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REPORT
TO
UNITED STATES DEPARTMENT OF STATE
AGENCY FOR INTERNATIONAL DEVELOPMENT
ON
FEASIBILITY STUDY
OF
WATER SUPPLY AND SEWERAGE FACILITIES
FOR
TAIZ, YEMEN ARAB REPUBLIC

VOLUME II

WATER RESOURCES EVALUATION

CONTRACT NO. AID/ASIA-C-1081

[1975]

JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.

PASADENA • IRVINE • LA JOLLA • RANCHO CALIFORNIA • UPLAND • WALNUT CREEK
BOISE • FORT LAUDERDALE • LAS VEGAS • WASHINGTON

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CHAPTER 1

CHAPTER 1

INTRODUCTION

Throughout the duration of the water resources investigation for the feasibility of water supply and sewerage facilities, city of Taiz, Yemen Arab Republic, a significantly large quantity of background and new basic data were collected. Because of the importance of such information and the interpretations derived therefrom to this, as well as future projects, it was considered appropriate to provide a separate volume (Volume II) titled Water Resources Evaluation. This volume, therefore, has been prepared to include all available historic and project related basic data, test drilling program results, findings, summaries, conclusions, and recommendations developed in the course of the subject feasibility study.

The scope of work to be accomplished for the water resources evaluation is included within Volume 1, Chapter 1, of this project document. Basically the water resources evaluation was performed in the vicinity of Taiz to determine the location of new water sources, within reasonable distances of the city. Such water must be of potable quality and in developable quantities to satisfy future water requirements of municipal growth. To obtain these objectives, an approach to investigate work was formulated and accomplished which included the following components:

1. Preliminary office study of existing information
2. Preparation of suitable project base maps
3. Geologic and hydrologic field studies
4. Formulation of a drilling and testing program
5. Implementation of the drilling and testing program
6. Analyses of historic and new project information

7. Preparation of preliminary project findings

8. Preparation of final project results, conclusions and recommendations

Because of time and budget limitations, as well as other practical considerations, several of these components were accomplished simultaneously or with significant activity overlap. Descriptions of the listed components of investigative work are presented in the following text.

PRELIMINARY OFFICE STUDY OF EXISTING INFORMATION

Subsequent to the selection of James M. Montgomery, Consulting Engineers, Inc. as the consultant for the feasibility study of water supply and sewerage facilities for the city of Taiz, YAR, the project engineer and chief hydrogeologist assigned to the study visited the project site in November - December 1973. This field examination was performed in order to determine availability of information, working conditions, local equipment and personnel availability, assistance to be provided by local agencies and USAID, and the general technical conditions to be met in the course of the project program.

Upon the return of the two technicians to the consultant's offices in Pasadena, California, the scope of work, funding required, and approach to project implementation were defined in conjunction with AID-Washington. On the basis of the defined project requirements, a contract document was prepared and the appropriate signatures obtained on April 17, 1974. The preliminary office study of existing information regarding water resources was initiated essentially immediately after contract approval, and was continued by the water resources team throughout the initial weeks of project activity in Taiz.

Preliminary office studies were directed toward gathering all available historic data regarding the existing water sources for the Kennedy Memorial Water System (KMWS), regional hydrology, regional geologic mapping, existing reports concerning water sources in the vicinity, and pertinent information available from the files of local and international agencies. This preliminary investigation resulted in an indication of the type and quantity of new information that would be required to successfully complete the water resources evaluation portion of the feasibility study project.

Pertinent information obtained during the preliminary office studies is included with that collected during the course of this project in tables and text of later chapters of this volume.

PREPARATION OF SUITABLE PROJECT BASE MAPS

Early in project planning it was determined that available maps of Taiz and the surrounding region were inadequate or too dated to be of use in water resources evaluation and/or water system planning. Fortunately, the Royal Air Force of the United Kingdom of Great Britain in cooperation with the Yemen Arab Republic had conducted an air photo survey of the Taiz region in 1973. Negatives of this air photo survey were made available by the Government of the Yemen Arab Republic for project use, and subsequently air photo coverage and topographic maps were prepared which proved to be of great value throughout the feasibility study program.

All photo processing and map preparation were completed by Aero Service Corporation utilizing base datum established by the United States Geological Survey on the 1:10,000 scale topographic map, Taiz Yemen, 1961. Representatives of James M. Montgomery, Consulting Engineers, Inc. (JMM) selected the coverage and scales of all photos and maps prepared, a listing of which is as follows:

- Regional Area covering 30 kilometers E. W. by 48 kilometers N. S. for a total area coverage of 1440 square kilometers.

    1. Topographic Mapping at a scale of 1:10,000, with 5 and 10 meter interval contours.

    2. Photographic four (4) times enlargements on double-weight, semi-matte paper of existing R. A. F. aerial photography from Sortie No. 855 exposure Nos. 24, 22, 37 and 35.

    3. Semi-controlled photographic mosaic at a scale of 1:30,000 of the Regional Area (1440 square kilometers).

- Metropolitan Area covering the city of Taiz and encompassing an area of 10 square kilometers, consisting of planimetric topographic map sheets at a scale of 1:2,000 with two (2) meter contour intervals.

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- Later in the project the 1:10,000 scale topographic mapping was expanded to include a small area west of Taiz in the Dh'bab basin sector. Additional photo coverage included:

  1. Two sets of contact prints of exposures 121 and 122

  2. One duplicate negative of exposure 121

  3. One four diameter enlargement of exposure 121

The individual air photos, air photo mosiacs and topographic maps were utilized during the water resources evaluation program in initial office investigations, field exploration, and preparation of hydrogeological maps. Maps included in Volume II are presented on the topographic base prepared for this project.

GEOLOGIC AND HYDROLOGIC FIELD STUDIES

Immediately upon the arrival of the project hydrogeologist in Taiz, reconnaissance surveys of the vicinity to assess the geologic features of the region with respect to the occurrence of potential water resources were commenced. Existing water source areas were examined and the conditions of ground water occurrence, movement, and production reviewed. Hydrologic elements such as climate, precipitation, surface water flows, and stream valley characteristics were analyzed on the basis of historic data and field observations. In an effort to facilitate progress of the project test drilling program, several areas in the direct vicinity of Taiz were surveyed during the initial days of field explorations and a number of test points were located. Locations of test areas more remote and inaccessible from Taiz were surveyed as project staging progressed.

FORMULATION OF DRILLING AND TESTING PROGRAM

From the results of hydrogeologic reconnaissance and examinations of air photos, a test drilling program was formulated to evaluate potential ground water resources within a reasonable distance of Taiz and in concert with equipment, machines and manpower committed to the project. Within two weeks of the arrival of the project hydrogeologist an initial approach to testing had been determined and test drilling had commenced. As hydrogeologic surveys continued, additional test areas were incorporated into the testing program. During the week of August 4, 1974, the proposed test drilling program, which included 18

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test areas, was submitted to the General Director T.C.O/KMWS Taiz and USAID/Yemen. In mid-September 1974, an additional test area (XIX) was included in the program as a result of further field observations. Appendix E includes a copy of the original recommended test program.

IMPLEMENTATION OF THE TEST DRILLING PROGRAM

Test drilling and other related testing of potential areas of new water sources of the city of Taiz were essentially continuous from the outset of project field activities until the week prior to the departure of the field team from the Y.A.R. Throughout the testing program 20 test and piezometer bores were completed. Three cable tool drilling rigs and one Ingersoll-Rand T-4 rotary drilling rigs were employed during the program. Twenty-five pumping tests of various types were performed on exploration test wells and 10 existing system wells were tested. Lithologic logs and aquifer test data for project test holes are shown in Appendices B and D, respectively.

Although 19 test areas were anticipated in the total test drilling program, drilling was performed in only 14 areas. The five test areas eliminated from the program were found to contain water of poor quality or to be located in areas where further exploration would be redundant or nonproductive. Later, during the progress of test drilling, an additional seven areas were eliminated as potential new water sources on bases of test information obtained. Table 1-1 lists the reasons twelve of the 19 project test areas were abandoned as water sources feasible for development for city use.

In addition to drilling and pump testing performed during this stage of the program, approximately 65 water samples from surface and well sources were collected and analyzed. These analyses are included in Appendix C. Water level measurements were also obtained from all exploration bores and existing wells periodically throughout the project duration.

ANALYSES OF HISTORIC AND NEW PROJECT INFORMATION

All new data collected in the course of the water resources evaluation was entered on tables and compared with data obtained in the past. Results of field observations, test drilling, pump testing, water quality analyses and other pertinent information collected in each test area were analyzed to determine the availability of water resources in each test area. The preliminary findings from these analyses were presented to project engineers for integration into the related water and sewerage con-

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TABLE 1-1

TEST AREAS EXCLUDED AS POTENTIAL NEW WATER SOURCES FOR TAIZ

Test Area Designation	Reason for Exclusion
I	Poor water quality, 2640 mg/l TDS. Poor production potential.
II	Poor water quality, 2000 mg/l TDS. Very poor production potential.
III	Very poor water quality, 5450 mg/l TDS. Very poor production potential.
V	Very poor water quality, 8490 mg/l TDS. Poor production potential.
VI	Redundant, in the immediate vicinity of Taiz.
VII	Redundant, in the immediate vicinity of Taiz.
IX	Poor water quality, 2400 mg/l TDS. Poor production potential.
XI	Poor water quality, 3500 mg/l TDS.
XII	Poor water quality, 1570 mg/l TDS. Poor production potential.
XIII	Poor water quality, 1870 mg/l TDS. Poor production potential.
XIV	Poor water quality, 2040 mg/l TDS.
XV	Redundant, within drainage area downstream from Hougala Basin.

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siderations of the total project. All basic data collected and the analyses resulting therefrom are included in text tables, figures, and appendices within this volume.

PREPARATION OF PRELIMINARY PROJECT FINDINGS

In mid-December 1974, a field document was prepared and presented in Taiz which reported the preliminary findings of the water resources evaluation. Included in that report were descriptions of potential new water source areas for the city of Taiz and quantitative and qualitative characteristics of these sources. The test areas from which new water for the city can be derived were designated as follows:

Test Area Designation	Local Name
IV	Wadi Salah Basin
VIII	Wadi Amad Basin
X	Dh'bab Basin
XVI	Mikbaba Basin
XVII-XVIII	El Hiama Basin
XIX	Upper Wadi Houban Basin

From the information presented in the preliminary report, project personnel concerned with transmission and distribution aspects of the proposed system were able to prepare preliminary facilities requirements and increments of long-term water supply staging.

