.	249206	397457	148251	0
Dec.	194868	410706	215838	0
Total	4950386	4835730	698653	813310

As a result, the volume of the cistern required would be 698653 litres. As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 803451 litres.

Total still area required = 4598.7 sq. meters

TABLE (20)

Variation in Monthly Fresh Water Supply and Demand for a Large-scale Solar Still to Supply Water for a Population of 1000 Based on a Constant Demand of 3.5 GPD (13.2 litres)/capita

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	C** Rain water collected off the roof tops of houses (litres)	A+B+C Total monthly supply of water (litres)	D Monthly demand (litres)	(A+B+C)-D Monthly deficit in supply (litres)	D-(A+B+C) Surplus water available (litres)
Jan.	208752	21.59	68692	52222	329666	410706	81040	0
Feb.	231407	29.46	93743	71266	396416	370960	0	25456
Mar.	334973	6.10	19396	14744	369113	410706	41593	0
Apr.	430446	11.43	36365	27648	494459	397457	0	97002
May	495175	2.79	8888	6757	510819	410706	0	100114
June	482229	0	0	0	482229	397457	0	84772
July	529159	0	0	0	529159	410706	0	118454
Aug.	469283	0	0	0	469283	410706	0	58578
Sept.	389993	0	0	0	389993	397457	7465	0
Oct.	320407	0.51	1616	1230	323254	410706	87452	0
Nov.	215225	8.38	26667	20274	262167	397457	135291	0
Dec.	168295	29.72	94553	71883	334731	410706	75975	0
Total	4275344	109.98	279920	266024	4891289	4845730	428816	484376

As a result, the volume of the cistern required would be 403360 litres. As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 463864 litres.

* average of precipitations at Gheshm Island and Bandar Abbas

**based on an overall collection efficiency of 65%

TABLE (21)

Variation in Monthly Fresh Water Supply and Demand for a Large-scale Solar Still to Supply Water for a Population of 1000 Based on a Variable Demand: May 15-Sept. 15 at 4.5 GPD (17 litres)/capita, the Rest of the Year 3 GPD (11.4 litres)/capita

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	C** Rain water collected off the roof tops of houses (litres)	A+B+C Total monthly supply of water (litres)	D Monthly demand (litres)	(A+B+C)-D Monthly deficit in supply (litres)	D-(A+B+C) Surplus water available (litres)
Jan.	208752	21.59	68692	52222	329666	352033	22367	0
Feb.	231407	29.46	93743	71266	396416	317966	0	78450
Mar.	334973	6.10	19396	14744	369113	352033	0	17080
Apr.	430446	11.43	36365	27648	494459	340678	0	153781
May	495175	2.79	8888	6757	510819	442881	0	67938
June	482229	0	0	0	482229	511016	28787	0
July	529159	0	0	0	529159	528050	0	1109
Aug.	469283	0	0	0	469283	528050	58767	0
Sept.	389993	0	0	0	389993	425847	35854	0
Oct.	320407	0.51	1616	1230	323254	352033	28779	0
Nov.	215225	8.38	26667	20274	262167	340678	78511	0
Dec.	168295	29.72	94553	71883	334731	352033	17302	0
Total	4275344	109.98	279920	266024	4891289	4843298	270367	318358

As a result, the volume of the cistern required would be 269258 litres. As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 309647 litres (309.6 cu. meters).

* average of precipitation at Gheshm Island and Bandar Abbas.

**based on an overall collection efficiency of 65%.

TABLE (22)

Variation in Monthly Fresh Water Supply and Demand for a Large-scale Solar Still to Supply Water for a Population of 1000 Based on a Constant Demand of 2.5 GPD (9.5 litres)/capita

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	C** Rain water collected off the roof tops of houses (litres)	A+B+C Total monthly supply of water (litres)	D Monthly demand (litres)	(A+B+C)-D Monthly deficit in supply (litres)	D-(A+B+C) Surplus water available (litres)
Jan.	153816	21.59	50545	52222	256583	293361	36778	0
Feb.	170509	29.46	68980	71266	310755	264971	0	45784
Mar.	246821	6.10	14271	14744	275835	293361	17526	0
Apr.	317171	11.43	26758	27648	371577	283898	0	87679
May	364866	2.79	6541	6757	378163	293361	0	84802
June	355327	0	0	0	355327	283898	0	71429
July	389905	0	0	0	389905	293361	0	96544
Aug.	345788	0	0	0	345788	293361	0	52426
Sept.	287362	0	0	0	287362	283898	0	3464
Oct.	236090	0.51	1189	1230	238508	293361	54853	0
Nov.	158585	8.38	19623	20274	198483	283898	85415	0
Dec.	124007	29.72	69574	71883	265464	293361	27898	0
Total	3150247	109.98	257481	266024	3673750	3454090	222470	442128

As a result, the volume of the cistern required would be 204944 litres. As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 235686 litres.

