Ground Water in the Sirte Area, Tripolitania United Kingdom of Libya

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1757-C

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

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By WILLIAM OGILBEE

CONTRIBUTIONS TO THE HYDROLOGY OF AFRICA AND THE MEDITERRANEAN REGION

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By William Ogilbee

ABSTRACT

The present study of the ground-water conditions in the Sirte area was made during December 1961 and March–April 1962 at the request of officials of the Government of Libya. Particular attention was given to the potential of the fresh-water aquifer near Qaşr Bu Hadi as a source of water for Sirte.

The Sirte area lies on the southern coast of the Mediterranean Sea about 450 kilometers east-southeast of Tripoli, cocapital of Libya. Although the area receives some winter precipitation, the climate is arid. The surface rocks of the area are chiefly Miocene limestone containing marl, clay, and some sandstone, though Quaternary deposits occur along the wadis and mantle the Miocene rocks in the coastal plain.

Fresh ground water occurs locally in Recent sand dunes near Zaafran and in Miocene limestone near Qaşr Bu Hadi, south of a probable fault. Elsewhere in the Sirte area, ground water occurs generally in Tertiary rocks but contains 3,000 or more parts per million of dissolved solids.

To establish the hydraulic characteristics of the fresh-water aquifer in the Qaşr Bu Hadi area, two test wells were drilled and a controlled pumping test was made. The coefficient of transmissibility was found to be about 25,000 gallons per day per foot (13.68 cubic meters per hour per meter), and the coefficient of storage, about 0.00055. The pumping test also established the presence of two barrier-type hydraulic boundaries for the aquifer, one about 250 meters westward and another about 535 meters northward from well 9a. The first boundary is probably the small anticline on which stands the fort of Qaşr Bu Hadi; the second boundary is probably a northwest trending fault. Using the transmissibility and storage coefficients derived from the pumping test, the writer concludes that (1) the total draft from the fresh-water aquifer should not exceed 13.5 cubic meters per hour and (2) production wells should be at least 3 kilometers south of well 9a.

INTRODUCTION

The town of Sirte currently (1962) is confronted with a serious shortage in its potable water supply. The ground water beneath the town and environs is too salty for normal human use, but usable water is obtained from shallow wells and galleries in the sand-dune area about 4 kilometers to the west of the town, near Zaafran. This supply is inadequate and is reportedly deteriorating in quality. At the request of the Nazirs of Agriculture and Public Health of Tripolitania and of other Government of Libya officials, field studies were made in December 1961 and in March–April 1962 to evaluate the general ground-water conditions in the area and the particular potential of the fresh-water aquifer near Qaṣr Bu Hadi as a source of water for Sirte. The work was part of a larger program of ground-water investigations in Libya that have been in progress since 1952 by geologists and engineers of the U.S. Geological Survey assigned to the U.S. Agency for International Development (US AID) Mission to Libya.

In the past, several efforts have been made to obtain fresh water in the Sirte area. The Italians in 1938 drilled a deep test, well 3, approximately 2 km (kilometers) south of Sirte, but salty water was found in each water-bearing zone penetrated. In 1941, during World War II, the Italians drilled wells near Qaşr Bu Hadi and obtained fresh water for their troops stationed in the area. Their well 8, which is 57 m (meters) deep, can yield 2.7 m^3 per hr (cubic meters per hour) of fresh water through pumping. Further study of the fresh-water potential in the Sirte area was made in 1958 by H. T. Smith International (1959). A test hole, well 7, was drilled in the Wadi Tlal, the principal stream in the area, about 2 km northeast of Qaşr Bu Hadi and 17 km south-southeast of Sirte. Because the water contained 958 ppm (parts per million) of chloride, the well was considered to be unsuitable for domestic use. Based on a brief field study in 1959, a preliminary memorandum report on a ground-water supply for Sirte was prepared by R. C. Vorhis (1959, written communication) for the US AID Mission. In 1960, several test holes of small diameter were drilled under the direction of G. H. Goudarzi, chief of the U.S. Geological Survey field party with the US AID Mission, to determine the northern extent of the fresh-water aquifer near Qaşr Bu Hadi. A chemical analysis of water from one test hole, well 4, is given in table 1.

The present study of the Sirte area (fig. 1) was made with the cooperation of Essayed Mohammed Bey Derna, Nazir of Agriculture and Forests of Tripolitania, the District Commissioner of the Sirte area, the Mayor of Sirte, the Shieks of the local Bedouin tribes in the Qaşr Bu Hadi area, and oil company officials. The pumping tests at Qaşr Bu Hadi were made under the supervision of the writer, assisted by Hadi Ali Tarhuni and Mohammed Amin Zintani, Hydrologic Technicians of the Government of Libya, and by Bu Agela Hassen Belgassem, Water Well Drilling Supervisor of the Nazarat of Agriculture.

