Preliminary Evaluation of the Feasibility of Artificial Recharge in Northern Qatar

by

John Vecchioli

U.S. Geological Survey Open-File Report 76-540

ERRATA

"Preliminary Evaluation of the Feasibility of Artificial Recharge in Northern Qatar"
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p. 10, line 7, replace Pile with Pike.

p. 12, line 2, replace describes with described.

p. 12, line 23, replace the with to.

p. 19 Caption for figure 2 should read, "Hydrogeologic section along latitude 25°45'. Contact of Dammam and Rus Formations based on R.B. Brown and W. Sugden (1954). Extent of water with specific conductance less than 4,000 μmhos/cm based on Geotest (1976). Water table altitude based on D.H. Parker and J.G. Pike (1976, enclosure 2).

p. 30, line 3, replace quantitatively with qualitatively.

p. 41, line 14, replace Gevtest with Geotest.

p. 41, line 22, replace Pile with Pike.

p. 47, line 6, replace 32,28 with 32.28.

p. 47, line 14, replace 28 490 with 28.49.

PRELIMINARY EVALUATION OF THE FEASIBILITY OF ARTIFICIAL RECHARGE IN NORTHERN QATAR

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Prepared in cooperation with the U.S. Agency for International Development

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ABBREVIATIONS AND METRIC-ENGLISH EQUIVALENTS

millimetre (mm)	= 0.03937 inch
centimetre (cm)	= .3937 inch
metre (m)	= 3.28 feet
kilometre (km)	= .62 mile
cubic metre (m^3)	=35.31 cubic feet or 262.4 gallons
day (d)	
month (mo)	
year (yr)	
milligrams per litre (mg/L)	
micromhos per centimetre (μmhos/cm)	
cubic metres per day (m^3/d)	= 0.00026 million gallons per day
metres squared per day (m^2/d)	= 10.764 feet squared per day (transmissivity)
cubic metres per year (m^3/yr)	= 0.00026 million gallons per year
litres per second (L/s)	= 15.85 gallons per minute
litres per second per metre [(L/s)/m]	= 4.83 gallons per minute per foot (specific capacity)
degree Celsius (°C) (temperature)	= [(1.8x°C)+32] degrees Fahrenheit

PRELIMINARY EVALUATION OF THE FEASIBILITY OF ARTIFICIAL RECHARGE IN NORTHERN QATAR

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Abstract

Fresh ground water in northern Qatar occurs as a lens in limestone and dolomite of Eocene age. Natural recharge from precipitation averages 17×10^6 cubic metres per year whereas current discharge averages 26.6×10^6 cubic metres per year. Depletion of storage is accompanied by a deterioration in quality due to encroachment of salty water from the Gulf and from underlying formations. Artificial recharge with desalted sea water to permit additional agricultural development appears technically feasible but its practicability needs to be examined further. A hydrogeological appraisal including test drilling, geophysical logging, pumping tests, and a recharge test, coupled with engineering analysis of direct surface storage/distribution of desalted sea water versus aquifer storage/distribution, is recommended.

Introduction

Purpose and Scope

The Agency for International Development requested from the Geological Survey, on behalf of the Government of Qatar, the services of a hydrogeologist to evaluate a scheme proposed by His Highness Sheikh Khalifa Bin Hamad Al-Thani, Emir of the State of Qatar, for artificially recharging the ground-water reservoir in northern Qatar with desalinated water. In response to the request, the author spent the period April 25 to May 16, 1976, in Qatar gathering information needed to evaluate the recharge proposal. The author was provided as a base of operations in Doha (fig. 1) the Office of the Integrated Water and Land Use Project, which is under the joint auspices of the Ministry of Industry and Agriculture of the State of Qatar and the Food and Agriculture Organization of the United Nations.

Activities engaged in during the visit included:

(1) Review of pertinent reports on the geology and (or) the ground-water resources of Qatar.

(2) Review of selected data in the files of the Integrated Water and Land Use Project.

(3) Discussions with personnel of the Integrated Water and Land Use Project and of the Water Department on ground-water conditions and water-supply problems.

(4) Aerial reconnaissance of Qatar by helicopter.

(5) Study of formation outcrops.

(6) Measurement of water levels, water temperatures, and water salinity at six locations.

(7) Aquifer tests at two locations.

(8) Well performance tests at two locations, and

(9) Presentation of preliminary conclusions and recommendations to His Highness the Emir.

This report presents a summary of the ground-water conditions that consists largely of material abstracted from previous reports, augmented somewhat by recent data communicated by personnel of the Integrated Water and Land Use Project and by observations of the author made during the 3-week visit. The proposal to recharge the ground-water reservoir in northern Qatar artificially is evaluated and recommendations for a practicability study are given. Lastly, observations made by the author are documented.