PREPARATION OF FINAL PROJECT RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Copies of all data and information obtained during field operations were returned to JMM Pasadena for further analysis, checking and collation in December, 1974. Further, preliminary designs of production and transmission facilities as well as cost estimates were determined. This volume contains all finalized project results, conclusions and recommendations concerning the water resources evaluation. Volumes I and III also include a number of water resources considerations relating to supply, system, construction and operations.

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CHAPTER 2

CHAPTER 2

SUMMARY COMMENTS

Throughout approximately seven months in the YAR, primarily in the vicinity of Taiz, and the subsequent several months expended in the preparation of this report, quite extensive quantities of data and information have been evaluated and reported. This summary chapter is included in order that those aspects considered to be the most salient to the project water resources evaluation can be clearly defined. More detailed and substantiating information regarding each item presented is included in pertaining chapters of this volume.

LOCATION AND GEOGRAPHIC SETTING

The city of Taiz is located in the Yemen Arab Republic on the Arabian Peninsula approximately 100 kilometers east of the Red Sea (see Figure 2-1). The area evaluated in the course of this study encompasses a region extending 10 kilometers east and west, three kilometers south, and twenty-five kilometers north of Taiz. Elevations in this mountainous study area range from about 1,000 to 3,500 meters, with the center of Taiz lying at near 1,300 meters above mean sea level.

WEATHER AND PRECIPITATION

The climate of the Taiz region is characterized by a dry season extending from November through March and a relatively wet season from April through October. For the period of record available the average annual rainfall is 599 millimeters (23.6 inches). During the dry period of the year daily temperatures may exceed 30 C for several continuing weeks.

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Summary Comments

STREAM SYSTEMS

All surface streams in the vicinity of Taiz may be included in one of four general drainage systems. Along each of these stream systems lie alluvium filled valleys through which perennial or intermittent streams flow. Such alluviated valleys form the potential new ground water source areas for future supplies for Taiz. Drainage areas of the four major stream systems are as follows:

In and south of Taiz	92 km^2
Southeast and northeast of Taiz	86 km^2
Dh'bab	145 km^2
El Hiama	461 km^2

There is no known surface stream flow data available in the Taiz region, consequently all hydrologic information utilized was extrapolated from an area having well-developed and similar hydrologic features.

GEOLOGIC FEATURES

Taiz lies along the east-west trending faulted escarpment of the Jabel Sabir massif at an elevation of approximately 1,300 meters above sea level. The Jabel Sabir itself is comprised predominantly of granitic type rocks with minor occurrences of a low grade metamorphic complex. Greater Taiz is founded largely upon an incised alluvial fan which parallels and spreads northward from the Jabel Sabir escarpment.

To the north of Taiz is a broad vista of moderate to rugged mountainous terrain. Rocks forming this complexly disrupted region are primarily of fine textured igneous types, through which narrow alluvium filled valleys trend.

Faults, regional structural disruptions, and geomorphically youthful land forms are evidence of the Quaternary tectonic activity which has disturbed this portion of the Arabian Peninsula.

The narrow alluvium-filled valleys most frequently follow along lines of structural weakness and are filled with detritus eroded from the older rocks in the vicinity. It is within these alluviated valleys that ground water resources are present which can be developed to supply the needs of the city of Taiz.

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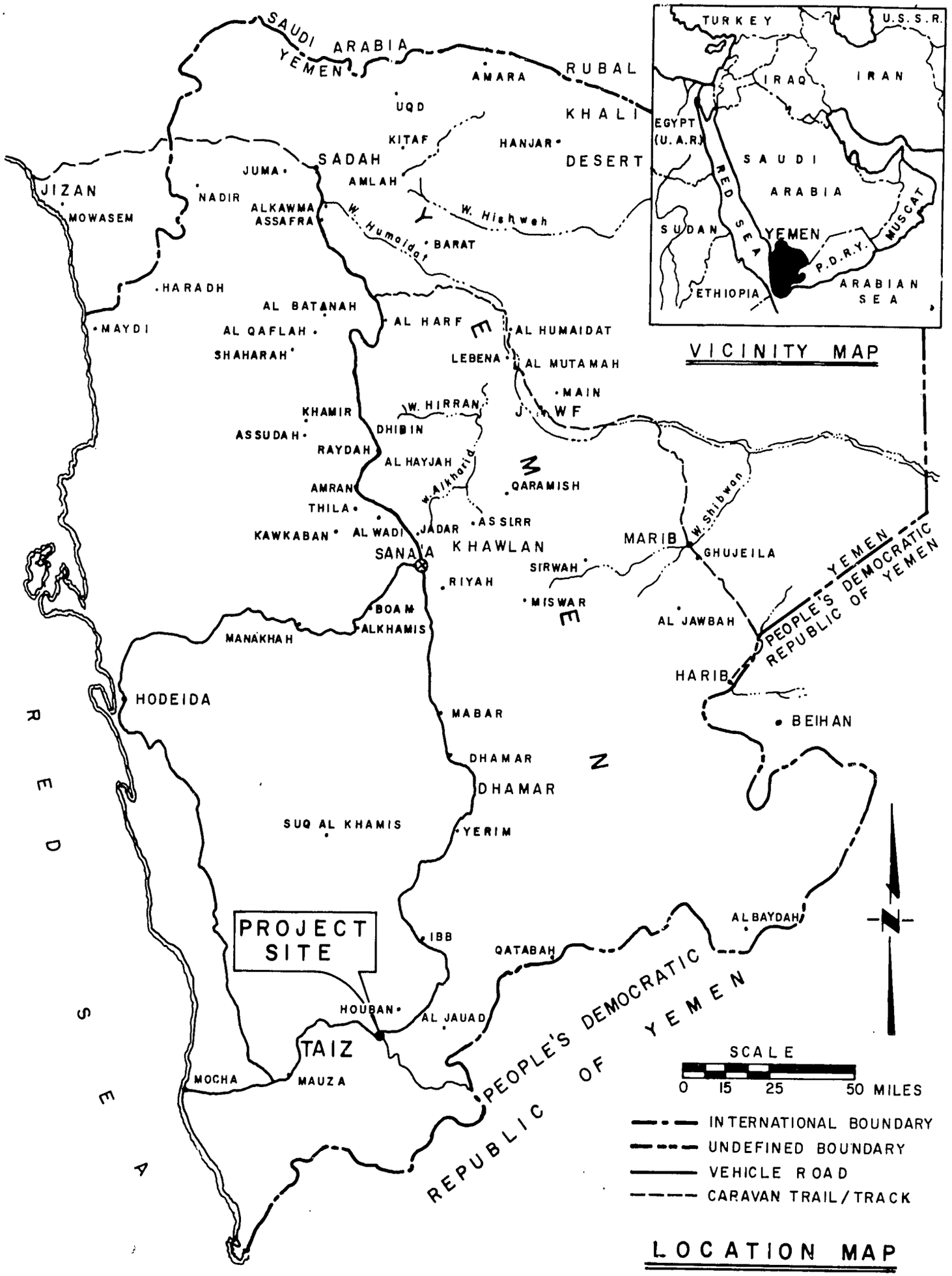

LOCATION MAP

FIGURE 2-1

JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.

Summary Comments

Geologic maps within this volume delineate the types and locations of rock types encountered in the course of field investigation. Geologic cross-sections are presented for the most significant ground water basins located.

EXISTING PRODUCTION AREAS

Current water production to the city of Taiz is derived from Hougfa-Houban and Hougala well fields. These production areas were constructed for the most part in 1963 and 1968, respectively, and presently yield approximately 1.2 million gallons of water per day to the Taiz Municipal System.

The quality of waters from the Hougfa-Houban and Hougala well fields generally degraded from approximately 1,000 mg/l to 2,400 mg/l TDS during the period 1964 through 1974. Within the same time interval nitrate ion content has risen at some well sources to 270 mg/l.

Pumping equipment in the Houban well field is in a state of rapid deterioration. Hougala well field equipment, exclusive of piping transmission facilities, appears to be in fair condition and, with proper maintenance, should continue operational for several more years.

Future additional city water supply demands, as well as deteriorating water quality in the present well fields, require that new water sources be located to satisfy the projected system needs of Taiz.

NEW POTENTIAL PRODUCTION AREAS

During the water resources evaluation and test drilling portion of the Taiz Water Supply and Sewerage Project, six new potential ground water source areas were located for the city of Taiz. These areas are designated as follows:

- Wadi Salah Basin
- Wadi Amed Basin
- Dh'bab Basin
- Mikbaba Basin
- El Hiama Basin
- Upper Wadi Houban Basin

In addition to these areas it is planned that production from Houban and Hougala basins, current sources of city water, will be utilized again at a later date (approximately 1991) for a portion of the Taiz water supply.

Summary Comments

Of the new areas explored, the El Hiama and Dh'bab basins offer the greatest resource potentials from aspects of both quantity and quality. The other four areas are considered of a magnitude suitable for augmenting the larger sources from Dh'bab or El Hiama, or providing water supplies to localized sectors within the new system.

Information developed regarding each of the newly determined ground water source areas is presented in Chapter 8 of this volume.

POTENTIAL NEW WATER RESOURCES

Other than the well fields at Houban and Hougala, which currently produce to the Taiz water system, ground water is essentially undeveloped throughout the region evaluated. Ground water resources, however, do and have historically resided within geologic environments of the Arabian Peninsula. This evaluation examined 19 potential water source areas and it was determined that six alluviated stream valleys were feasible locations for development of new municipal water supplies. Each of these six new water source areas was evaluated to determine the hydrogeologic conditions prevailing which would determine the perennial water yields available to the Taiz water system. In the absence of historic hydrologic data, field observations and hydrologic parameters developed in similar known areas were applied to the Taiz regional condition.

Assumptions employed in the basin analyses and the methods utilized in determining hydrogeologic values are described in Chapter 8 of this report. A summary of the water resources analyses for the six new source areas is indicated on Table 8-1. Potential average daily basin yields based on the analyses of average annual yields are as follows:

- Wadi Salah Basin — 0.32 mgd / 1210 cu m/d
- Wadi Amed Basin — 0.12 mgd / 454 cu m/d
- Dh'bab Basin — 1.8 mgd / 6808 cu m/d
- Mikbaba Basin — 1.1 mgd / 4160 cu m/d
- El Hiama Basin — 4.2 mgd / 15880 cu m/d
- Upper Wadi Houban Basin — 0.33 mgd / 1248 cu m/d

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Summary Comments

The values indicated assume that cultivation within the areas of ground water withdrawal will be essentially undisturbed and in some locations crop growing conditions will be improved.

Prior to the commencement of production water well drilling, additional test drilling should be performed in each new source area to better define well locations and designs. Test drilling may be conducted using either percussion or rotary drilling equipment, although the latter is recommended.

Production drilling will require rotary drilling equipment with highly qualified supervisory and construction personnel. Only rotary drilled gravel envelope type wells are recommended for Taiz system production wells.