As part of the present study, two test wells were drilled near Qaşr Bu Hadi by the Well Boring Section of the Nazarat of Agriculture. These were drilled near existing well 8, reportedly the only source of fresh water from many kilometers south of the dunes of Zaafran. A controlled pumping test was conducted by pumping from

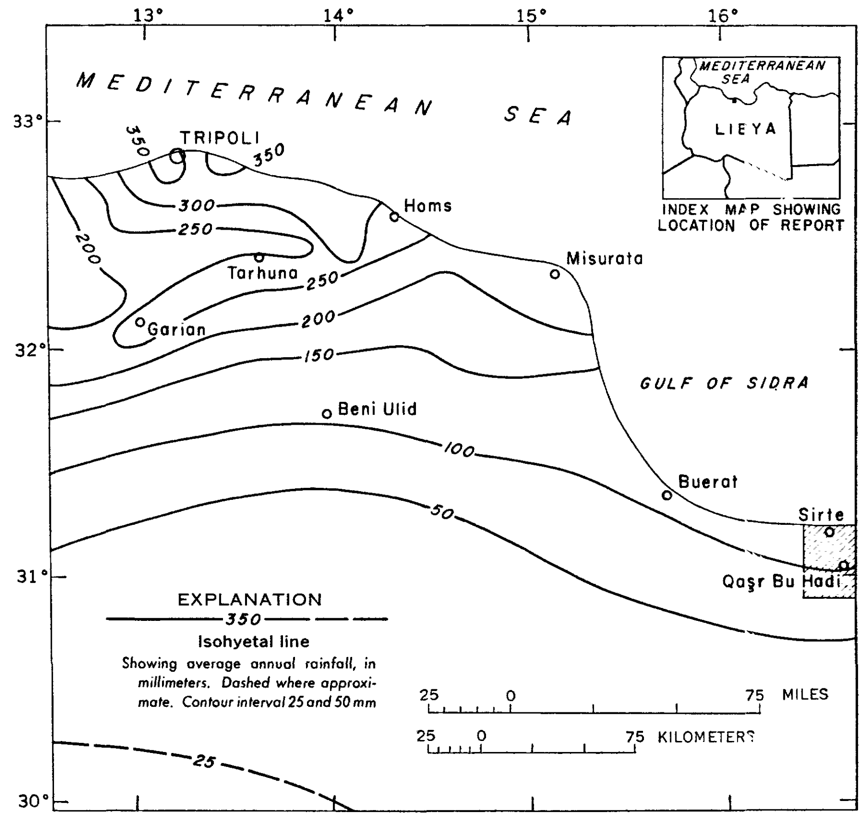

FIGURE 1.—Map showing location of the Sirte area and average annual rainfall in northern Tripolitania. After Stewart (1960).

one of the test wells while the other was used to determine the effects of the pumping. The data obtained were used to predict the effects of prolonged withdrawal on the aquifer. Other work in the area included geological reconnaissance and evaluation of available geologic and hydrologic data relevant to the water problem.

GEOGRAPHIC AND CLIMATIC FEATURES

The Sirte area (fig. 2) as described in this report lies in eastern Tripolitania between lat 31°00′ and 31°15′ N. and long 16°30′ and 16°50′ E. Sirte, the principal town, is near the coast of the Gulf of Sidra, an embayment of the Mediterranean Sea. The town, which is the administrative center of the geographic region known as Sirtica, lies about 450 km east-southeast of Tripoli, cocapital of Libya.

The Sirte area includes a narrow coastal plain which extends inland some 3–4 km from the shoreline. Along the shore is a belt of low-