Acknowledgments

The author wishes to thank His Highness The Emir for providing generously facilities and personnel of the State of Qatar. Thanks are due also to their Excellencies the Ministers of Industry and Agriculture and of Electricity and Water for the help given by personnel within their ministries. Particular thanks are due to Mr. John G. Pile, Project Manager, and Mr. Michael Farah, Project Co-Manager, of the Integrated Water and Land Use Project for making available use of their office, equipment, and personnel. The author is especially grateful to Dr. David Parker, FAO Senior Hydrogeologist, and to Mr. Ibrahim Harhash, Government Hydrologist, for the invaluable technical assistance they provided and for the numerous kindnesses they extended in both the field and office. Finally, the author thanks also the Ambassador of the United States of America, Mr. Robert P. Paganelli, and Mr. Ryan C. Crocker, Commercial Attaché of the Embassy, for the logistical support they provided. All this help made it possible to conduct the investigation expeditiously and with thoroughness during the time allotted.

Previous Work

The geology of the Qatar peninsula was mapped in detail by Claude Cavelier, Abdullah Salatt, and Yves Heuze (1970) and discussed by Claude Cavelier (1970). The Lexique Stratigraphique International (1975) contains detailed descriptions of the overall stratigraphy of Qatar by W. Sugden and H. J. Standring and of the Tertiary System by C. Cavelier.

Several reports discuss the hydrogeology and ground-water resources of Qatar. Le Grand Adsco, Ltd. (1959) describes the results of extensive test drilling conducted in northern Qatar particularly in reference to the quality of the water encountered. A later study by Parsons Engineering and Construction Corp. (1962) reviewed all available hydrogeologic information and proposed additional studies to evaluate the ground-water potential of Qatar with emphasis on the deeper water-bearing zones. The Food and Agriculture Organization of the United Nations studied the water resources of Qatar and reported their findings in a report (1974) that evaluates aquifer characteristics, water quality, water usage, and the water balance of the area. A report by L. W. Hyde (1975) presents a review of the hydrogeology of Qatar and develops guidelines for a test-well drilling program to define the extent of the fresh ground water and for recharge wells to infiltrate surface runoff that collects in depressions. An evaluation of precipitation and ground-water recharge was made by J. G. Pike, I. Harhash, and B. A. P. Gemmell (1975). Thickness of the fresh ground-water reservoir was delineated through an electrical resistivity survey done by Geotest (1976). Lastly, D. H. Parker and J. G. Pike (1976) reviewed the ground-water resources in Qatar and evaluated their potential for development, with emphasis on a plan the recharge the ground-water reservoir in northern Qatar artificially.

Geology

The Qatar peninsula is underlain by a flat-lying to gently dipping sequence of sediments that was deposited upon gradually subsiding basement rocks. The major structure of the peninsula is that of a broad, north-south trending anticline that plunges to the north and south and that has a surface expression of a broad shallow dome. "Dips on the flanks and north plunge are on the order of one half to two metres per kilometre. The south plunge in less clearly defined," (Sugden and Standring, 1975, p. 18). Parallel to the west coast is the more pronounced, narrow, elongate Dukhan anticline which is separated from the shallow dome by a syncline. Trend of the Dukhan anticline and the adjoining syncline are north-northwest to north.

Topography of the peninsula varies from moderately rough terrain in the south where deep surface depressions and steep mesa-type hills occur to gently rolling terrain in the north where surface depressions are shallow but more numerous. Maximum altitudes of about 100 m occur in the southwestern part of the country. In the north the higher altitudes are between 40 and 50 m. Just to the west of Dukhan is an area of sabkhah (salt flats) that lies at an altitude of a few metres below sea level.

Geologic formations or units of the Qatar peninsula from youngest to oldest include Quaternary sand dunes, sabkah deposits, alluvial deposits in wadi bottoms and surface depressions, and marine deposits; the Miocene Hofuf and Dam Formations; the Eocene Dammam and Rus Formations; the lower Eocene and Paleocene Umm er Radhuma Formation; the Cretaceous Aruma and Wasia Groups; and other older formations. The total thickness of these units is roughly 5 000 m.

"Only the Cretaceous age and younger rocks have been considered and explored for production of potable water supplies and only the Eocene age rocks have been found to contain potable water" (FAO, 1974, p. 7 and 8). Descriptions of the Eocene and Paleocene formations are given below in descending order.