Throughout the operational years of the KMWS, data collection in and regarding the water source areas for the utility has been largely ignored. It is recommended that, commencing immediately, a systematic approach to resources data collection, storage, and analysis be formulated and instituted. Such a program will prove extremely valuable to any future evaluations conducted in the vicinity of Taiz. It should also be noted that the absence of such a data program may result in undesirable and expensive effects on the proposed new water system.

CHAPTER 3

CHAPTER 3

HISTORIC WATER RESOURCES DEVELOPMENT VICINITY OF TAIZ

The city of Taiz, one of the ancient cities of the world, was founded on its original mountainous redoubt for the protection of the population against the historic invaders of the Arabian Penninsula. Springs issuing from the abrupt slopes of the Jabel Sabir massif south of the city insured water supplies to residents during periods of prolonged siege as well as peaceful intervals of history. Through time, many of the spring water sources became the private supplies of families and other social units of power; thereby an elemental city water system evolved. This method of city supply probably persisted for centuries with the only substantial changes being in the power of control over the sources. In addition to the springs, people in the vicinity also utilized a few dug wells and the sparse seasonal surface flows to augment water needs. Until 1960 the population of approximately 20,000 within the city existed on an estimated water consumption of about two gallons per day per capita.

During the summer of 1961, construction of an emergency water supply system was begun by I.C.A., the forerunner of USAID, to cope with a severe drought being experienced by the city. The emergency system increased the available per capita water supply to about five gallons per day. This initial system consisted largely of two storage tanks, four water wells, piping and a few public hydrants.

From 1962 through September 1965, studies, design, training and eventually construction activities, performed under USAID direction, resulted in a one million gallon per day water system for the city; the first such facility in the Yemen Arab Republic. Water wells, from which this new city source was derived, were located in the Wadi Houban, approximately 2.5 kilometers north of the city center. Since 1965 two additional well fields have been completed at Hougala and Hougfa; the latter of which is considered an extension of the original Houban well field. The earlier spring water supply also continues to serve localized sectors of the city through private gravity piping systems.

Historic Water Resources Development
Vicinity of Taiz

The current feasibility study was performed to consider increased capacity and system improvements to meet water needs of the city that have resulted from a large and rapid population growth far in excess of that anticipated when the current system was planned. Immigration from the People's Republic of Yemen and other areas within the Yemen Arab Republic itself was not predictable at the time of original construction.

Because of a projected city population growth to 305,400 by the year 1995, new dependable sources of water to supply the city system will be required. Volume I indicates that by 1975 approximately 14.4 million cubic meters per year or 10.4 mgd will be required.

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CHAPTER 4

CHAPTER 4

HYDROLOGIC CONDITIONS - VICINITY OF TAIZ

The Taiz project area lies within semiarid mountainous terrain on the Arabian Peninsula approximately 100 kilometers east of the Red Sea. Throughout the long history of this region, water has been an important factor in the survival and prosperity of the country of Yemen, which has frequently been termed "the breadbasket of Arabia". In ancient history Yemen was, even then, referred to as "Arabia Felix" because of its relatively pleasant climate and the lush agricultural sectors cultivated by the early inhabitants of the region. Characteristics of the regional climate are described in more detail in Volume I of this project report.

Although the population of the region has historically been largely dependent on rainfall and natural stream flows to maintain crops and provide living requirements, some of the most ancient examples of water control structures in the world have been discovered in the country. One such structure is located at Mareb, where a dam nearly one kilometer long and 30 meters high, with a complex irrigation works, was built. The date of construction for this monumental example of water engineering was about 1000 B.C.

Throughout Yemen, numerous irrigation control channels and ditches presently direct water through cultivated valleys and communities much in the manner of the ancients. The ages of these rudimentary irrigation systems cannot be determined, but some are certainly several hundred years old. Through the centuries, water supplies in Yemen have been controlled on very localized bases, consequently little information regarding natural water regimes has been recorded. Basic hydrologic data, therefore, is sparse to nonexistent.

In the area of evaluation, the city of Taiz has a fair rainfall record dating back to 1953, however no record of the quantity or quality of stream flows is available. During the course of project field operations, observations of stream flow conditions were made and several surface water quality analyses were conducted (see Appendix C). Such information was later compared to a location hydrologically similar in order that a resource analysis could be made for each potential new water

source within the project area. Because of the problems inherent in such a comparative analysis, most quantitative determinations can only be considered as relative magnitudes of actual values.

At the outset of the project the feasibility of developing surface water sources was considered. However, analyses of climate, runoff characteristics, watershed areas, and topography demonstrated a restricted potential for surface supply capture and storage. The location and development of ground water resources was, therefore, considered the most feasible approach to satisfying the future water needs of the city of Taiz.

The following text describes the hydrologic data, field observations, and approaches to analyses used in this report.

PRECIPITATION - VICINITY OF TAIZ

Precipitation in the Taiz vicinity occurs predominantly as rainfall, although severe hail storms are not uncommon to the area. The local climate is characterized by one wet season and one dry season which are as follows:

- Rainfall season - April through October
- Dry season - November through March

Known historic precipitation records in the region of interest are exclusively from the city of Taiz; the recording stations of which have been changed within the city on several occasions throughout the period of record. Currently, rainfall data is obtained daily at an unofficial station located at the offices of the Kennedy Memorial Water System.

Rainstorms entering the Taiz region are generally of the convectional or shallow front types, thus intensities and durations of precipitation vary geographically for each storm.

For purposes of this report, the records at Taiz are considered as reasonably valid for the region. It is also assumed that geographic and elevation changes modify precipitation patterns within the area of evaluation. Table 4-1 lists available rainfall data collected since 1953 and the long-term average values derived therefrom. Figure 4-1 depicts average monthly precipitation for the period of record.

Although average annual rainfall has been determined to be 23.6 inches (599 millimeters) and a seasonal weather pattern exists, periods of prolonged drought are known to have occurred. In contrast, are reported periods of torrential storms which result in heavy flooding of large

TABLE 4-1

RAINFALL AT THE CITY OF TAIZ, YEMEN ARAB REPUBLIC
(Inches)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1953	0.1	0.3	0.7	3.5	4.6	3.4	2.6	1.9	3.3	3.3	0.2	0.5	24.4
1945	0.02	0.03	0.44	0	3.75	0.93	1.77	2.43	1.31	3.75	0.71	1.39	16.53
1950	0.03	0.79	0.46	5.12	4.96	5.91	3.81	2.80	4.02	4.33	0.01	0.11	32.35
1960	-	-	-	-	2.5	2.5	2.4	2.3	4.0	1.9	0.4	0.3	-
1961	0	0.3	0.9	2.7	1.8	3.4	0.4	1.6	3.55	0.60	1.45	0.90	17.60
1962	0	0	1.68	0.74	5.36	3.13	2.75	3.00	3.20	0.74	0.65	0	21.25
1963	0.60	0.02	0.33	5.46	4.32	3.71	3.53	2.90	5.40	1.70	0.95	0.30	29.2
1964	0	0	0	3.19	6.25	4.24	1.99	3.53	2.82	3.54	1.45	1.06	28.07
1965	0.04	0.11	1.16	4.30	1.55	2.77	1.71	3.20	3.57	0.22	2.12	0	20.75
1966	0	3.45	0.30	3.88	4.56	4.01	5.30	5.57	2.47	3.07	0.23	0	33.61
1967	0	0	2.0	2.2	2.5	2.2	1.5	2.0	4.6	2.3	0.6	0.6	20.5
1968	0	1.5	0.5	1.5	0.7	3.8	2.3	4.9	2.7	2.3	0.4	0	20.6
1969	0	0.2	0.4	2.5	3.7	1.8	2.2	3.8	1.7	0.9	1.2	0	18.4
1973	-	-	-	-	-	-	-	-	-	-	1.04	0.41	-
1974	0	1.31	0.46	0.27	3.40	5.42	2.28	5.31	2.65	1.80	0.09		22.99
Monthly Total	0.79	8.01	9.33	35.36	49.95	47.22	34.54	45.24	45.29	30.45	11.50	5.57	306.25
Monthly Average in	0.06	0.61	0.71	2.72	3.57	3.37	2.47	3.23	3.24	2.18	0.77	0.39	
Monthly Average mm	1.52	15.49	18.03	69.08	90.67	85.59	62.74	82.04	82.29	55.37	19.56	9.90	

Twelve full years record $\frac{23.6}{599.4}$ in average / mm average

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surface areas. Both of the preceding conditions attest to the unreliable nature of the annual water crop.

STREAM DRAINAGE SYSTEMS - VICINITY OF TAIZ

GENERAL

Stream drainage in the regional vicinity of Taiz may be roughly divided into four general systems: 1) in and south of Taiz along the north front of the Jabel Sabir; 2) north and east of Taiz in the Wadi Houban - Wadi Salah system; 3) the western Jabel Sabir - Dh'bab system; and 4) the El Hiama system northwest of the city. Table 4-2 lists the areas of the designated units of each drainage system.

SYSTEM IN AND SOUTH OF TAIZ

Several intermittent stream courses commence on the steep north-facing flank of the Jabel Sabir and flow from south to north through the city. Major streams in sequence from west to east include:

- Wadi Seena (Sawayell)
- Wadi Sayelet (Al-Haijah)
- Wadi Medjalia (Sohlla)
- Wadi Taiz (Al Wad)

Channels of these streams are deeply incised and well defined along the Jabel Sabir front, pass to and through the city, and join to comprise the major drainage source to Wadi Taiz south of the city. The Hougala and Houban well fields lie within the downstream sector of this drainage system. The left half of Figure 4-2 depicts the drainage area south, through and north of Taiz in which test areas II, III, V, VI, VII, and XV are located.

SYSTEM SOUTHEAST AND NORTHEAST OF TAIZ

Southeast of the city the streams of Wadi Hassanat and Wadi Salah rise and are fed by smaller tributaries rising along the north flank of the Jabel Sabir. Flows from both streams reach Wadi Kolabat which, during flood stages, empties to the lower Wadi Houban. The Wadi Houban (Khowban) drainage area rises approximately 20 kilometers northeast of Taiz, courses south, turns northwest two kilometers north of the city, then continues north to a confluence with Wadi Taiz at the Hougala well field. The right half of Figure 4-2 covers the subject drainage system within which test areas I, IV, XIV and XIX lie.