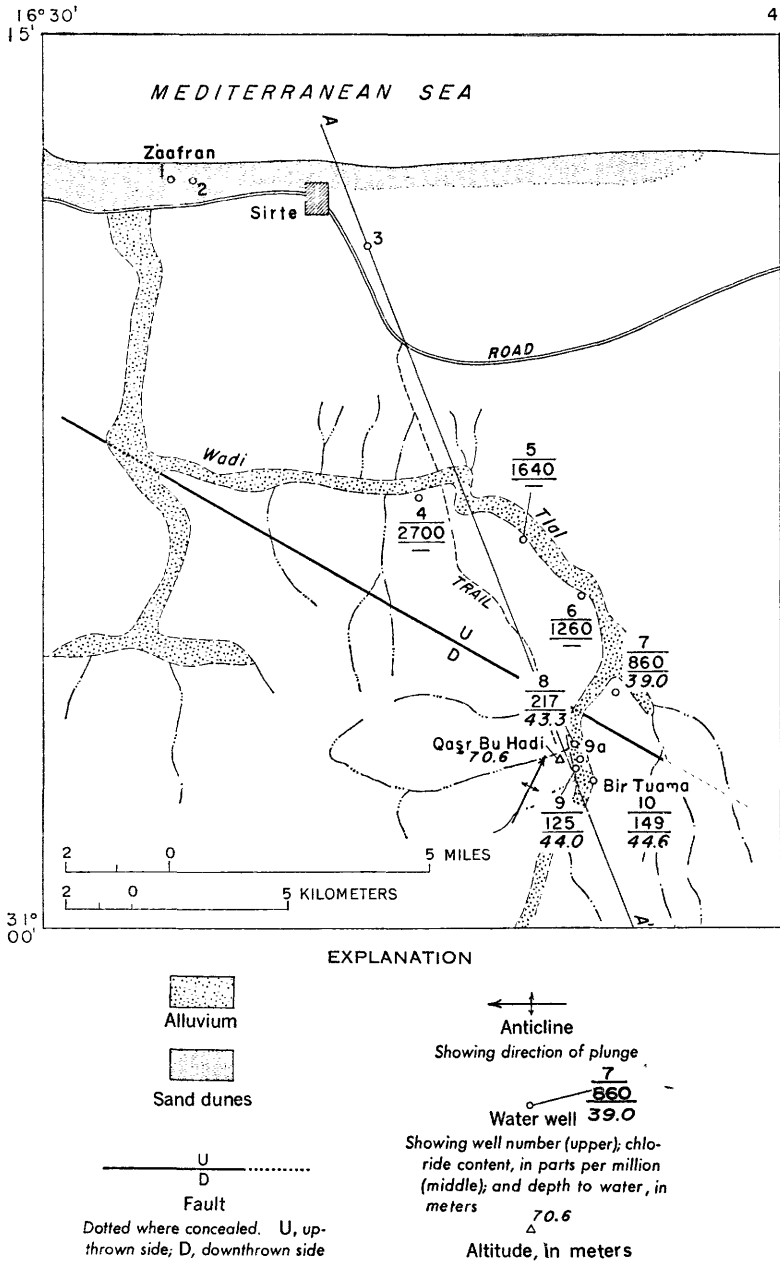

FIGURE 2.—Map of the Sirte area showing location of wells and geologic and hydrologic features.

lying sand dunes, and just inland from these is a series of salt flats or "sebkas" that lie at or near sea level and are subject to flooding during the rainy season. South of the coastal plain the land surface rises gradually in a gently undulating plateau which is about 60–70 m above sea level near Qaşr Bu Hadi. The principal stream in the area is the Wadi Tlal, which rises about 60 km south of the map area and drains north into the sea near Zaafran. This stream and its tributaries, which slightly incise the plateau, are all ephemeral and carry runoff only after heavy or prolonged rain storms.

The climate of the Sirte area includes mild winters and hot dry summers; it is typical of the Mediterranean region. The bulk of the annual rain falls during the fall and winter months—that is, from October to March. Rainfall during the remainder of the year is generally insignificant. The average annual precipitation ranges from about 125 mm (millimeters) at Sirte to about 100 mm at Qaşr Bu Hadi (fig. 1). South from the Sirte area, annual precipitation diminishes rapidly. On the fringe of the Sahara, 100 km south of Qaşr Bu Hadi, the average annual rainfall is probably no more than 25 mm.

GEOLOGY

The Sirte area is underlain by stratified marine and continental sedimentary rocks of Tertiary and Quaternary age. The oldest rocks cropping out in the area are principally thin to massive beds of soft to hard marine limestone which are white to yellow. Soft green, yellow, and gray marl, as well as clay and some sandstone, is intercalated with the limestone. These rocks, of probable Miocene age, lie at or near the surface in the plateau, but they are mantled by younger Quaternary deposits in the coastal plain and in the Wadi Tlal and its tributaries.

The coastal plain is underlain by sand and loosely cemented sandstone of Quaternary age, and along the Mediterrranean shore these deposits are covereed by Recent dunes of unconsolidated sand. As indicated by the log of well 3, the Quaternary deposits reach a thickness of at least 46 m and, elsewhere in the area, possibly more. Quaternary stream deposits of sand and of sand and gravel occur extensively along the channels of the Wadi Tlal and its principal tributaries. In well 7, for example, fine red sand and waterworn gravel and sand were penetrated from the surface to a depth of 26.6 m. The logs of typical wells in the Sirte area are shown in Figure 3.