* average of precipitations at Gheshm Island and Bandar Abbas

**based on an overall collection efficiency of 65%

TABLE (23)

Variation in Monthly Fresh Water Supply and Demand for a Large-scale Solar Still to Supply Water for a Population of 1000 Based on Variable Demand: May 15-Sept. 15 at 3.5 GPD (13.2 litres)/capita, the Rest of the Year 2GPD (7.5 litres)/capita

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	C** Rain water collected off the roof tops of houses (litres)	A+B+C Total monthly supply of water (litres)	D Monthly demand (litres)	(A+B+C)-D Monthly deficit in supply (litres)	D-(A+B+C) Surplus water available (litres)
Jan.	153816	21.59	50545	52222	256583	234689	0	21894
Feb.	170509	29.46	68980	71266	310755	211977	0	98778
Mar.	246821	6.10	14271	14744	275835	234689	0	41146
Apr.	317171	11.43	26758	27648	371577	227118	0	144459
May	364866	2.79	6541	6757	378163	317966	0	60198
June	355327	0	0	0	355327	397457	42130	0
July	389905	0	0	0	389905	410706	20800	0
Aug.	345788	0	0	0	345788	410706	64918	0
Sept.	287362	0	0	0	287362	312288	24926	0
Oct.	236090	0.51	1189	1230	238508	234689	3819	0
Nov.	158585	8.38	19623	20274	198483	227118	28635	0
Dec.	124007	29.72	69574	71883	265464	234689	30775	0
Total	3150247	109.98	257481	266024	3673750	3454092	216003	366475

As a result, the volume of the cistern required would be 216003 litres. As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 248403 litres.

* average of precipitations at Gheshm Island and Bandar Abbas

**based on an overall collection efficiency of 65%

TABLE (24)

Variation in Monthly Fresh Water Supply and Demand for a Family Utilizing a Small-scale Solar Still (Based on a Constant Water Demand of 2 GPD (7.5 litres)/capita)

Month	A Distillate produced by the Still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	A+B Total monthly supply of water (litres)	C Monthly demand (litres)	C-(A+B) Monthly deficit in supply (litres)	(A+B)-C Surplus water available (litres)
Jan.	786	21.59	225	1011	1173	162	0
Feb.	848	29.46	306	1154	1060	0	94
Mar.	1116	6.10	63	1179	1173	0	6
Apr.	1330	11.43	119	1449	1136	313	0
May	1491	2.79	29	1520	1173	0	347
June	1443	0	0	1443	1136	0	307
July	1560	0	0	1560	1173	0	387
Aug.	1431	0	0	1431	1173	0	258
Sept.	1236	0	0	1236	1136	0	100
Oct.	1080	0.51	5	1085	1173	88	0
Nov.	819	8.38	87	906	1136	230	0
Dec.	669	29.72	309	978	1173	195	0
Total	13809	109.98	1143	14952	13815	988	1499

As a result the volume of the cistern required would be 888 litres ($0.89 m^3$). As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 1021 litres ($1.02\ m^3$).

* average of precipitations at Bandar Abbas and Gheshm Island

TABLE (25)

Variation in Monthly Fresh Water Supply and Demand for a Family Utilizing a Small-scale Solar Still (Based on a Constant Water Demand of 2.5 GPD (9.5 litres)/capita)

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	A+B Total monthly supply of water (litres)	C Monthly demand (litres)	C-(A+B) Deficit in supply (litres)	(A+B)-C Surplus water available (litres)
Jan.	967	21.59	276	1243	1467	224	0
Feb.	1044	29.46	377	1421	1325	0	96
Mar.	1374	6.10	78	1452	1467	15	0
Apr.	1637	11.43	146	1783	1419	0	364
May	1835	2.79	36	1871	1467	0	404
June	1776	0	0	1776	1419	0	357
July	1920	0	0	1920	1467	0	453
Aug.	1761	0	0	1761	1467	0	294
Sept.	1522	0	0	1522	1419	0	103
Oct.	1329	0.51	7	1336	1467	131	0
Nov.	1008	8.38	107	1115	1419	304	0
Dec.	823	29.72	380	1203	1467	264	0
Total	16996	109.98	1407	18403	17270	938	2071

As a result the volume of the cistern required would be 842 litres (0.84 m^3). As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 968 litres (0.97 m^3).