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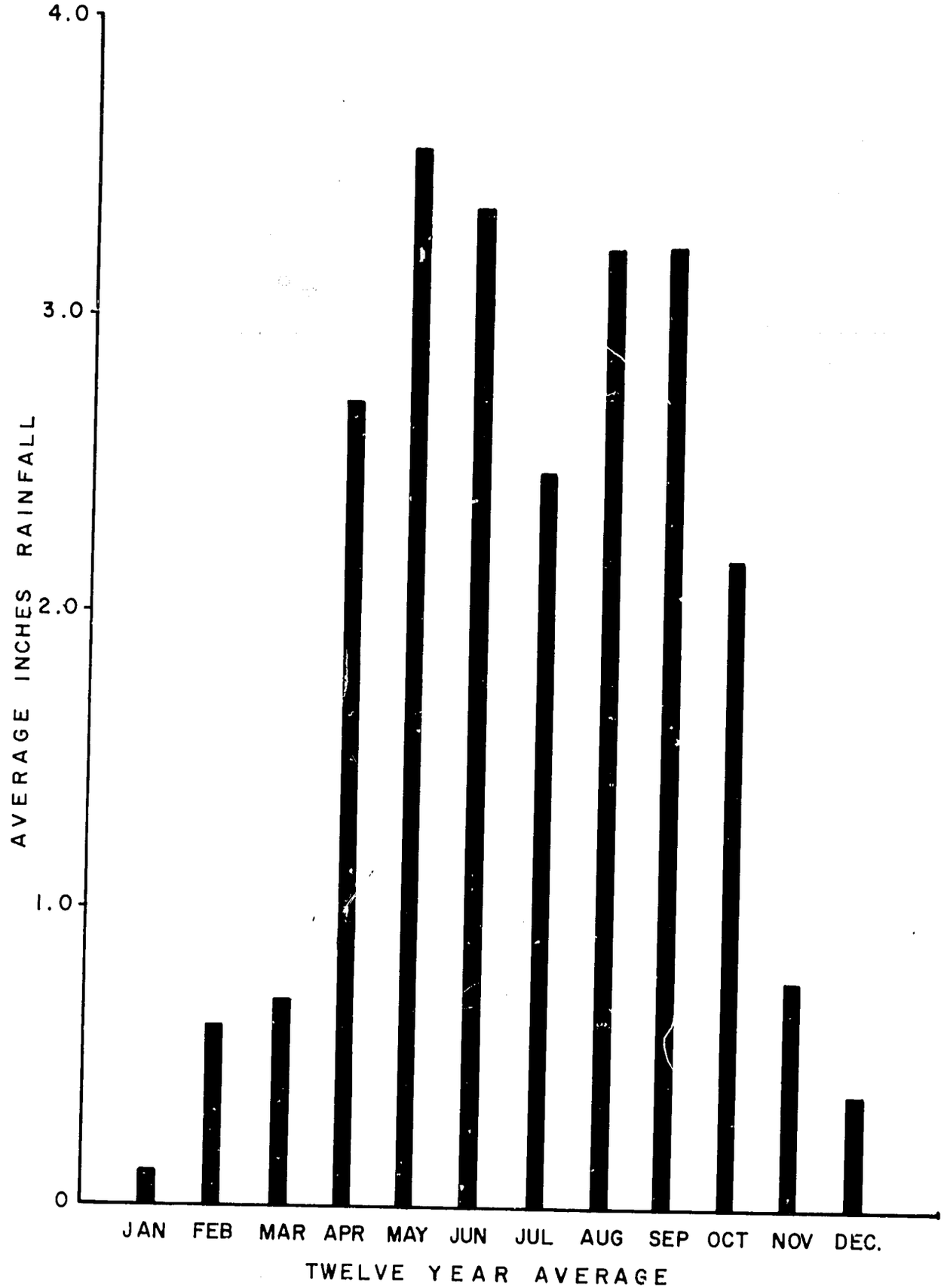
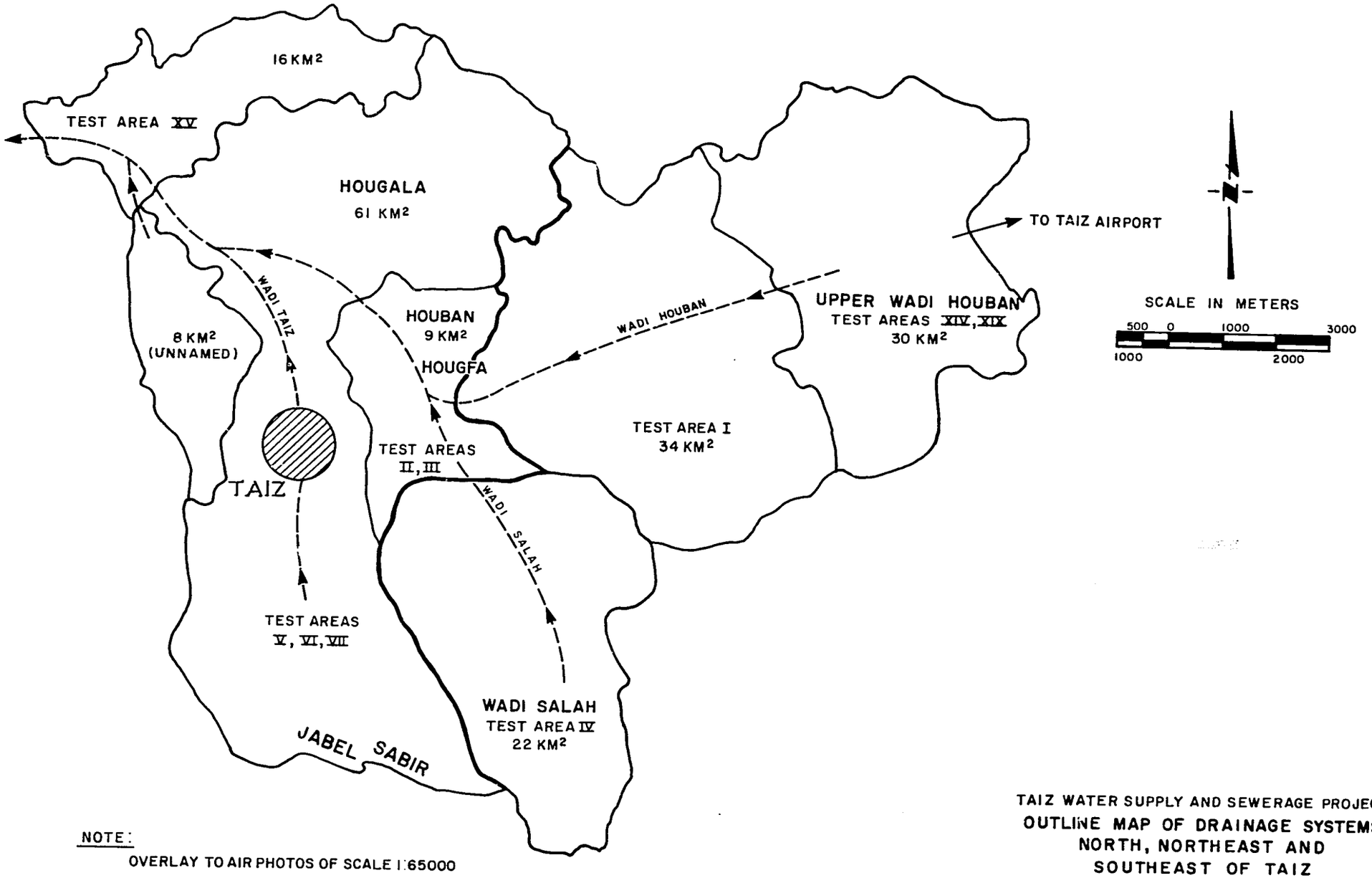


TAIZ WATER SUPPLY AND SEWERAGE PROJECT
AVERAGE MONTHLY RAINFALL
IN THE CITY OF TAIZ, Y.A.R.



NOTE:
OVERLAY TO AIR PHOTOS OF SCALE 1:65000

TAIZ WATER SUPPLY AND SEWERAGE PROJECT
OUTLINE MAP OF DRAINAGE SYSTEMS
NORTH, NORTHEAST AND
SOUTHEAST OF TAIZ

FIGURE 4-2

WESTERN JABEL SABIR - DH'BAB SYSTEM

A well defined divide separates the Wadi Taiz drainage from the drainage areas to the west. This divide generally follows the north-south trending ridges of the Jabel Al Jarrah and Al-Thaba, then continues through the village of Seena and into the abrupt slope of Jabel Sabir. Relatively narrow and shallow stream channels characterize the water courses throughout this catchment sector which flows to a lower mountainous region northwest of Taiz. A small portion of this western drainage system reaches the Taiz-Hougala drainage approximately one kilometer downstream from the Hougala well field. (See unnamed area, Figure 4-2).

TABLE 4-2

AREAS WITHIN MAJOR DRAINAGE SYSTEMS
VICINITY OF TAIZ

	km^2
System In and South of Taiz	
Test Areas V, VI, VII and Hougala	61
Test Areas II, III, Hougfa and Houban	9
Unnamed Area Northwest of Taiz	8
Test Area XV	16
Total Drainage Area	92
System Southeast and Northwest of Taiz	
Test Area IV (Wadi Salah)	22
Test Area I (Middle Wadi Houban)	34
Test Areas XIV and XIX (Upper Wadi Houban)	30
Total Drainage Area	86
Dh'bab System	
Test Area X, Dh'bab	145
Total Drainage Area	145
El Hiama Drainage System	
Test Area XI (Taiz Airport)	42
Test Area XII	24
Test Area XIII	27
Test Area XVI (Mikbaba)	137
Test Areas XVII and XVIII (El Hiama)	231 (approx)
Total Drainage Area	461 (approx)

West of and adjacent to the western Jabel Sabir system is the Dh'bab drainage area. Wadi Dh'bab rises on the south slopes of Jabel Sabir over the drainage divide from Taiz. The Wadi then turns gradually to the north and debouches from the north flank of Jabel Sabir through Dh'bab Narrows, nine kilometers west of Taiz. This stream course continues north and eventually intercepts Wadi Houban and El Hiama streams several kilometers downstream. Test areas VIII, IX and X are located in the western Jabel Sabir - Dh'bab drainage system. The Dh'bab drainage area is outlined on Figure 4-3. Wadi Amed (Figure 5-1) is tributary to a drainage area of 8 km^2, but is not shown on the outline maps of drainage systems because of the small catchment sector involved.

EL HIAMA DRAINAGE SYSTEM

Headwaters of streams within the El Hiama system rise approximately 30 kilometers north of Taiz, flow in a southerly direction, then turn west and eventually converge with the Taiz-Houban-Hougala drainage some 12 kilometers northwest of the city. El Hiama and Mikbaba basins (test areas XVI, XVII and XVIII) lie within the major catchment areas of the system. Downstream from Mikbaba basin lie the minor tributary drainages of test areas XI, XII and XIII.