Dammam Formation: The Dammam Formation crops out over most of the Qatar peninsula. The upper part of the Dammam consists of dolomitic marl and limestone, known as the Abarug Member, underlain by highly recrystallized chalky limestone of the Umm Bab Member. The lower part of the Dammam is comprised of massive clayey whitish to yellowish fossiliferrous limestone, called the Dukhan Alveolina Limestone Member, underlain by the Midra Shale Member made up of yellow-brown to greenish-gray attapulgite shale more or less rich in carbonate, and in turn underlain by the Rujm Aid Velates Limestone Member consisting of whitish, crystalline, hard, fossiliferrous limestone. The Dammam Formation is about 50 m thick of which the upper part makes up 40 m. The upper part is well fractured and contains vugs and solution cavities.

Rus Formation: The Rus Formation conformably underlies the Dammam. It consists of generally whitish to yellowish, soft, chalky, irregularly dolomitized limestone with thin intercalations of greenish to brownish clay. Varying thicknesses of gypsum and anhydrite beds within the Rus have been reported. In northern Qatar these evaporite beds are generally absent and are thought to have been removed by dissolution, evidence for which is given by the circulation losses commonly experienced in the drilling of rotary bore holes and by the abundance of collapse features. Thickness of the Rus Formation ranges from 28 to 84 m. The Rus contains abundant fractures, vugs, and solution cavities.

Umm er Radhuma Formation: The Umm er Radhuma Formation underlies the Rus conformably. It consists of a sequence more than 300 m thick of brownish or grayish limestone that is dolomitic and very porous in the upper part and argillaceous in the lower part. The formation is well fractured. Some anhydrite has been reported within the Umm er Radhuma.

Ground-Water Hydrology

Occurrence of Ground Water

Over most of Qatar the water table generally occurs either in the Dammam Formation, especially in coastal areas, or in the underlying Rus Formation. Shallow ground water is more or less a lens of "freshwater" floating on more dense saltier water below. Most of the "freshwater" occurs in the Rus Formation and in the upper part of the Umm er Radhuma Formation. Fractures, vugs, and solution channels provide the principal means for storage and movement of ground water in this limestone aquifer.

The maximum altitude of the water table, which marks the upper surface of the "freshwater" lens in northern Qatar, is less than 5 m above mean Gulf level. The configuration of the "freshwater" lens at depth is not accurately known. Using 2 000 mg/L total dissolved solids concentration as the upper limit of "freshwater", D. H. Parker and J. G. Pike (1976, p. 12) estimated the maximum thickness of the freshwater lens to be up to 120 m on the basis of a salinity-depth profile in the center of the lens. Results of a recent electrical resistivity survey (Geotest, 1976) defines the maximum thickness of water having a specific conductance of less than 4 000 µmhos per cm at 25°C to be 120 m. Seawater of the Arabian Gulf has a density of 1.033 and ground water at depth beneath the freshwater lens is probably of comparable salinity. Accordingly, applying the Ghyben-Herzberg relationship, one obtains a maximum thickness of the freshwater lens that approximates that indicated by the salinity-depth profile and by the resistivity survey. A hydrogeologic section showing the vertical extent of the "freshwater" lens in northern Qatar is given in figure 2. The "freshwater" lens in northern Qatar is considered to be the principal aquifer.