The Tertiary sedimentary rocks form part of a regional homocline that dips gently toward the north (fig. 4). However, field observations by G. H. Goudarzi (1962, oral communication) indicate that the

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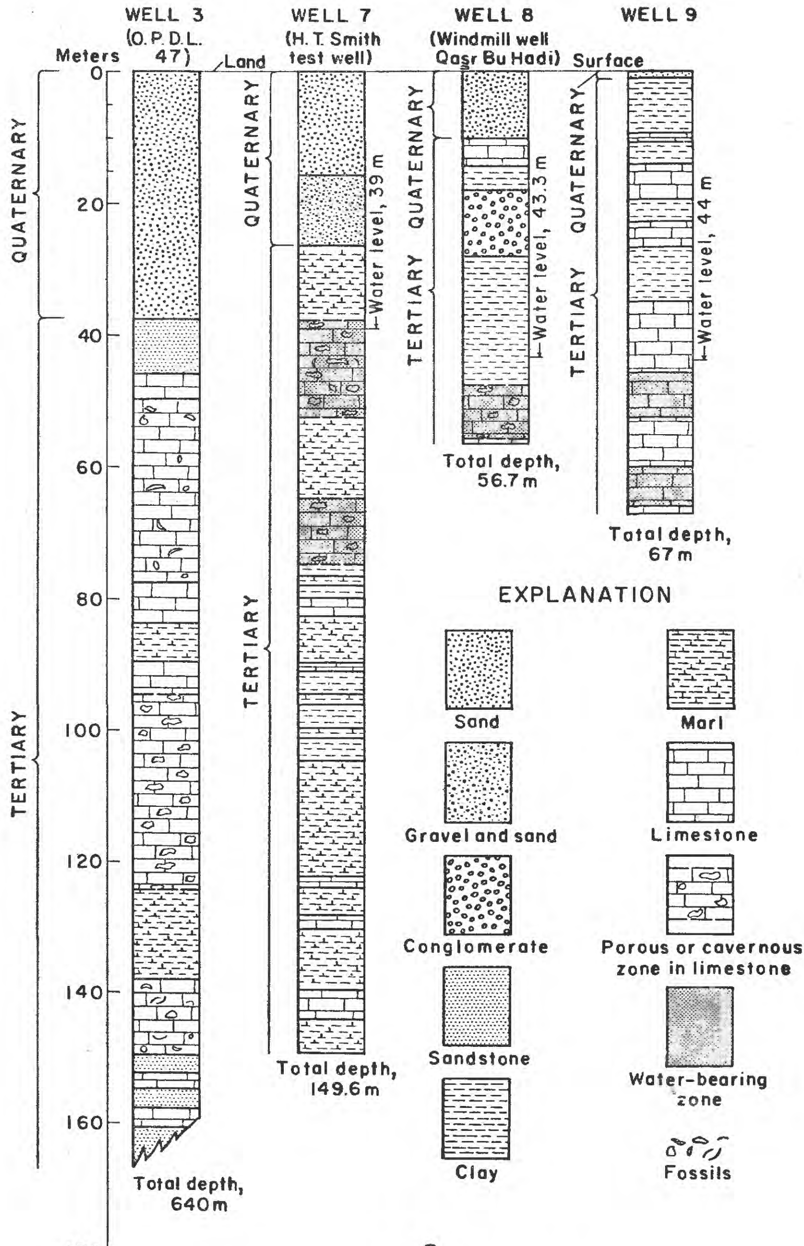

FIGURE 3.—Graphic logs of typical wells in the Sirte area.