The stream valleys of El Hiama and Mikbaba are relatively broad and flat. As the drainage leaves Mikbaba it increases gradient rapidly in a narrow, deep canyon course. At the entrance of the catchment area of test area XIII the gradient reduces and continues on a rather gentle course through wide valleys to a downstream confluence with the Taiz-Houban-Hougala drainage systems. Figure 4-4 indicates the general stream system and aerial extents of catchments within the El Hiama system.

SURFACE STREAM FLOW

No records of surface stream flows are known to exist for the area evaluated in this project. However, within the irrigated sectors of some fertile valleys, rudimentary facilities to divert surface waters are present.

In the absence of runoff data it was necessary during the field investigation to make observations which could establish some element of understanding of the quantity and nature of surface flows in the Taiz region.

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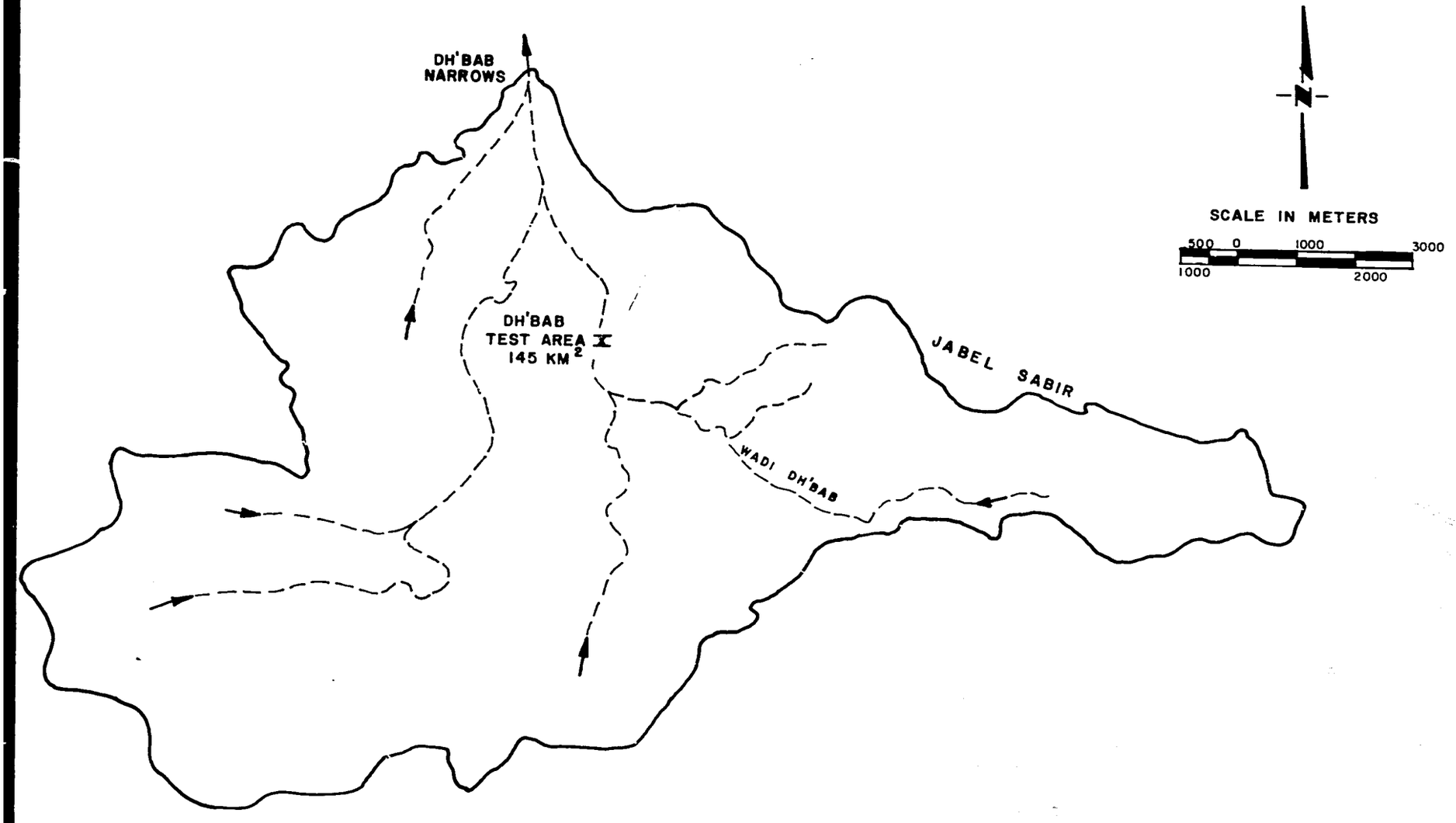

NOTE:
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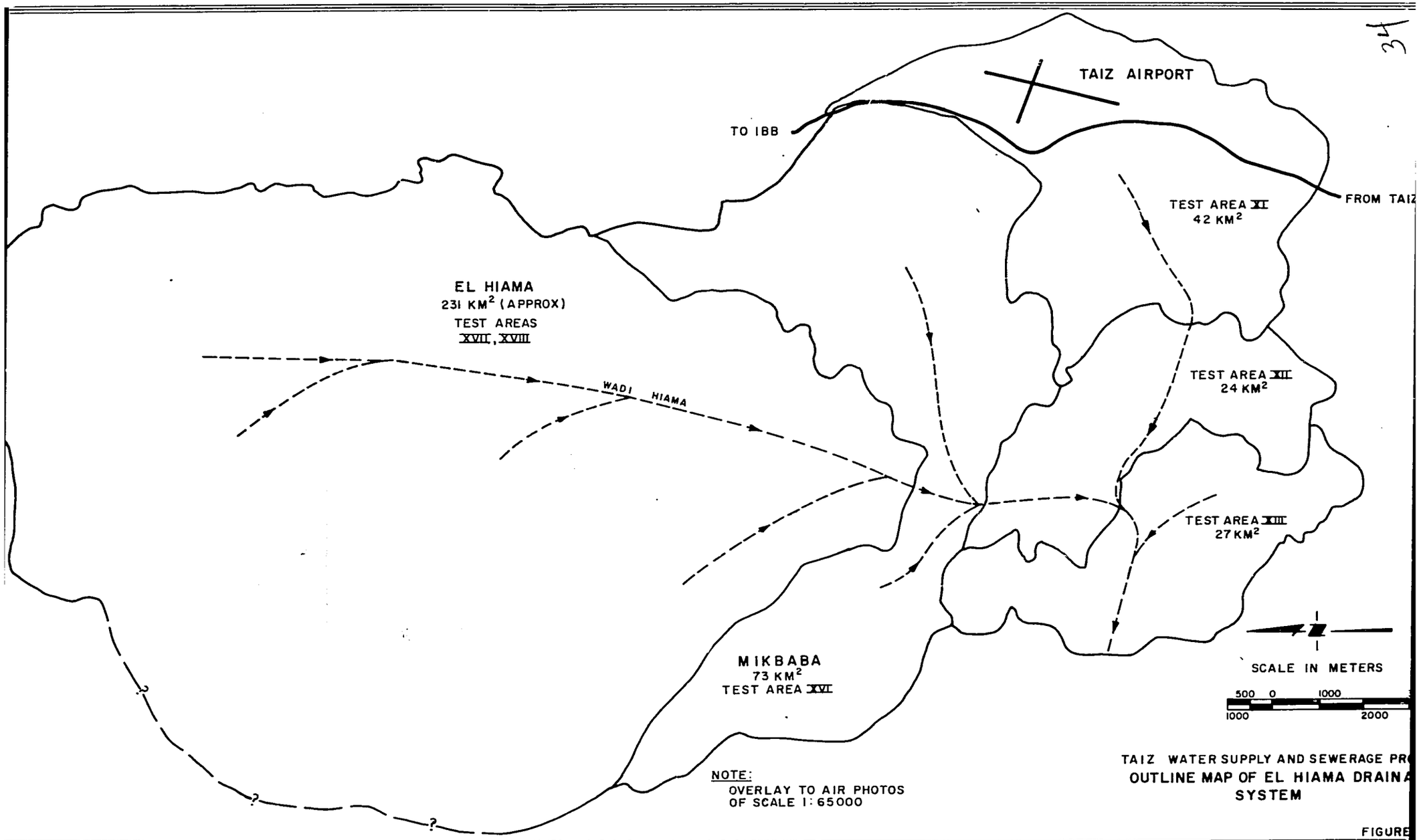
TAIZ WATER SUPPLY AND SEWERAGE PROJECT
OUTLINE MAP OF DH'BAB
DRAINAGE SYSTEM



TAIZ WATER SUPPLY AND SEWERAGE PR
OUTLINE MAP OF EL HIAMA DRAINA
SYSTEM

FIGURE

Hydrologic Conditions - Vicinity of Taiz

Within the subject region most stream valleys are cultivated to the maximum extent possible. Complex and extensive terracing of all arable lands is normal practice in the general vicinity of Taiz. Only excessively steep or rocky terrain is devoid of the cultivated terraces; some of which may date back more than a thousand years.

Surface streams rising in the barren rocky highlands enter the lower cultivated sectors and are diverted to flood irrigate crops planted in the terrace soils. During torrential flows large acreage is frequently inundated and eroded severely, resulting in disastrous crop losses. More moderate flows are controlled and spread gradually downslope from one terrace to the next. By retarding runoff in this manner maximum conservation of available water for crops is obtained. Secondarily, the terraces may act as recharge basins to ground water supplies in the alluviated wadis.

In order to establish a basis for determining surface stream flows and features of runoff to potential new water source areas, it was considered appropriate to utilize hydrologic parameters developed for inland Southern California in the evaluation of the Taiz region. Hydrologic similarities considered were as follows:

- Type and quantity of precipitation
- Highland soil development features
- Highland bedrock features
- Elevation above mean sea level
- Distance from a large water body
- Observed stream configurations and flow characteristics
- Vegetation types and quantities

Each of these points was considered in the quantification of surface runoff to the potential new water source areas for the city of Taiz. The values derived from the new source areas are shown in Table 4-3.

TABLE 4-3

QUANTITIES OF ANNUAL SURFACE FLOW AVAILABLE AS RECHARGE TO POTENTIAL NEW WATER SOURCE AREAS

Test Area Designation	Percent Annual Precipitation as Runoff	Volume of Water as Runoff
IV	7	924,000 m^3/yr
VIII	7	364,000 m^3/yr
X	7	6,009,000 m^3/yr
XVI	7	3,070,000 m^3/yr
XVII - XVIII	7	10,510,000 m^3/yr
XIX	5	900,000 m^3/yr

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CHAPTER 5

CHAPTER 5

GEOLOGY

GENERAL GEOLOGIC SETTING

The city of Taiz lies along the base of the East-Westtrending escarpment of the Jabel Sabir massif, the jagged peaks of which rise directly south of the city to an elevation of more than 2900 meters above sea level. Elevations within the municipal area itself range from approximately 1130 to 1430 meters above mean sea level. A broad vista of moderate to rugged hills and narrow valleys extends northward for several tens of kilometers from the city.