* . . average of precipitations at Bandar Abbas and Gheshm Island

TABLE (26)

Variation in Monthly Fresh Water Supply and Demand for a Family Utilizing a Small-scale Solar Still Based on a Variable Demand: May 15-Sept. 15 at 3.5 GPD (13.2 litres)/capita, the Rest of the Year 2 GPD (7.5 litres)/capita

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	A+B Total monthly supply of water (litres)	C Monthly demand (litres)	C-(A+B) Monthly deficit in supply (litres)	(A+B)-C Surplus water available (litres)
Jan.	967	21.59	276	1243	1173	70	0
Feb.	1044	29.46	377	1421	1060	0	361
Mar.	1374	6.10	78	1452	1173	0	279
Apr.	1637	11.43	146	1783	1136	0	647
May	1835	2.79	36	1871	1628	0	243
June	1776	0	0	1776	1987	211	0
July	1920	0	0	1920	2055	135	0
Aug.	1761	0	0	1761	2055	294	0
Sept.	1522	0	0	1522	1563	41	0
Oct.	1329	0.51	7	1336	1173	0	163
Nov.	1008	8.38	107	1115	1136	21	0
Dec.	823	29.72	380	1203	1173	0	30
Total	16996	109.98	1407	18403	17312	772	1723

As a result the volume of the cistern required would be 579 litres (0.58 m^3). As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 665 litres (0.7 m^3).

* average of precipitations at Bandar Abbas and Gheshm Island

TABLE (27)

Variation in Monthly Fresh Water Supply and Demand for a Family Utilizing a Small-scale Solar Still (Based on a Constant Water Demand of 3.5 GPD (13.2 litres)/capita)

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	A+B Total monthly supply of water (litres)	C Monthly demand (litres)	C-(A+B) Deficit in supply (litres)	(A+B)-C Surplus water available (litres)
Jan.	1330	21.59	380	1710	2054	344	0
Feb.	1435	29.46	518	1953	1855	0	98
Mar.	1889	6.10	107	1996	2054	58	0
Apr.	2251	11.43	201	2452	1987	0	465
May	2523	2.79	49	2572	2055	0	517
June	2442	0	0	2442	1987	0	455
July	2639	0	0	2639	2054	0	585
Aug.	2421	0	0	2421	2054	0	367
Sept.	2092	0	0	2092	1987	0	105
Oct.	1828	0.51	9	1837	2055	218	0
Nov.	1386	8.38	147	1533	1987	454	0
Dec.	1132	29.72	523	1655	2055	400	0
Total	23368	109.98	1925	25302	24188	1474	2592

As a result the volume of the cistern required would be 1376 litres (1.4 m^3). As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 1582 litres (1.58 m^3).

* average of precipitations at Bandar Abbas and Gheshm Island

TABLE (28)

Variation in Monthly Fresh Water Supply and Demand for a Family Utilizing a Small-scale Solar Still Based on a Variable Demand: May 15-Sept. 15 at 4.5 GPD (17 litres)/capita, the Rest of the Year 3 GPD (11.4 litres)/capita

Month	A Distillate produced by the still (litres)	* Rainfall (mm)	B Rain water collected off the cover of solar still (litres)	A+B Total monthly supply of water (litres)	C Monthly demand (litres)	C-(A+B) Monthly deficit in supply (litres)	(A+B)-C Surplus water available (litres)
Jan.	1330	21.59	380	1710	1760	50	0
Feb.	1435	29.46	518	1953	1590	0	363
Mar.	1889	6.10	107	1996	1760	0	236
Apr.	2251	11.43	201	2452	1703	0	749
May	2523	2.79	49	2572	2225	0	347
June	2442	0	0	2442	2255	0	187
July	2639	0	0	2639	2640	1	0
Aug.	2421	0	0	2421	2640	219	0
Sept.	2092	0	0	2092	2130	38	0
Oct.	1828	0.51	9	1837	1760	0	77
Nov.	1386	8.38	147	1533	1703	170	0
Dec.	1132	29.72	523	1655	1760	105	0
Total	23368	109.98	1934	25302	23926	583	1960

As a result the volume of the cistern required would be 506 litres (0.51 m^3). As a safety factor 15% extra allowance should be made. Hence the required volume of the cistern would be 582 litres (0.58 m^3).