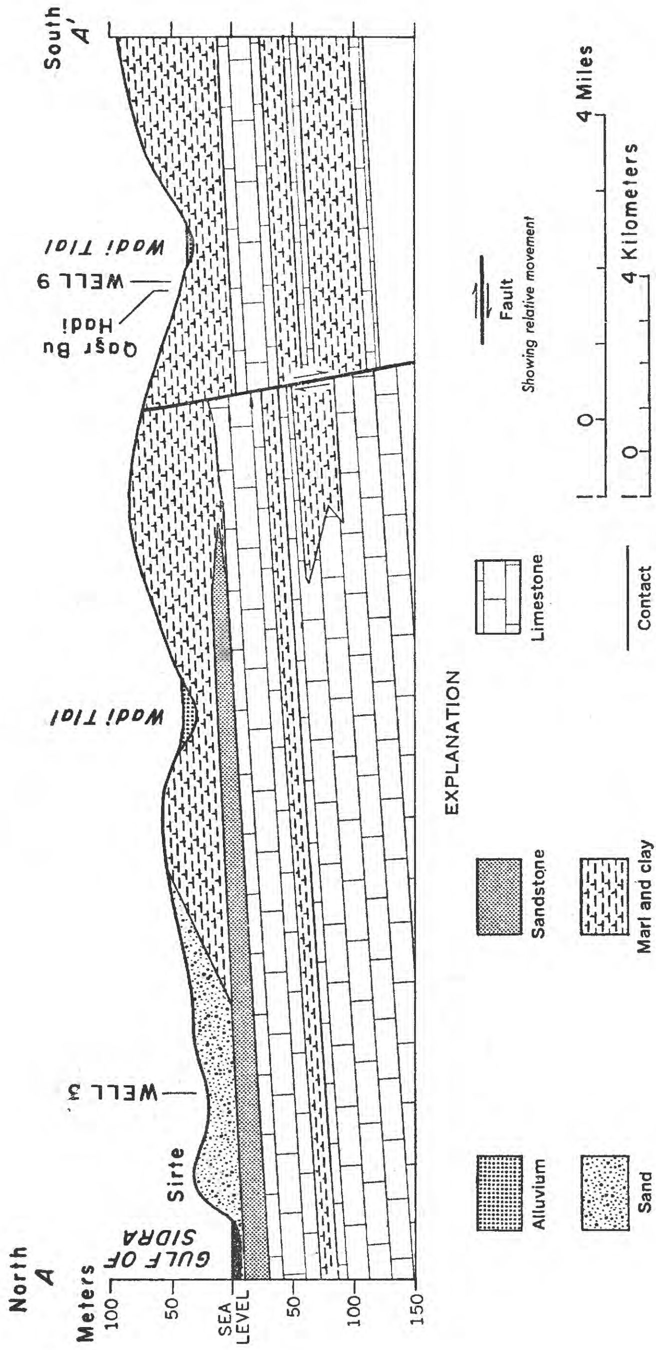

FIGURE 4.—Generalized north-south geologic section *A–A'*, Sirte to Qaṣr Bu Hadi. Line of section shown in figure 2.

Tertiary rocks are apparently traversed by a fault to the northwest of Qaṣr Bu Hadi. Information from oil companies confirms this observation. Accordingly, a fault trending northwest is indicated in figure 2. Also, a small anticlinal flexure trending north-northeast passes through the hill on which is Qaṣr Bu Hadi (fig. 2). As substantiated by the hydraulic behaviour of wells 9 and 9a during pumping tests, the junction of these two structural features may form a trap in which fresh ground water has accumulated. Highly mineralized ground water is reported in wells drilled by oil and geophysical exploration companies at points adjacent to the Qaṣr Bu Hadi area.

GROUND WATER

OCCURRENCE

The principal ground-water reservoir in the Sirte area is in the Tertiary sedimentary rocks and probably extends beneath and beyond the report area (fig. 2). This reservoir is probably recharged by occasional infiltration from sporadic heavy rains and from resulting runoff in ephemeral streams of the area. Water circulates through the reservoir and is stored chiefly in porous or cavernous beds, bedding planes, and fractures in limestone. Typical are permeable and saturated limestone beds penetrated between depths of 38.6 and 50.6 m in well 7, 48 and 56 m in well 8, and 60 and 66.5 m in well 9 (fig. 3). The beds of marl and clay have fairly low permeability and, although they may be saturated, probably yield little water to wells. Sandstone beds may also contain water in some places in the area, but as indicated in the logs of figure 3, such beds do not appear to be common in the Tertiary sequence.

Generally, the first water reached in drilling in the Tertiary rocks is under water-table, or unconfined, conditions; but water at deeper levels is under artesian, or confined, conditions. For example, water in well 8 in limestone between depths of 48 and 56 m rose to 43.3 m below the surface. The depth to water in wells depends on the relative difference between altitudes of the land surface and the water table. Among the wells in the Tertiary rocks shown in figure 2, depth to water ranges from about 35 to 44 m below the land surface. Sufficient data were not available from the present investigation to construct a water-table map of the area; however, it is evident from the known water levels in existing wells that the water table has a northerly slope. These data indicate that the water which moves through the ground-water reservoir in the Tertiary rocks discharges principally in the Gulf of Sidra or in the "sebkas" near the sea.

A local ground-water body is also found in the coastal sand dunes near Zaafran and is probably sustained chiefly by recharge from local rainfall. This water body, which is tapped by wells and galleries at depths of 10 m or less, has been used the past several years for the potable water supply of Sirte. The quality of the water, however, has deteriorated progressively in recent years probably because of salt water encroachment, resulting from overpumping, lack of recharge, or both. The depth to water in wells tapping this water body is generally less than 6 m below the surface.