The abrupt escarpment of Jabel Sabir is formed along a major linear fault zone which continues some 8.5 kilometers west and 9 kilometers east of Taiz. Dissected alluvial fans and terraces, associated with erosion and uplift of the Jabel Sabir, butt against the escarpment and locally form the surface upon which the city lies. Throughout the region to the north the physiography is formed largely by structural disruptions within a complex of finely textured igneous rocks. Stream valleys and mountain flanks lie primarily along fault trends, reflecting the effects of past regional upheavals.

REGIONAL LITHOLOGY

Rock types occurring in the area of investigation are primarily of igneous origin. Metamorphic and older sedimentary rocks are relegated to localized outcrops. Younger sedimentary deposits are found predominantly in the Taiz Alluvial Fan and along stream courses incising the older igneous rocks.

Rocks comprising the Jabel Sabir block are generally of deep seated igneous origin and have been assigned by earlier investigators as Cretaceous in age. Granite, quartz monzanite, and other rocks of acidic igneous character predominate.

Geology

In the regions east, north and west of Jabel Sabir a broad suite of fine grained igneous rock types, usually associated with surface or near surface emplacement, are prevalent. Rhyolite, andesite, porphyry and basalt are most common. The time of emplacement of these rocks has previously been determined as Tertiary, however, surface evidence indicates that regional volcanism may have persisted through Quaternary time.

Metamorphic rocks located in the vicinity appear to be related to the Jabel Sabir fault zone. These rocks usually occur in small hills west of Taiz in the immediate vicinity of the faulted escarpment. Contact metamorphism in this location appears to have produced only low grade quartzites, schists and gneises.

Sedimentary rocks exposed are associated primarily with the alluvial fan lying in the north flank of Jabel Sabir and the narrow stream valleys crossing the region. Boulder fanglomerates, conglomerates, sand, silt, clay, and beds of volcanic ash (igneous effusive) are found to be present in the alluvial fan. Unconsolidated gravel, sand, silt and clay comprise the bulk of the stream valley alluvium. Alluvial fan and valley alluvial sediments are considered to have been deposited essentially continuously from Late Tertiary through Quaternary time.

In a small group of hills west of Taiz along the Jabel Sabir fault zone, a fossiliferous limestone occurs. No age has been determined for these sediments, but stratigraphic position suggests Pre-Cretaceous deposition.

Of the rock types described above, the most significant in the context of water resources is the Quaternary alluvium occurring within stream valleys.

REGIONAL STRUCTURAL AND GEOMORPHIC FEATURES

The area of investigation has, in past geologic history, been a region of intense tectonic activity. Most formations in the vicinity have been severely faulted and otherwise disrupted; as evidenced by existing landforms. Directional orientations of mountainous ridges and stream valleys north of Taiz reflect structural breaks or weaknesses with general regional trends.

Stream courses in the region relate to the youthful nature of the surfaces they incise. Streams on the north flank of Jabel Sabir flow in narrow, steep V-shaped valleys, which are practically devoid of alluvial fill. These streams usually continue along deeply incised courses across the alluvial fan at the toe of the Jabel Sabir escarpment, then enter

the alluvial-filled valleys to the north of Taiz. Portions of the alluviated valleys are in erosional as well as depositional phases of development. This condition is expressed in the unstabilized gradients of regional stream courses. Streams rising to the north of Taiz follow erratic and dendritic drainage patterns which, for the most part, trend along alignments of structural weaknesses. It is within the alluvial fill of these valleys that ground water is accumulated and stored, and from which new water resources for the city of Taiz can be derived.

GEOLOGIC MAPPING

Field geologic mapping was performed during the course of the water resources evaluation primarily to determine the relationship of geologic features to ground water occurrence and movement. Geologic maps presented are therefore generalized. Formation designations are based on previous maps prepared by agencies and individuals who formerly explored the geology of the Arabian Peninsula. Major regional formation attitude trends and structural features were included on geologic maps to indicate the regional geologic conditions in the study area and the specific conditions in the direct vicinities of potential new water source areas for the city.

In essence, the basic purpose of the project geologic maps is to delineate the extent of potential water bearing formations and the boundaries formed by the nonwater bearing formations. Mapped rock units, shown on Figures 5-2 through 5-5, may be classified as water bearing or nonwater bearing as follows:

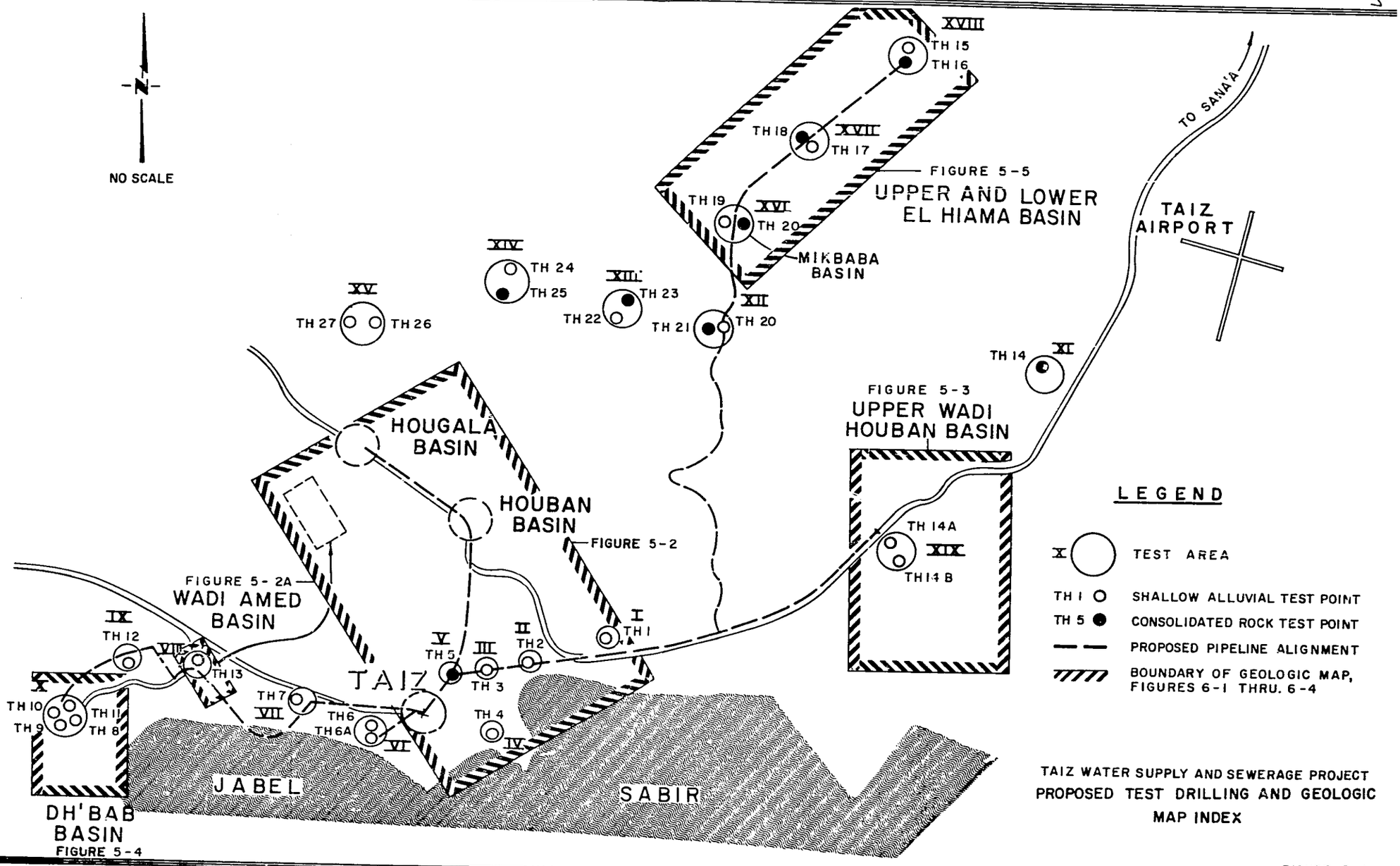
- Water Bearing Rocks

  Recent Alluvium
  Pleistocene Alluvium
  Plio-Pleistocene Alluvium
  Plio-Pleistocene Fanglomerates

- Nonwater Bearing Rocks

  Tertiary Dike Rocks
  Tertiary Stratoid Series
  Tertiary Chaotic Series
  Tertiary Intrusive Series
  Paleozoic Carbonates
  Pre-Cambrian Crystalline Rocks

Figure 5-1 indicates the locations for test drilling proposed in August 1974 and the coverage of geologic maps related to this study.



TAIZ WATER SUPPLY AND SEWERAGE PROJECT
PROPOSED TEST DRILLING AND GEOLOGIC MAP INDEX

FIGURE 5-1

REFER TO FICHE

3 OF 4

FOR

FIGURE(S):

Houbian – Hougia and Wadi Amed Basins
Figures 5-2 + 2A

Upper Wadi Houbian
Figures 5-3

Dhi Bab Basin
Figures 5-4

REFER TO FICHE

4 OF 4

FOR

FIGURE(S):

Upper And Lower EL HIAMA BASIN

FIGURE:- 5-5

CHAPTER 6

CHAPTER 6

HYDROGEOLOGIC FEATURES OF EXISTING PRODUCTION AREAS

GENERAL

Current production of the city of Taiz water system (Kennedy Memorial Water System) is derived from the Hougfa, Houban, and Hougala well fields. Figure 5-2 depicts the locations of the three basin areas and the production wells. A total of approximately 1.2 million gallons of water per day is pumped from the well fields each day, with Hougfa and Houban contributing 0.4 mgd and Hougala 0.8 mgd.

Hougfa basin lies within the surface drainage system of Wadi Houban (Khowban) and is tributary to Houban basin downstream. In addition to receiving Wadi Houban flows, Houban basin lies within the drainage system of Wadis Salah and Kolabat. All of the named streams eventually converge and form Wadi Korima which passes through Houban basin and joins Wadi Taiz (Shajarah) at Hougala basin. Of these stream systems, Wadis Salah, Kolabat and Taiz drain both surface and subsurface flows originative in or upstream from the city.

Hougfa, Houban and Hougala basins all lie within relatively narrow alluvium-filled stream valleys which are parallelled and underlain by an igneous rock complex. Water resources in the basins are contained chiefly within the alluvial fill materials. Although small quantities of water may percolate to the basins from the adjacent igneous rocks, the igneous complex is, in general, considered to be nonwater bearing. Figure 5-2 indicates the configurations, areas and geological conditions surrounding the basins. Geological cross sections (Figures 6-1 and 6-2) show the depths and subsurface hydrogeologic characteristics of the well field areas.