* average of precipitations at Bandar Abbas and Gheshm Island

TABLE (29)

Capital Cost of a Large-scale Solar Still in Gheshm Island and the Bandar Abbas Region, Iran
(Still area 2926.3 sq. meters)

Item	Cost (Dollars) (based on 236 m^3 storage capacity and constant water demand of 2.5 GPD (9.5 litres)/capita)	Cost (Dollars) (based on 248 m^3 storage capacity and variable water demand of 2-3.5 GPD (7.5-13.2 litres)/capita)
Site preparation	1756	1756
Bricks for frame--including labour	1976	1976
Glass cover, sealants	11523	11523
Basin liner, Butyl rubber	2950	2950
Concrete tank (25 cm. thick walls) to store fresh water	1450	1504
Pumping station	2400	2400
Miscellaneous, piping	1322	1322
Contractor's fee (12% of material cost)	2595	2601
Total	25972	26032
Cost per sq. meter of still	8.88	8.90

TABLE (30)

Fresh Water Cost from a Large-scale Solar Still in Gheshm Island and the Bandar Abbas Region, Iran (Still area 2926.3 sq. meters)

Item	Cost (Dollars) per year (based on 236 m^3 storage capacity and constant water demand of 2.5 GPD (9.5 litres)/capita)	Cost (Dollars) per year (based on 248 m^3 storage capacity and variable water demand of 2-3.5 GPD (7.5-13.2 litres)/capita)
Amortization and interest charge[(a)]	2645	2651
Maintenance[(b)]	260	260
Operating labour and supervision[(c)]	1946	1946
Total	4851	4857
Fresh water cost per cubic meter	1.40	1.41

(a) Amortization and interest charges based on 20 years life of the system and an annual interest rate of 8%.

(b) Maintenance and repairs estimated at 1% of the capital investment.

(c) Operating labour costs based on 2 full-time labourers.

TABLE (31)

Capital Cost of a Large-scale Solar Still in Gheshm Island and the Bandar Abbas Region, Iran
(Still area 3971.5 sq. meters)

Item	Cost (Dollars) (based on 464 m^3 storage capacity and constant water demand of 3.5 GPD (13.2 litres)/capita)	Cost (Dollars) (based on 219.6 m^3 storage capacity and a variable water demand of 3-4.5 GPD (11.3-17 litres)/capita
Site preparation	2383	2383
Bricks for frame, including labour	2240	2240
Basin liner, Butyl rubber	8040	8040
Glass cover, sealants	15012	15012
Concrete tank to store fresh water	2423	1506
Pumping station	2665	2665
Miscellaneous, piping	2760	2760
Contractor's fee (12% of material cost)	3977	3867
Total Cost	36536	35509
Cost per sq. meter of still	9.2	8.9

TABLE (32)

Fresh Water Cost from a Large-scale Solar Still in Gheshm Island and the Bandar Abbas Region, Iran (Still area 3971.5 sq. meters)

Item	Cost (Dollars) per year (based on 464 m^3 storage capacity and constant water demand of 3.5 GPD (13.2 litres)/capita)	Cost (Dollars) per year (based on 277.8 m^3 storage capacity and variable water demand of 3-4.5 GPD (11.3-17.0 litres)/capita)
Amortization and interest charge[a]	3721	3617
Maintenance[b]	365	355
Operating labour and supervision[c]	1946	1946
Total	6032	5918
Fresh water cost per cubic meter	1.25	1.22

[a] Amortization and interest charge based on 20 years life of the system and an annual interest rate of 8%

[b] Maintenance and repairs estimated at 1% of the capital investment

[c] Operating labour costs based on 2 full-time labourers.