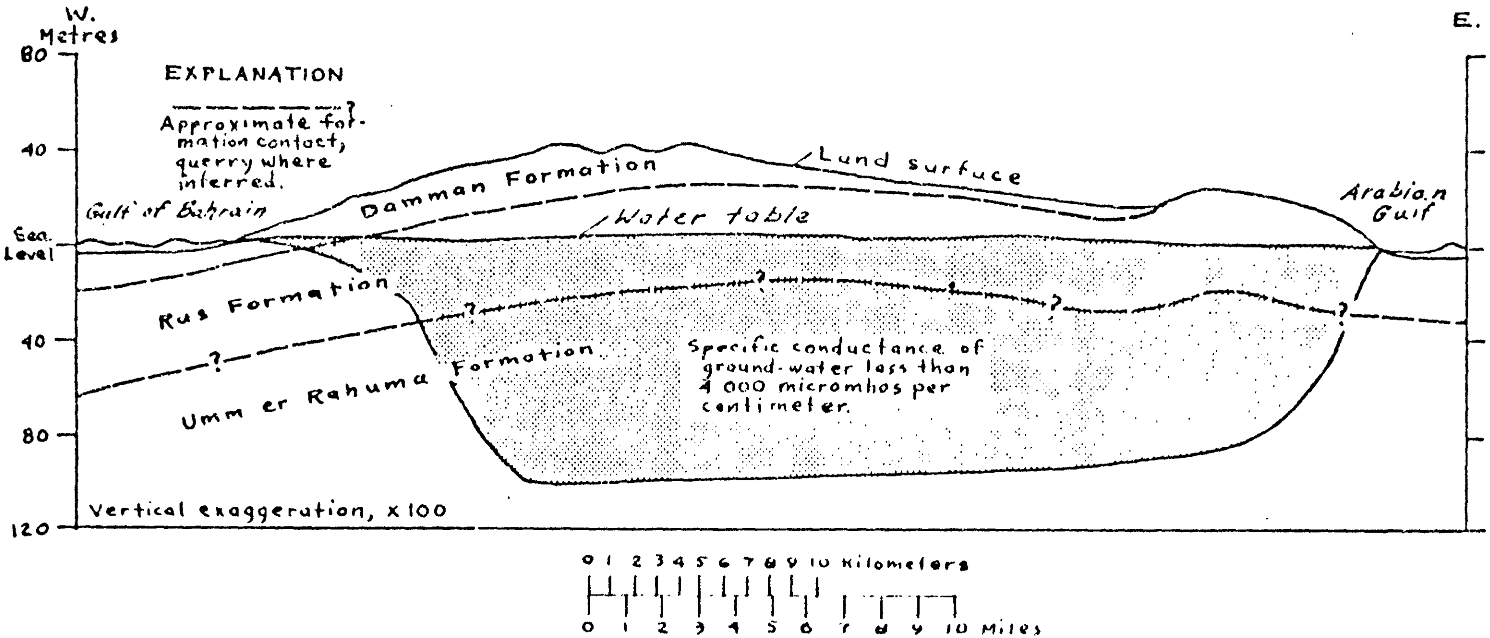

Figure 2.--Hydrogeologic section along latitude 25°45'. Contact of Dammam and Rus Formations based on R. B. Brown and W. Sugden (1954). Extent of water with specific conductance less than 4000 umhos/cm based on D. H. Parker and J. G. Pike (1976, enclosure 2).

Shallow ground water in southern Qatar generally has a higher total dissolved solids concentration than that in the north, although there are small isolated areas of water containing less than 2 000 mg/L concentration. Evaporite beds are reported to be more prominent in central and southern Qatar (FAO, 1974, p. 10). Apparently there has been less dissolution of these beds there and, consequently, less secondary permeability has developed.

In the southwestern corner of Qatar, near Abu Samra, the Abarug Member of the Dammam Formation contains water under sufficient confined head to rise several metres above land surface. This water has a specific conductance ranging between 3 000 and 4 000 μmhos per cm at the new government sheep farm but elsewhere in the southwest region the specific conductance has been reported to range from 4 300 to 16 500 μmhos per cm.

Results of deep drilling at several locations from extreme north to extreme south Qatar indicate that there is little likelihood of encountering freshwater at depth in formations that in Saudi Arabia and Bahrain contain usable water. Reported specific conductances of water from the Umm er Radhuma Formation and the Wasia Group range from 24 000 to 100 000 μmho/cm.

Status of Ground-Water Supply

All of the fresh ground water in Qatar originates from local rainfall, except for the confined slightly brackish water near Abu Samra which is believed to have its source to the west in Saudi Arabia. Mean annual rainfall at Doha for 17 years of record was 60.4 mm and the range recorded was from a minimum of 2.0 mm to a maximum of 190.7 mm (Pike and others, 1975, p. 6). The greater part of the annual recharge results from infiltration of runoff that collects in surface depressions, commonly from storms of more than 10 mm precipitation. Such storms have a 90 percent probability of occurring at least once each winter and a 50 percent probability of occurring twice (Pike and others, 1975, p. 12). Recharge to ground water is estimated to be 7 to 10 percent of annual rainfall in northern Qatar and 3.5 to 5 percent in southern Qatar. Annually this amounts to 20.9 x $10^6 m^3$ of which 17 x $10^6 m^3$ occurs in northern Qatar (Parker and Pike, 1976, p. 14).

According to D. H. Parker and J. G. Pike (1976, p. 14), for the period 1972-75, the major part of the withdrawal from the ground-water reservoir was for agriculture, estimated to be 28.7 x $10^6 m^3$ per year, of which 26.6 x $10^6 m^3$ was from the principal aquifer in the north. An additional 4.6 x $10^6 m^3$ per year was extracted for domestic-industrial use, all from the north. Another 3.0 x $10^6 m^3$ per year discharged annually to the sea--1.8 x $10^6 m^3$ from the northern area and 1.2 x $10^6 m^3$ from the southern area.

Based on the above estimates of recharge and discharge, the northern area experienced a depletion from storage of about $16 \times 10^6 m^3$ per year during this 4-year period. Change in storage in the southern area was insignificant. Depletion of storage in the north is thought to have been in progress since 1966.