CHEMICAL QUALITY

As is common in many arid to semiarid regions of the world, the ground water in most of the Sirte area is moderately to highly mineralized. According to available analyses (table 1) and reports from oil-well tests, the water in the Tertiary rocks of the area commonly contains more than 3,000 ppm of dissolved solids; however, water of low dissolved-solids content is found in the wells drilled along or near the Wadi Tlal (fig. 2). From this relation it is inferred that infiltration of fresh water from runoff in the wadi system locally may have diluted or perhaps partly flushed out the prevalent, more highly mineralized water of the Tertiary rocks. Also, for wells drilled in or near the Wadi Tlal, it is inferred that the water found in shallow water-bearing zones may have better chemical quality than that at deeper levels. For example, in well 7 (table 1) the water from limestone between 38.6 and 50.6 m contained 860 ppm of chloride, but in water from limestone between 65.6 and 74.6 m the chloride content increased to 958 ppm. Elsewhere in the area the shallow ground water may also be of better quality than deeper water. In deep well 3 (table 1), for example, water from 368 m contained 1,120 ppm of chloride, but a sample taken from a depth of 515 m contained 4,780 ppm of chloride.

As indicated by chemical data given in table 1 and chloride concentrations shown in figure 2, ground-water salinity gradually increases downgradient in wells drilled along the Wadi Tlal. For example, between wells 10 and 4 (fig. 2) the chloride concentration increases from 149 to 2,700 ppm, respectively, in the shallow ground water of the Tertiary rocks. Perhaps the most pronounced change takes place between wells 8 and 7 where the chloride increases from 217 to 860 ppm (fig. 2) in a lateral distance of about 2 km. A probable fault (fig. 2) passes between these two wells and acts as a partial, but probably not complete, obstruction to the northerly flow of ground water through the Tertiary rocks. Thus, fresh water tends to accumulate to the south of the fault, which probably also impedes the mixing of this water with brackish and salty water to the north.

TABLE 1.—*Chemical analyses of water from wells in the Sirte area, Tripolitania, United Kingdom of Libya*

[Chemical analyses in parts per million. Analyses by Chemical Laboratory. Libyan-American Joint Services]

Well	Depth of water-bearing zone (meters)	Date of collection	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue on evaporation at 180°C.)	Specific conductance (micromhos at 25°C.)	Hardness as $CaCO_3$	pH
1	5.0±	2–57	----	----	----	----	----	----	----	----	512	1,440	----	570	----
1	5.0±	5–57	----	20	857	322	1,520	104	114	346	2,180	4,880	5,970	773	7.4
2	5.0±	2–57	----	----	----	----	----	----	----	----	----	945	----	400	----
2	----	5–57	22	16	86	44	94	12	165	112	153	712	1,050	391	7.6
3	368	7–39	----	----	----	----	----	----	----	----	1,120	----	----	2,600	----
3	515	8–39	35	13	740	306	2,910	108	542	2,260	4,780	11,670	14,900	3,020	----
4	42	8–60	----	----	328	273	1,420	33	183	1,100	2,700	6,150	8,770	1,950	7.2
5	35+	1958	----	----	----	----	----	----	----	----	1,540	----	----	----	----
6	38±	1958	----	----	----	----	----	----	----	----	1,260	----	----	----	----
7	50±	10–58	----	----	----	----	----	----	----	----	860	----	----	----	----
7	75±	10–58	----	----	----	----	----	----	----	----	958	----	----	----	----
8	57	1940	----	23	52	38	182	----	250	73	217	720	1,120	277	7.4
9	67	12–61	26	7	70	3	126	8	284	54	124	541	760	314	7.5
10	47	1957	----	20	63	44	137	12	152	99	149	688	1,150	334	7.5

The quality of the water in the local ground-water body near Zaafran is indicated by the analyses for wells 1 and 2 (table 1). Apparently its quality deteriorated markedly in 1957 (table 1), and the water currently (1962) is reported to have an even higher concentration of dissolved solids.

FRESH-WATER AQUIFER IN THE QASR BU HADI AREA

Two major hydraulic characteristics that affect development of the fresh-water aquifer near Qaşr Bu Hadi, as well as of all aquifers, are the ability of the aquifer to transmit water and the capacity of the aquifer to yield water from storage. These characteristics, which affect the water levels and yields of wells, are called the coefficient of transmissibility, first defined by Theis (Ferris and others, 1962, p. 72–73), and the coefficient of storage (Ferris and others, 1962, p. 74–78), respectively. When these coefficients are known for an aquifer or part of an aquifer, it is possible to forecast approximate water-level trends at different rates of withdrawal from production wells.