TABLE (33)

The Capital Cost of a Small-scale Solar Still in Gheshm Island and the Bandar Abbas Region, Iran
(Still area 16 sq. meters)

Item	Cost (Dollars) (based on 0.97 m^3 cistern capacity and constant water demand of 2.5 GPD (9.5 litres)/capita	Cost (Dollars) (based on 0.7 m^3 cistern capacity and variable water demand of 2-3.5 GPD (7.5-13.2 litres)/capita
Bricks for frame including labour	7	7
Cement	2	2
Glass cover, sealants	60	60
Basin liner, Butyl rubber	35	35
Barrels required to collect the fresh water	4	4
Piping	7	7
Total Cost	115	115
Cost per sq. meter of the still	7.18	7.18
Amortization and interest charges	11.7	11.7
Maintenance	5.0	5.0
Fresh water cost per cubic meter	0.96	0.96

TABLE (34)

The Capital Cost of a Small-scale Solar Still in Gheshm Island and the Bandar Abbas Region, Iran
(Still area 22 sq. meters)

	Cost (Dollars) (based on 1.58 m^3 cistern capacity and constant water demand of 3.5 GPD (13.2 litres)/capita)	Cost (Dollars) (based on 0.58 m^3 cistern capacity and variable water demand of 3-4.5 GPD (11.34-17 litres)/capita)
Bricks for frame	10	10
Cement	3	3
Glass cover, sealants	165	165
Basin liner, Butyl rubber	74	74
Barrel required to collect the fresh water	8	4
Piping	7	7
Total Cost	267	263
Cost per sq. meter	12.13	11.95
Amortization and interest charges	27.18	26.77
Maintenance	6	6
Fresh water cost per cubic meter	1.37	1.35

APPENDIX A

The Evaluation of the Rates of Evaporation From Open Water Surfaces for Gheshm Island, Iran

The rate of evaporation was calculated by using the Rohwer forumla (17)

$$E = C(1.465 - 0.0186B)(0.44 + 0.118W)(e_s - e_d)$$

where

E = the evaporation from open-water surfaces in inches per day

C = a coefficient, usually taken as 0.75

B = the mean barometric reading, inches of mercury at $32^{o}F$

W = the mean wind velocity at ground level, mph

e_s = the saturated water vapor pressure at the surface water temperature, in inches of mercury

e_d = the mean vapor pressure of the saturated ambiant air at its dew point in inches of mercury

Month	Mean daily Ambient Air Temperature Deg. F.	Mean wind Velocity, mph	e_s	e_d	B	E inches	
						Per day	Per month
Jan.	69.8	5.6	0.732	0.541	30	0.143	4.433
Feb.	69.1	5.9	0.731	0.529	30	0.156	4.368
Mar.	71.6	7.9	0.734	0.480	30	0.227	7.037
Apr.	77.7	7.3	0.871	0.733	30	0.122	3.660
May	86.4	7.8	1.251	0.900	30	0.324	10.044
June	90.5	3.8	1.428	1.070	30	0.215	6.450
July	91.6	4.6	1.440	1.100	30	0.228	7.068
Aug.	92.7	3.8	1.520	0.775	30	0.447	13.857
Sept.	89.6	5.1	1.409	1.040	30	0.262	7.860
Oct.	86.2	7.1	1.221	0.890	30	0.288	8.928
Nov.	77.2	4.6	0.872	0.370	30	0.332	9.960
Dec.	70.2	6.0	0.733	0.450	30	0.221	6.960
Total						2.965	90.516

APPENDIX B

Estimation of Total Solar Radiation for the Southern Coast of Iran Using Reddy's Empirical Formula

Since no information is available on the intensity of total solar radiation incident on a horizontal surface for the southern coast of Iran, it was found necessary to make estimates of it. The empirical formula suggested by Reddy (50) was used as one of the means for arriving at these estimates. The formula is given as:

$$I_H = K\left[\frac{(1 + 0.8S)(1 - 0.2t)}{\sqrt{\phi}}\right] \text{cal/cm}^2 - \text{day} \qquad (1)$$

where $K = (\lambda N + \psi_p \cos l) \times 10^2$ cal/cm^2 - day

l = latitude of the place, deg.