Continual depletion of storage in the northern area has caused and will continue to cause the freshwater lens there to shrink in size both laterally and vertically. Ground-water levels declined an average of 0.11 metre per year during 1972-75 (Parker and Pike, 1976, p. 15). The total dissolved-solids concentration of the ground water increased an average of 22 percent during this period (Parker and Pike, 1976, p. 15). Saltwater apparently is encroaching on the domain of the freshwater laterally from the sea and vertically from the deeper-lying formations. If extractions continue, and especially if their rate exceeds the rate of recharge, further deterioration in water quality will result. Any increase in the rate of extraction from the freshwater lens in the north will accelerate the depletion of storage and aggravate the increases in salinity to the point where much of the ground water will become unusable for either agricultural or domestic purposes.

Predictions of the life of the freshwater lens at various given rates of overdraft cannot be made reliably with the data available. Little is known, except in a general way, about the change in salinity with depth. Also, the specific yield of the limestone aquifer has not been reliably determined. It has been estimated to be 2 percent but recently acquired aquifer test data (tables 2 & 3) suggest that the specific yield could be much smaller than 2 percent. If the specific yield were only 1 percent, the estimated 3 500 x $10^6 m^3$ of freshwater contained in the lens (Parker and Pike, 1976, p. 16) would be reduced by half and, correspondingly, the estimated life of the resource would also be halved.

Potential for Artificial Recharge in Northern Qatar

Large additional extractions from the ground-water reservoir in northern Qatar cannot be made over an extended period of time without causing severe deterioration in the quality of ground water. As indicated previously, current extractions already exceed the average annual rate of replenishment. Some deterioration in quality of ground water has already been observed, particularly in the coastal areas in the north and east sides of the peninsula.

Agriculture currently consumes annually almost $29 \times 10^6 m^3$ of ground water, of which almost $27 \times 10^6 m^3$ are from the ground-water reservoir in northern Qatar (Parker and Pike, 1976, p. 7). The Government of Qatar expects to expand agriculture considerably and, consequently, large additional volumes of water would be required for irrigation. Areas containing irrigable soils in northern Qatar occur scattered in numerous small depressions rather than in large contiguous tracts. Areas currently irrigated are supplied with ground water from numerous wells stratigically located near the irrigated fields. However, because the current level of agricultural development already has resulted in mining of ground water, and because available data are not sufficient to determine the life of the ground-water resource reliably under current and increased rates of mining, significant agricultural expansion should be preceded by detailed studies of the amount and distribution of usable ground-water in storage and by plans to develop conjunctively other sources of water for irrigation.

Desalinated seawater is being used directly in increasingly greater quantities for the domestic-industrial needs of Doha and other urban centers. It has been proposed to use desalinated seawater, either directly or indirectly, for agricultural needs as well. Indirect use would involve artificial recharge of the ground-water reservoir in northern Qatar with desalinated seawater in order to maintain the rate of replenishment in balance with the rate of extraction from numerous irrigation wells.

Benefits that could accrue from a properly designed and executed artificial recharge scheme would include:

(1) Stabilization or retardation of the deterioration in quality of fresh ground water resulting from encroachment of saline water from the Gulf and(or) from deeper-lying saltwater aquifers.

(2) Use of the freshwater aquifer as a storage reservoir to even out fluctuations in demand, seasonally and daily, by irrigation.

(3) Use of the freshwater aquifer as a transmission system to distribute desalinated seawater from one or perhaps two or three plants to numerous dispersed small tracts of irrigable land where the needed water could be recovered through on-site wells, and

(4) Use of the freshwater aquifer as a standby reserve of potable water in the event of a massive failure of distillation equipment.

Based on available information on the hydrogeology and hydraulic properties of the limestone aquifer in northern Qatar, artificial recharge of the aquifer with desalted seawater appears technically feasible and worthy of further study. Recharge in the interior areas of the peninsula would probably be of greater overall benefit than recharge in coastal areas. The lengthy coastline and the irregularity in hydraulic conductivity of the limestone aquifer would make extremely difficult the development of a hydraulic pressure barrier that would reliably stabilize or retard the encroachment of salt water from the Gulf everywhere along the coast. Moreover, less of the water injected would be recoverable if recharge is done near the coast as compared to inland areas. Also, recharge done near the coast would not provide as much protection to inland wells from encroachment upward of salty water from deeper-lying formations as would recharge done inland. Therefore, for these reasons, as well as for the need to avoid local water-logging of land that could result from a rise in the water table, inland areas in which depth to the water table is at least 10 m would be the preferred areas to investigate as potential recharge sites.