To establish the transmissibility and storage coefficients of the fresh-water aquifer near Qaşr Bu Hadi, two test wells were drilled for a controlled pumping test. The first test well (well 9, fig. 2), completed in December 1961, was drilled and cased to a depth of 67 m. Fresh water with 124 ppm of chloride was tapped in porous limestone between depths of 44 and 67 m, and the casing between those depths was perforated. A pump was then installed temporarily and operated for 72 hours at a pumping rate of 9 m^3 per hr.

During this period no change in chemical quality was observed. The second test well (well 9a, fig. 2), 75 m north of well 9, was completed in March 1962 at a depth of 67 m.

For the pumping test, made between April 5–17, 1962, well 9a was equipped with a pump which was operated for 159 hours at a pumpage rate of 18 m³ per hr. Water-stage recorders were installed on well 9 and on well 10, an Arab-dug well known as Bir Tuama about 325 m south of well 9a, to determine the time and rate of drawdown caused by pumping in well 9a. Water levels in well 8, which is about 195 m north of well 9a, were measured using a steel tape during the pumping period and during part of the recovery period. Data obtained from measurements in well 10 were inconclusive because the well penetrates only the top 1.5 m of the aquifer. Also, during the recovery period, water-level measurements in well 8 were disrupted so that the well could be pumped to serve the water requirements of local Bedouin tribesmen. Pertinent hydrologic data from the pumping test are given in table 2.

TABLE 2.—*Hydrologic data from pumping test at well 9a near Qaşr Bu Hadi*

Well	Depth of well (m)	Static water level below land-surface datum (m)	Dynamic water level below land-surface datum (m)	Pumping period (hrs)	Drawdown (m)	Yield (m³ per hr)	Distance from well 9a (m)
9a	67.6	44.0	62.1	159	18.2	18	
9	67.0	43.9	44.5		.57		75
8	56.7	43.3	43.4		.14		196
10	47.0	44.6	44.5		.04		325

After 159 hours, pumping in well 9a was discontinued, and water levels were observed during the recovery period in both wells 9a and 9. The coefficients of transmissibility and storage were computed by the nonequilibrium formulas of Theis and Jacob (Ferris and others, 1962, p. 92–100). The computed coefficient of transmissibility was about 25,000 gpd per ft (U.S. gallons per day per foot) or 13.68 M³ per hr per ft (cubic meters per hour per foot). The coefficient of storage, computed as about 0.00055, suggests that the aquifer may be semiartesian or perhaps a water-table aquifer grading into an artesian aquifer.

During the pumping of well 9a, the outward spread of the cone of depression was rather rapid; however, breaks in the slope of the time-drawdown curves for wells 9 and 9a indicate the presence of two hydraulic boundaries that do not transmit water readily. The first boundary, computed as 250 m westward from well 9a, is attributed to the small anticline on which stands the fort of Qaşr Bu Hadi. The second boundary, computed as about 535 m northward from well 9a, corresponds to the northwesterly trending fault shown in figure 2, the possible attitude of the fault is indicated in figure 4. Apparently, this fault partly limits the flow from the fresh-water aquifer on the south to the brackish-water transition zone on the north. Therefore, prolonged pumping from a well or wells near the fault could probably reverse the hydraulic gradient and induce flow of brackish water from the north. To minimize this possibility, production wells in the fresh-water aquifer should be drilled as far south of the fault as practical.

To forecast approximate water-level trends at prescribed pumping rates in production wells that may be constructed in the fresh-water aquifer, the pumping-test data were evaluated taking into account the limitations of accepted formulas and also compensating for the two hydraulic boundaries. Having well 9a as the focal point, figure 5 shows the computed decline of water level (drawdown) that would occur at prescribed rates of pumping. For example, at a pumping rate of 13.5 m^3 per hr, the pumping water level would decline about 1.7 m at the end of 1,000 days of pumping. As shown in figure 5, the decline of water level increases at comparable rates in the first three curves but diverges sharply in the lowest curve. These predictions indicate that a pumping rate of 18 m^3 per hr is beyond the capacity of the fresh-water aquifer. In fact, pumping from well 9a at 18 m^3 per hr for 10 years would result in a pumping water level of 67 m, which is the bottom of the well. For this reason, it is believed that the pumping