$\lambda = 0.2/(1 + 0.1l)$, the latitude factor

N = mean length of the day during the month

ψ_p = seasonal factor

The values of ψ_p for coastal regions are listed below:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1.46	1.77	2.05	2.15	2.05	2.05	2.10	2.17	2.14	1.96	1.60	1.43

$S = n/N$

n = the mean hours of bright sunshine per day during a month

$t = r/M$

(r = number of rainy days during the month and

M = number of days in the month)

ϕ = the monthly mean humidity

Evaluation of the parameters appearing in equation (1)

$$\lambda = 0.2/(1 + 0.1\ell)$$

An average latitude of 27 deg. was used in calculating; the resulting value of λ is given as 0.05405

N = mean length of the day during the month. At sunrise, (or sunset) the angle of solar altitude $\beta = 0$

Let H represent the hour angle, for sunrise, or sunset, then

$$\sin\beta = \sin 0 = \cos\ell \cos H \cos d + \sin\ell \sin d = 0$$

or $$\cos H = -\tan\ell \tan d$$

Knowing the latitude (ℓ) and the declination (d), the value of H and, hence, the time for sunrise and sunset can be calculated. This in turn will determine the length of a particular day under consideration. Three days in each month (first, fifteenth and the last day) were considered and their lengths were averaged to find the mean length of the day for that particular month.

S = N/M

Data is available (Table 2) for Gheshm Island which records the number of bright sunshine hours for each month. This data was used to evaluate n and consequently the factors.

t = r/N

No information is available regarding the number of rainy days occurring in a particular month. However, records of precipitation are available (Table 1) for a six-year period (1960-66) for Gheshm Island. Additional information is available (Table 2) for Gheshm Island for the year 1966 which gives some estimate of the number of rainy days that could have occurred in a particular month. This data was used in conjunction with that given in Table (1) to estimate the value of r and consequently the value of t.

Relative humidity (ϕ)

The maximum and minimum humidity have been recorded for Gheshm Island (Table 3). These values were averaged to determine ϕ .

The results are summarized in Tables (B-1) and (B-2). Table (B-1) records the annual variation in sunrise and sunset timings, whereas Table (B-2) lists the values of the parameters N,r,k and the resulting intensity of total solar radiation on a horizontal surface (I_H).

Table (B-1)

Annual Variation in the Sunrise and Sunset Timings
on the Southern Coast of Iran

Date	Time of Sunrise solar time	Time of Sunset solar time
January 1	06.50 hours	17.10 hours
January 15	06.46	17.14
February 1	06.36	17.24
February 15	06.27	17.33
March 1	06.16	17.44
March 15	06.05	17.55
April 1	05.52	18.08
April 15	05.41	18.19
May 1	05.29	18.31
May 15	05.20	18.40
June 1	05.13	18.47
June 15	05.19	18.51
July 1	05.10	18.50
July 15	05.14	18.46
August 1	05.22	18.38
August 15	05.30	18.30
September 1	05.43	18.17
September 15	05.53	18.07
October 1	06.06	17.54
October 15	06.17	17.43
November 1	06.30	17.30
November 15	06.38	17.22
December 1	06.47	17.13
December 15	06.51	17.09

TABLE (B-2)

Annual Variation of the Parameters N, r, s, k and the Intensity of Total Solar Radiation (I_H)

Month	N(hrs.)	S	r(days)	K	I_H	
				cal/cm^2-day	cal/cm^2-day	BTU/ft^2-day
Jan.	10.53	0.838	2	187.01	349	1287
Feb.	11.13	0.638	3	217.87	329	1213
Mar.	11.83	0.652	1	246.82	455	1677
Apr.	12.63	0.644	3	259.84	433	1596
May	13.33	0.767	1	254.71	481	1773
June	13.63	0.748	0	256.34	473	1744
July	13.50	0.593	0	260.08	429	1582
Aug.	12.93	0.676	0	263.24	465	1714
Sept.	11.97	0.743	0	255.38	472	1740
Oct.	11.40	0.789	0	236.26	452	1666
Nov.	10.73	0.714	2	200.56	474	1747
Dec.	10.37	0.749	5	183.46	363	1338

APPENDIX C

Estimated Costs of Labour and Construction Materials in Gheshm Island and the Bandar Abbas Region, Iran

Item	Unit	Cost (Dollars)
Bricks	1000	10.00
Portland Cement	100 kilograms	2.00
Concrete (2500 Kg)	cubic meters	36.00
Sand and Gravel	1000 kilograms	0.09
Plastic sheet	square meters	0.67
Glass (ordinary household	square meters	3.00
Butyl rubber	square meters	1.94
P.V.C. pipe (10.2 cms. dia.)	meter	1.13
Land levelling	square meters	1.10
Labourer	person/day	4.00
Technician	person/day	6.00