Recharge should be done through wells rather than through surface spreading techniques in order to avoid high water losses to evaporation. A typical recharge well would have a diameter of about 30 cm and a depth of about 60 m. A conservative estimate of the rate of recharge per well, based upon yield characteristics of existing supply wells and on aquifer-test data, most likely would be on the order of 1 000 m^3/d, given that at least 10 m of head buildup could be tolerated at the well site.

Higher rates could be realized where the transmissivity of the aquifer is higher or the depth to the water table greater. Potential recharge rates for different values of transmissivity are given in table 1. Regional transmissivity values for most areas in the north are probably in the range of 100 to 500 m^2/d. The cost of a typical recharge well, based on current (1976) costs experienced by the Water Department for supply wells, would be at least 40 000 Riyals ($10 000).

Table 1.--Potential rate of recharge per well and number of wells required to recharge $60 \times 10^6 m^3/yr$ for different values of aquifer transmissivity. [1/]

Transmissivity (m^2/d)	Recharge rate (m^3/d)	Number of wells
100	674	244
200	1 302	127
500	3 101	53
1 000	5 964	28

1/ Storage coefficient = 0.02, time = 1 000 d, head buildup at recharge well = 10 m

Recommended Scope of Practicability Study on Artificial Recharge in Northern Qatar

Implementation of artificial recharge of desalted sea water on a large scale such as the proposed 60 x $10^6 m^3$/yr scheme would require perhaps as many as 200 recharge wells, many kilometres of transmission line, one or more pumping stations, and construction of numerous other wells to be used for extraction in currently undeveloped farm areas. Even though consideration of capital costs of such a scheme may be unnecessary, the complexity of the operations and the continuing operation and maintenance costs indicate the need to conduct a thorough evaluation of the practicability of large-scale recharge. The scope of the investigation required is detailed below.

Hydrogeological Appraisal

Available information is enough to evaluate ground-water conditions quantitatively but is not sufficient to make quantitative predictions reliably. Detailed data on the changes in salinity with depth and on the variations in the water-yield characteristics of the individual rock layers are required in order to evaluate the size of the fresh ground-water reservoir properly and to identify the hydrogeologically best potential sites for recharge wells. Because of the complex nature of secondary permeability developed in the limestone aquifer, acquisition of the needed information should be done under a carefully planned and executed test-drilling program that is under the direction of a ground-water hydrologist experienced in the hydrology of limestone aquifers. The testing program should include the drilling of about 10 test holes through the boundary between fresh and salt water to a depth where the water has a dissolved solids content of 10 000 mg/L. Preferably the drilling should be done by the percussion method because this method is best for monitoring changes in salinity, water level, water yield, and lithology as the hole is deepened, all of which are vital for a thorough hydrogeologic appraisal. Geophysical logs, including at least caliper, electrical resistivity, fluid conductivity, natural gamma, and calibrated neutron, should be run on the completed holes. These test holes should be distributed strategically within approximately the central third of the peninsula that extends from latitude 25°15' north to latitude 25°50'. Once the geophysical logs have been obtained, the lower part of the hole should be cemented to seal off the deeper water with dissolved solids concentration above 2 000 mg/L.

Upon completion of the test-drilling program, at least three of the test-hole sites should be selected for further testing of the aquifer's hydraulic properties. At each of the three sites selected, piezometers should be installed, at least three per site, near the test holes. Pumping tests of a week or more should be made at each site to determine the transmissivity and storage properties of the aquifer.

At least one extended recharge test should be made to demonstrate the aquifer's capability to accept water injected continuously for a 1- to 3-month period. Ground water from existing wells could be used for the recharge test in lieu of a desalinated water supply. It should be noted that desalinated water might react differently with the aquifer than would water recirculated from existing wells, although it is unlikely that the difference, if any, would be great in the limestone aquifer. The water should be injected into one of the test holes on which a pumping test was made.

Costs for making the hydrogeological appraisal are estimated as follows:

1)	Drilling 10 test holes, 30-cm diameter, 200-m deep @450R/m=	900 000Riya:
2)	Geophysical logging 10 test holes @4 000R=	40 000R
3)	Installing 10 piezometers, 15-cm diameter, 60-m deep @300R/m=	180 000R
4)	Pumping 3 test holes, 7 days each @4 800R/d=	100 000R
5)	Recharge test, 90 days @4 800R=	432 000R
6)	Ground-water hydrologist, 2 for 12 months each @40 000R/mo=	960 000R
	Subtotal	2 612 800R
	Contingency allowance 15%	387 200R
	Total	3 000 000R

Total Water Management Plan

An integrated water-management plan that embraces coordinated utilization of all sources of water should be developed in conjunction with the hydrogeological appraisal. The only likely sources of fresh water in addition to the dwindling ground-water supply are desalted seawater and renovated wastewater.