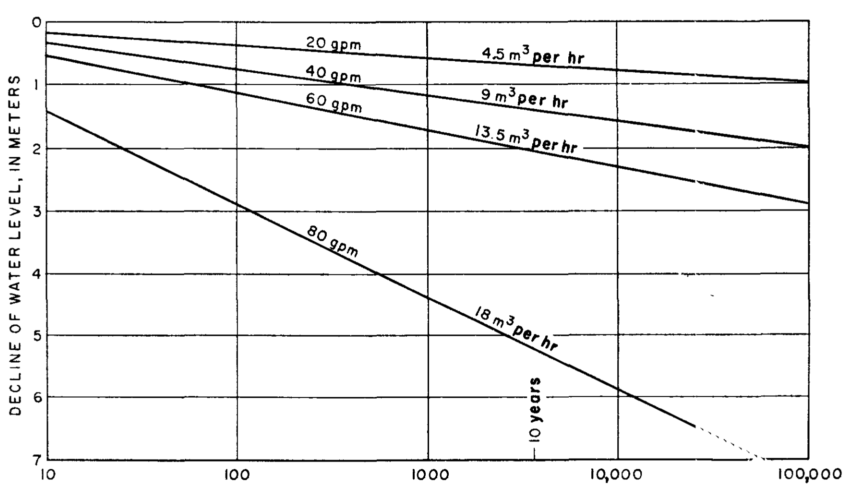

FIGURE 5.—Predicted decline of water level (drawdown) in fresh-water aquifer at prescribed pumping rates.

rate from the fresh-water aquifer in the Qaṣr Bu Hadi area should not exceed 13.5 m³ per hr.

The predicted declines of water level (drawdown) in the fresh-water aquifer at prescribed distances after pumping at prescribed rates for 10 years are shown in figure 6. A pumping rate of 13.5 m³

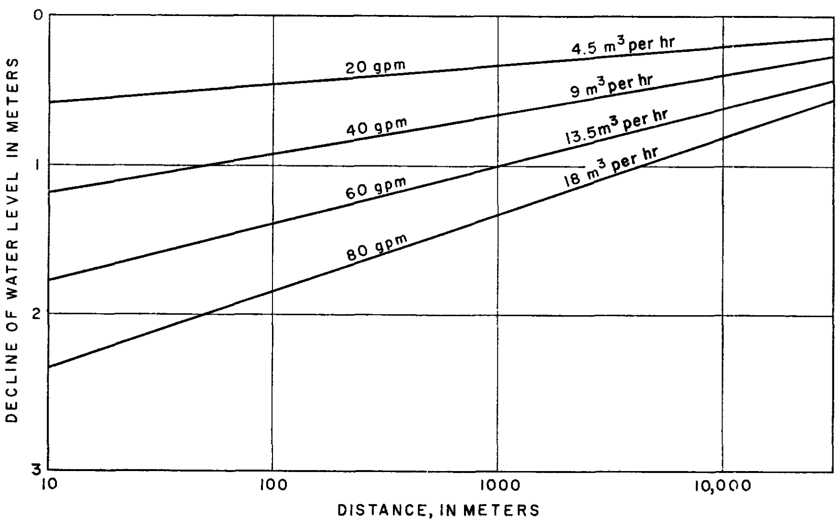

FIGURE 6.—Predicted decline of water level drawdown) in fresh-water aquifer at prescribed distances after pumping 10 years at prescribed rates.

per hr for 10 years would result in a decline of water level of 0.63 m at a distance of about 3 km. This predicted decline indicates that new production wells preferably should be at least 3 km south of well 9a. Care should be taken in drilling and completing such wells, as the shallow aquifer probably contains water of better quality than that of the deeper aquifers. If wells are drilled too deep, contamination, at least locally, of the fresh-water aquifer may result.

CONCLUSIONS

The present study and previous work by other investigators have established the presence of a moderately productive fresh-water aquifer in the Qaṣr Bu Hadi area. This aquifer, if properly developed and carefully utilized, can probably sustain most, if not all, of the potable water requirements of Sirte for some years to come. To help assure proper development, the following measures are suggested.

1. The predicted decline of water level after 10 years of pumping at 13.5 m³ per hr (fig. 6) indicates that at 3 km from well 9a, the decline in water level would be only about 0.62 m. Thus, new produc-

tion wells should be drilled at least 3 km south of present wells 9 and 9a. This measure would minimize the possibility of drawing brackish or salty water from north of the fault into the fresh-water aquifer.

2. The production wells should not be pumped at rates exceeding 13.5 m^3 per hr. At greater rates, the water level in the wells would decline to the point where contamination of the fresh-water aquifer would follow.

3. Two or more production wells may be desirable to give standby capacity for emergency, to minimize local drawdown in the aquifer, and to obtain the same amount of water in shorter pumping periods. The effects upon the aquifer would be similar if the total withdrawal in a 24-hour period were the same.

4. The present test wells 9 and 9a should not be used for production except in emergency.

5. A well should be available for periodic measurement of the effects of pumping on the aquifer. Either well 9 or 9a could be used for this purpose.

6. When the new production wells are drilled, there should be close supervision of the drilling to determine whether the character of the aquifer is the same as that at the present test wells 9 and 9a. The production wells should be tested as they are drilled to check the yield and quality of the water before construction of hydraulic works is begun.

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