HOUGFA BASIN

Hougfa basin is located 2.5 kilometers northeast of Taiz along the lower course of Wadi Houban (Khowban) and occupies a roughly triangular area of near 0.3 square kilometers. Water bearing sediments in the

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basin include both present stream valley alluvium and a remnant portion of the Taiz Alluvial Fan. The fan deposits lap onto an igneous rock mass, primarily dark brown basalt, lying to the south of the basin. The valley of lower Wadi Salah effectively isolates the Hougfa area from the main portion of the Taiz Alluvial Fan to the south.

Recharge to the Hougfa ground water basin occurs from percolation of surface and subsurface flows through Wadi Houban and probably subsurface flows from Wadi Salah. The nature of recharge from Wadi Salah is subject to some question due to a paucity of data, but exploration at Test Holes 2 and 3 suggests that the majority of subsurface flows moves into Hougfa basin from Wadi Salah rather than following the surface course of the stream into Wadi Kolabat.

Three attempts have been made by KMWS to drill production wells in this basin; one of which was successful at Houban No. 14. This well penetrated 48.8 meters of alluvial material, and originally encountered water at a depth of 25.9 meters below ground surface (elevation 1114.1 meters). Well No. 14 is presently producing at a rate of 220 gpm. In available records this well is considered part of the Houban well field.

Because no access hole existed in the well head prior to July 1974, historically water levels have not been measured, but for the four project months, September through December 1974, the static water level rose 1.3 meters (see Table 6-2). Although evidence is minimal, it is considered probable that current withdrawal from Hougfa basin is equal to recharge. If, however, recharge does exceed withdrawal it is only by a small increment and any excess of recharge over withdrawal flows into Houban basin to be produced by wells there.

The quality of waters produced from Well No. 14 is the best in the existing Taiz well system. Total dissolved solids were 975 mg/l in August 1974 (see Appendix C) however, no historic record of water quality is available to establish long-term trends. Nitrate (NO_3) was 56 milligrams per liter, indicating possible degradation from return wastewaters from some source.

Testing in Hougfa basin is currently restricted to Houban Well No. 14. This well appears to have a leaky column pipe and depth to water cannot be measured accurately while producing. Consequently, it was not possible to determine specific capacity or perform aquifer tests at this well during the course of the project.

Hydrogeologic Features of Existing Production Areas

HOUBAN BASIN

The southern extent of the Houban production area lies approximately 2.5 kilometers north of the city center and continues for one kilometer north along Wadi Kolabat. Following an irregularly shaped alluviated sector along the wadi, the basin encompasses a surface area of about one square kilometer. Surface and subsurface flows enter the production area along the alluvium filled stream valleys of Wadis Salah and Khowban.

Production from the Houban well field commenced in 1962. Throughout the period from 1962 through 1974 additional wells have been constructed at Houban to provide for increased system requirements or to replace wells that have failed during that interval. Due to some confusion in existing records, with respect to well designations and locations, the status of some of the added wells are somewhat clouded. Nevertheless, reliable data is available on enough wells to yield an analysis of historical basin conditions.

Geologic cross sections A-A' and B-B' on Figure 6-1 are based on dependable well logs and indicate the Houban basin to be flanked and underlain by a basement complex comprised primarily of rhyolite and basalt. Aquifers in the basin are contained within Recent sand gravel and clay deposits which reach known depths of 38 meters (125 feet), but because of an irregular basin bottom configuration, many wells penetrate bedrock within less than 30 meters of the surface. Well logs and test information demonstrate the aquifers in Houban basin to be semiconfined to confined. This condition results from a clayey aquitard 5 to 10 meters thick overlying the major production aquifers.

Since 1964 water levels in Houban basin have dropped drastically with the result that pumping levels in some wells have declined to the point that pumping is no longer feasible. In 1974 some static water levels were more than 7 meters below those measured in 1964 and had fallen beneath the tops of perforated zones in several production wells. Tables 6-1 and 6-2 list all available water level data collected in Houban basin.

Current water production from Houban basin is pumped from four wells which are operational on a 24 hour basis when functioning. Daily production from Houban averages approximately 0.4 million gallons per day.

The quality of water produced from wells in Houban basin has deteriorated significantly with time. Analyses made by USAID in 1964 showed total dissolved solids (TDS) to range from 996 to 1094 milligrams per

TABLE 6-1

PRE 1974 WATER LEVEL MEASUREMENTS
OF WELLS IN THE VICINITY OF TAIZ, YEMEN ARAB REPUBLIC

Well Designation	Surface Elevation Meters	Date Measured / Depth in Meters to Water Surface		
Houban No. 1	1122.03	10/26/63 / 19.7 st.	1/30/64 / 12.3 st	12/20/72 / 12.2 st.
Houban No. 2	1112.76	1/28/64 / 12.3 st.	12/20/72 / 11.0 st	
Houban No. 3	1099.61	1/30/64 / 9.3 st.		
Houban No. 4	1099.16	10/20/63 / 9.5 st,	1/30/64 / 9.7 st	
Houban No. 5	1103.51	10/19/63 / 13.4 st,	1/30/64 / 12.6 st	
Houban No. 6	1094.23	10/19/63 / 9.7 st	1/30/64 / 9.2 st	
Houban No. 7	1110 (app)	10/19/63 / 16.8 st		
Houban No. 11	1101	8/20/67 / 21.3 st	12/20/72 / 13.4 st	
Houban No. 14	1140 (app)	9/23/69 / 25.9 st	12/20/72 / 27.1 pp	
Houban No. 16	1136 (app)	4/23/69 / 23.4 st		
Hougala No. 1	1023.6	6/18/69 / 4.0 st.	12/20/72 / 16.8 pp	
Hougala No. 2	1023.0	8/12/68 / 1.8 st	12/20/72 / 18.9 pp	
Hougala No. 3	1024.7	5/23/69 / 4.9 st	12/20/72 / 23.8 pp	
Hougala No. 4	1018.9	6/25/69 / 2.4 st	12/20/72 / 22.8 pp	
Hougala No. 5	1021.3	7/25/69 / 4.0 st	12/20/72 / 17.7 pp	
Hougala No. 6	1026.6	8/12/68 / 4.0 st	12/20/72 / 22.6 pp	

*Note st. = Static Water Level
pp = Pumping Water Level
app = Approximate

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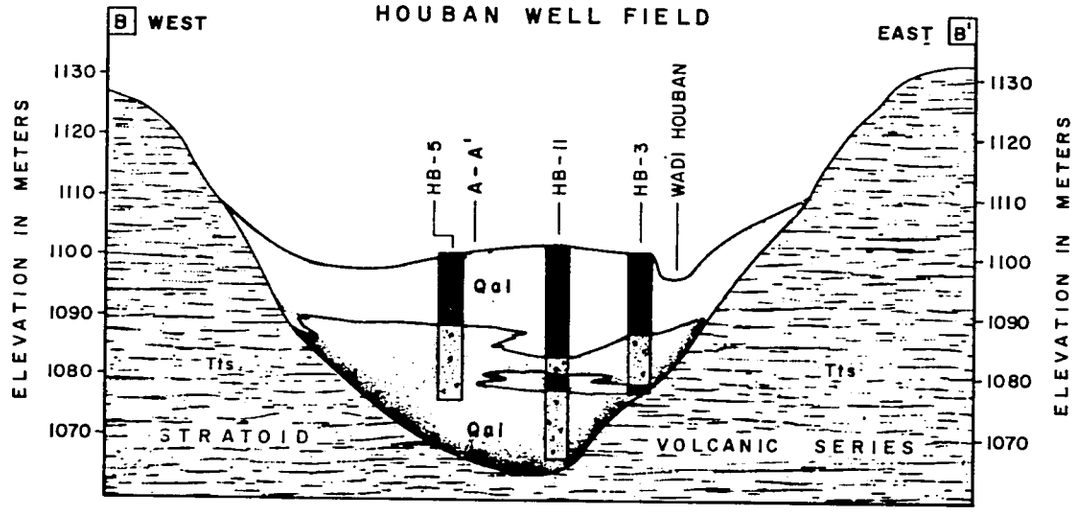
WADI HOUBAN GEOLOGIC CROSS SECTIONS

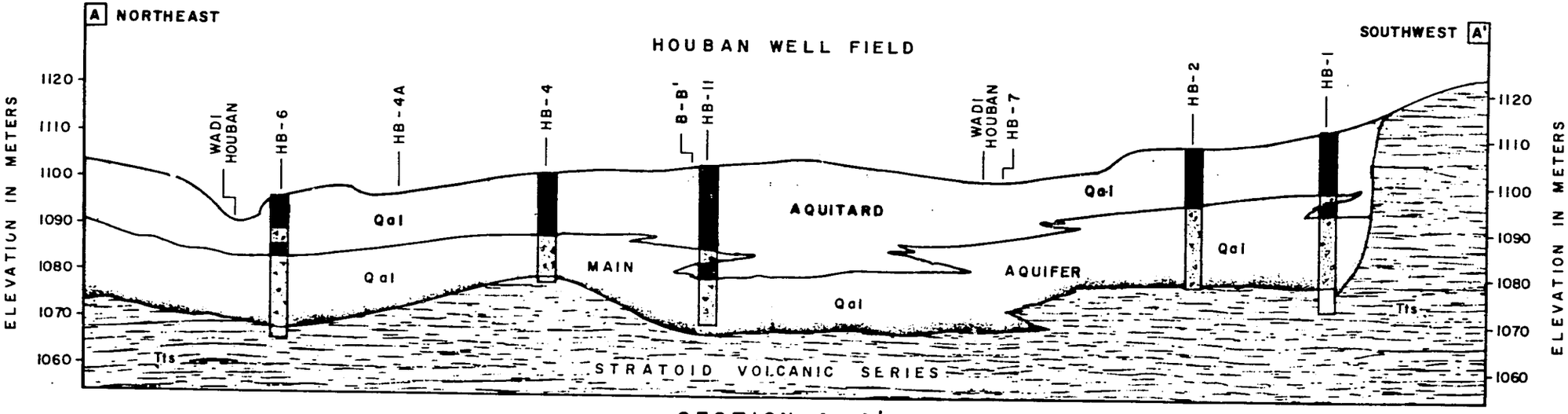
HORIZONTAL SCALE
1cm = 30m

LEGEND

- AQUITARD - CLAYS, SILTS
- MAIN AQUIFER - COARSE SANDS AND GRAVELS
- STRATOID VOLCANIC SERIES
- HB-5 WATER SYSTEM PRODUCTION WELL