The potential of the desalted seawater supply is constrained mainly by economic considerations, that is, capital costs and operation and maintenance costs which include cost of energy, chemicals, repairs, and manpower.

On the other hand the potential of the renovated waste-water supply depends mainly on the growth of the domestic-industrial demand for water in urban areas. According to studies reported by D. H. Parker and J. G. Pike (1976, p. 17-19), the domestic-industrial demand in Doha and Umm Said is projected to be as follows:

Year	Demand (m^3/yr)
1980	43×10^6
1984	58×10^6
1990	81×10^6
1994	98×10^6

Assuming it were possible to collect and reclaim about 50 percent of the water used for domestic-industrial purposes, this source would grow in volume as follows:

Year	Renovated waste water (m^3/yr)
1980	21×10^6
1984	29×10^6
1990	40×10^6
1994	49×10^6

The amount of renovated wastewater that could be made available by 1984 to help support agricultural development equals the 29 x 10^6 m^3/yr of ground water currently consumed for agriculture. By 1994, 1.7 times the currently consumed amount would be available. The cost of reclaiming water from sewage is generally considered to be less than the cost of desalting sea water. Treated sewage would be suitable for irrigation of many types of crops, and, in fact, because of the nutrients contained in treated sewage, its use could be preferred to other sources. Therefore, a thorough engineering analysis of the practicality of integrating renovated waste water into a total water-management plan should be made. Highly treated wastewater could be used directly for irrigation or used as part of the supply to be artificially recharged to the ground-water reservoir.

Another aspect of the total water-management plan that should be examined is the phasing out of the pumpage from well fields in northern Qatar that is used, blended with distilled water, to supply the domestic-industrial needs of Doha. Those well fields could then be utilized, in part at least, as artificial recharge sites.

An alternate plan that might be less costly overall than implementing artificial recharge at a scale of 60 x $10^6 m^3$/yr would be that of supplying either entirely or partly the needs of larger farms and closely clustered smaller farms directly with desalted sea water from one or two distillation plants. Areal irrigation demand varies little seasonally in Qatar, but varies greatly diurnally and from day to day. A distillation plant or a sewage treatment plant would operate under comparatively steady daily output. Therefore, storage is required to even out the fluctuation demands of irrigation.

The ground-water reservoir could be used as the storage facility by recharging it with desalinated sea water at times when direct use of irrigation was less than the supply capacity of the system. Wells used for recharge could be used also for extraction of the injected desalinated water at times when irrigation demand exceeded the supply capacity of the surface distribution system. For example, water is applied to the farmed fields in Qatar only during daylight hours, or approximately half a day. Hence, the rate of application needs to be twice the actual daily crop requirement. If the desalination plant(s) and distribution system were sized according to the average daily water requirement and operated continuously, the ground-water reservoir could be recharged with desalinated water delivered during the night. During the day, the desalinated water that was injected at night would be recovered and used to supplement the rate at which the desalinated water from the distribution system was being delivered directly to the irrigated fields. Various modifications of this concept of dual use of wells could be developed to suit specific situations so as to make optimum use of existing extraction wells. An engineering cost analysis of various combinations of surface storage/distribution and aquifer storage/distribution through artificial recharge should be made. This analysis would, of course, be dependent on information acquired through the hydrogeological appraisal.

Lastly, the water-management plan should include recommendations for the organizational structure of a single governmental agency to administer the water plan and regulate use of all waters for all purposes. Jurisdiction by a single agency would facilitate the integrated management of all water sources for the optimum development of Qatar.

Costs of developing the total water-management plan would be in addition to the cost of the hydrogeologic appraisal. The cost of developing the plan cannot be estimated reliably by the author in that details of the scope of the effort involved are outside of the author's expertise. It is suggested that proposals for development of an integrated water plan, including the hydrogeological appraisal, be solicited from large international water-resources engineering firms. These firms should have the capacity to provide all of the technical expertise and equipment required, through their own company or through association with other firms, so as to expedite the work and to assure proper coordination of the various facets involved.

Conclusions and Recommendations

1. Large additional extractions from the ground-water reservoir most likely cannot be made over an extended period of time without causing severe deterioration in the quality of ground water. Current extractions exceed rate of replenishment. Some deterioration in quality has already been observed. The life of the freshwater resource cannot be accurately predicted on the basis of existing data.
2. Expansion of agriculture will require large additional supplies of freshwater. The only likely sources of additional large supply over long periods of time are desalted seawater and renovated waste water.
3. It appears technically possible to recharge the aquifer in northern Qatar artificially with desalinated seawater. The benefits of artificial recharge would include a stabilization or retardation of the deterioration in ground-water quality, aquifer storage and transmission of desalinated seawater, and maintenance of a standby supply of potable water.
4. The practicability of artificial recharge should be studied further through a hydrogeological appraisal that includes test drilling, geophysical logging, pumping tests, and a recharge test. Cost of this work is estimated to be 3 000 000 Riyals.

5. The hydrogeological appraisal should be accompanied by the development of an integrated water-management plan. The plan should evaluate the practicability of using enovated waste water to meet part of the agricultural demand. It should also analyze costs of various combinations of direct surface storage/distribution of desalinated water and aquifer storage/distribution through artificial recharge. The plan should recommend the administrative structure required to manage the plan and regulate water use.

6. Proposals for development of the water plan, including the hydrogeological appraisal, should be solicited from large international water-resources engineering firms who have the capacity to provide all of the technical expertise and equipment required.

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Table 2.--Results of Pumping Test made May 3 and 4, 1976, on Well No. 7 at Government Farm at Rawdat Al Faras

Length of test:	1 410 min
Discharge rate:	1 100 m^3/d (approximate)
Water temperature:	29°C
Specific Conductance:	2 100-2 400 µmhos/cm at 25°C
Observation wells:	
a) Test well located 14.6 m southwest of well No. 7	
b) Recharge well No. 2 located 210 m north of well No. 7	
Method of Analyses:	log-log time-drawdown
Transmissivity:	
a) Test well:	520 m^2/d
b) Recharge well No. 2:	2 950 m^2/d
Storage Coefficient:	
a) Test well:	0.0017
b) Recharge well No. 2:	0.0014
Remarks:	Some interference from other pumping wells. Measurement of discharge poor.

Table 3.--Results of Pumping Test made May 10-12, 1976, on Well No. 1 at Government Experimental Farm south of Rawdat Al Faras

Length of test: 2 380 min

Discharge rate: 1 187 m^3/d (metered)

Water Temperature: 28°

Specific Conductance: 700-730 umhos/cm

Observation wells:

a) Pumping well (No. 1)

b) Well No. 2 located 187.6 m south of well No. 1

c) Well No. 4 located 161.7 m north of well No. 1

Method of analysis:

a) Log-log time-drawdown

Transmissivity:

a) Well No. 2: 350 m^2/d

b) Well No. 4: 320 m^2/d

Storage Coefficient:

a) Well No. 2: 0.003

b) Well No. 4: 0.008

Table 4.--Observations made May 6, 1976, on recently completed wells at new Government sheep farm at Abu Samra

Well Number	Depth of well (metres)	Shut-in head (metres) Above concrete pad	Shut-in head (metres) Above land surface	Temperature °C	Specific Conductance (umhos per centimetre at 25°C)	Flow rate (litres per second)	Drawdown (metres)	Specific capacity 1/ litre per second per metre
1	35.0	3.20	3.4	28.5	3 700	6.0	1	6.0
2	36.6	3.08	3.1	29	4 000	--	--	--
4	32.6	2.90	3.2	28.5	3 100	--	--	--
9	33.5	3.35	3.5	28.5	3 500	--	--	--
10	31.1	3.33	3.5	28.5	3 200	--	--	--
11	36.6	3.71	3.9	28	3 600	--	--	--
12	34.1	2.92	3.4	28.5	3 600	9.2	1	9.2
						13.3	2	6.7

1/ Duration of flow test about 5 minutes

Table 5.--Observation made May 1, 1976, during well performance test on Decca Well No. 3

Drilled depth of well:	47.6 m
Depth at time of test:	42.6 m
Static water level:	29.15 m below land surface
Pumping rate:	3.0 L/s
Drawdown after 37.5 minutes:	6.71 m
Specific capacity:	0.44 (L/s)/m
Temperature:	30°C
Specific Conductance:	3 000 µmhos/cm

Table 6.--Observation made May 2, 1976, at Water Department well field at Umm El Ghab

1. Measured water level in and temperature and specific conductance of water from well at extreme southwest corner of grid. Well pumping at time of measurement.

Depth to water	= 32, 28 m below top of well (at surface of concrete pad about 2 m above land surface)
Specific conductance	= 1 850 μmhos/cm
Temperature	= 30°C

2. Measured water level in nonpumping well in second grid line from westernmost edge and second grid line from southermost edge of field.

Depth to water	= 28 490 m below top of well (at surface of concrete pad about 0.8 m above land surface)