SECTION B-B'



SECTION A-A'

FIGURE 6-1

TABLE 6-2

WATER LEVELS IN HOUBAN AND HOUGALA WELLS IN THE VICINITY OF TAIZ, YEMEN ARAB REPUBLIC YEAR 1974

Well Designation	Elevation (Meters)	Water Level Depth Below Ground Surface in Meters																
		June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Houban Wells		6/25/74	7/9/74		9/7/74	10/3/74	11/2/74	12/4/74									
1	1122.03		30.4 st		25.7 st	25.5 st	25.6 st	25.4 st									
2	1112.76		18.8 st		18.7 st	18.5 st	18.5 pp	19.7 pp									
2A	1112 (app)		19.6 st		18.7 st	18.6 st	19.4 st	18.7 st									
3	1099.66		16.9 st		15.7 st	15.6 st	15.8 st	14.7 st									
4A	1098 (app)		13.7 st		12.8 st	12.4 st	12.7 st	11.4 st									
6	1094.23		16.5 pp		15.9 pp	16.5 st	15.6 pp	16.7 pp									
7	1110 (app)				12.3 st			20.9 st									
11	1101		22 pp		20.5 st												
14	1140 (app)				29.2 st	28.5 st	28.4 pp	27.9 pp									
Hougala Wells																	
1	1044 (app)				9.2 st	9.6 pp	10.3 st	10.7 pp									
2	1047 (app)		7.3 st		11.5 pp	11.9 pp	11.1 st	12.8 pp									
3	1044 (app)	9.3 pp	8.9 pp		10.4 pp	10.8 pp	-	11.5 pp									
4	1041 (app)	6.6 pp	6.6 pp		7.6 pp	7.3 pp	8.8 pp	9.1 pp									
5	1043 (app)	6.3 st	7.1 st		7.8 st	7.4 pp	9.9 pp	10.4 pp									
6	1043 (app)	8.4 pp	8.6 pp		6.5 pp	7.1 pp	11.2 pp	10.1 pp									
7	1049 (app)				13.6 pp												

Note: st = Static
pp = Pumping
app = Approximate

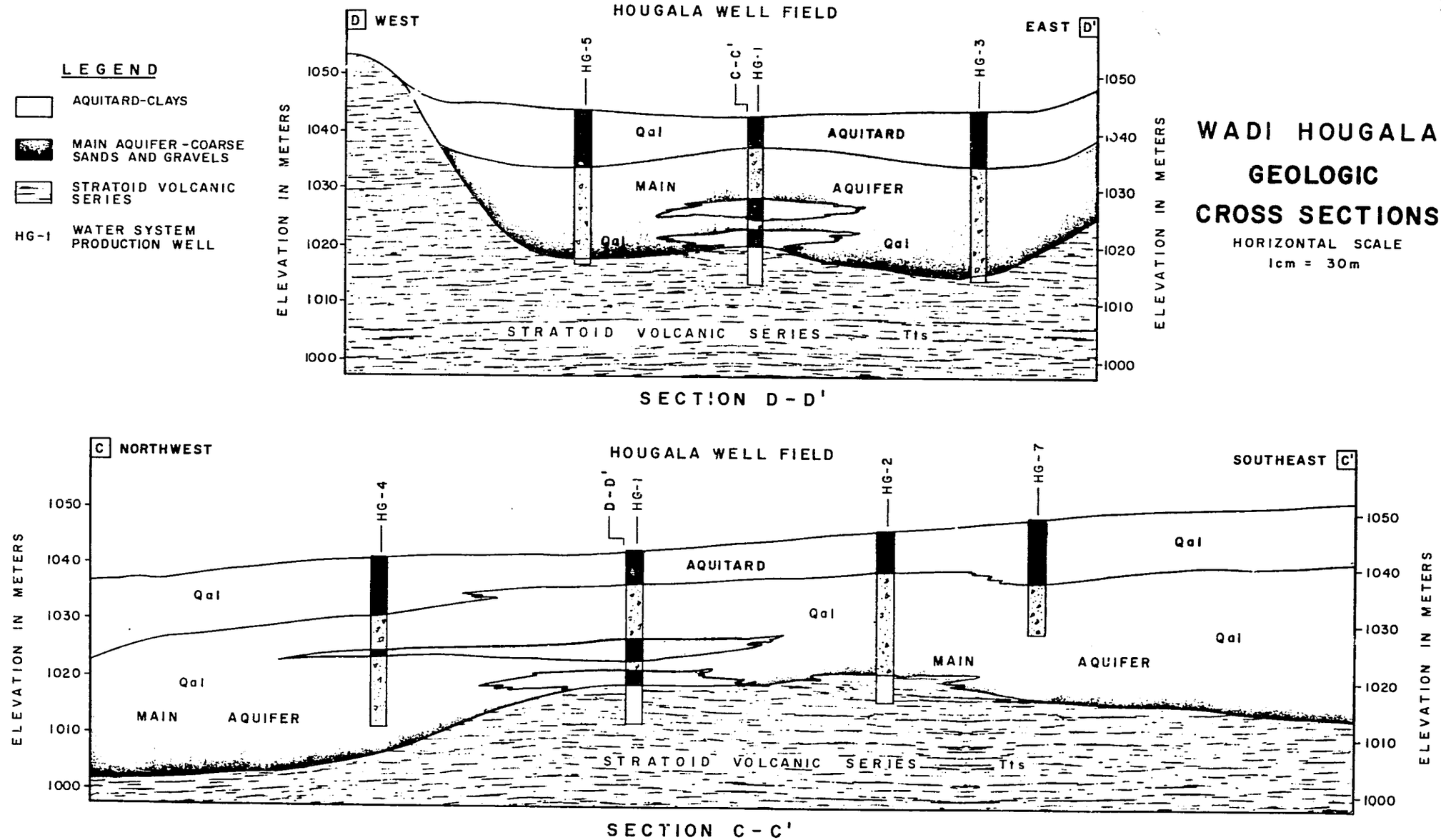
liter. In 1974 analyses revealed a TDS range of from 2190 to 2400 milligrams per liter. Current nitrate ion levels range from 56.4 to 89 milligrams per liter. Although only fragmental chemical analysis data are available from 1964 through 1974 (see Appendix C) the trend has been toward continuously increased degradation of Houban basin waters. In view of the location of the basin and the type of degradation noted, it is likely that return irrigation waters and wastewaters from within the drainage area of the basin are the major sources of quality impairment. Overpumping of the basin, as indicated by the severe decline in water levels throughout the past 10 years, probably also contributes to water quality degradation by enhancing and accelerating the movement of return wastewaters into the basin during the dryer periods of each year.

Because of the need to maintain the flow of water to Taiz from the Houban well field, it was possible to perform well or aquifer tests only while other wells in the basin were producing. Specific capacity tests were made at Houban basin wells Nos. 2, 4, 6 and 11 under the above noted conditions. The results of these tests are shown on Table 6-3. One aquifer test, a recovery pump test, was completed at Houban well No. 4 (see Appendix D). This test indicated a transmissibility coefficient of 684 gallons per day per foot for the Houban aquifer. This value appears extremely low when compared to well specific capacity (5.1) and probably reflects intrabasin pumping effects of other wells. Until satisfactory testing conditions can be achieved, a reliable analysis of aquifer characteristics in Houban basin will not be possible.

HOUGALA BASIN

The Hougala well field lies approximately 5 kilometers north of the center of Taiz at the confluence of Wadis Taiz (Al Shajara) and Kolabat. Wells producing in this basin were constructed in 1968-69 to increase the water supply to the Taiz system. Presently about 0.8 million gallons of water per day are derived from six producing wells at Hougala.

Geologic cross sections C-C' and D-D' on Figure 6-2, prepared on the basis of available well logs, show Hougala basin to lie within an alluviated intersection of Wadi Kolabat and Wadi Taiz which encompasses an area of some 0.8 square kilometers. The alluvial deposits there are bordered and underlain by bedrock of igneous origin. Wells in the basin area have penetrated a maximum of 31.1 meters (102 feet) of sand, gravel, and clay alluvial deposits before reaching bedrock. A clay deposit a maximum of 9.1 meters thick occurs at the surface and confines water within underlying aquifer zones. The confined nature of the aquifers was confirmed at the time of drilling when water rose in the bores



WADI HOUGALA GEOLOGIC CROSS SECTIONS

HORIZONTAL SCALE
1cm = 30m

JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.

FIGURE 6-2

after water bearing deposits beneath the clay aquitard were encountered. Lithologic logs of wells drilled in Hougala basin are included in Appendix A.

Static water levels in Hougala basin in 1969 were within five meters of the surface. In 1974, the static levels in comparable wells had been lowered to an average of approximately 10 meters below ground surface. It is probable that a portion of this lowered static level is a result of residual pumping drawdown within the well field, since a number of the static water level measurements were made while other wells within the field were producing. Because of the need to maintain the supply of water to the city, it was possible to measure static water levels only once in two wells with all wells inoperative. Those measurements were made on July 23, 1974, when a well field power failure interrupted production for two hours. From field observations it is considered that Hougala basin water levels would recover to near 1969 elevations if pumping were discontinued for a few days. All evidence obtained in the course of the project strongly suggests that Hougala basin is not, at this time, operating under overdraft conditions.

As in the case of Houban basin, it was not feasible to interrupt the Taiz city water supply to perform well and aquifer tests. Therefore, all testing executed was subject to interference of other producing wells in the basin. Five specific capacity tests were accomplished which indicate the Hougala basin wells to be moderately good producers. Pumping rates ranged from 180 gallons per minute to 220 gallons per minute with respective specific capacities of 22 and 30.6. Complete well field test data are listed on Table 6-3 in both English and Metric values. One aquifer recovery pump test was conducted in the basin at Hougala well No. 6. This test indicated an aquifer transmissibility coefficient of 48,000 gallons per day per foot. In comparison with the well specific capacity (45.5) obtained at the time of the test, the transmissibility derived is somewhat below that which would be anticipated. It is assumed that intrabasin well interference contributed to the discrepancy noted. Appendix D includes the transmissibility curve and calculations obtained from Hougala well No. 6 testing.

Ground water recharge to Hougala basin is from underflow within the alluvium of Wadis Taiz and Khowban. Both of these wadis are within the surface and subsurface drainage regimes of greater Taiz. The valley of Wadi Taiz is under intensive and expanding agricultural development with significant areas of irrigated and artificially fertilized crops. Agricultural activity in Wadi Kolabat essentially employs only traditional dry farming procedures.

Hydrogeologic Features of Existing Production Areas

As in the Houban basin, water quality has become poorer in Hougala basin since production began. At the time Hougala well No. 2 was constructed in 1969, an analysis of total dissolved solids of a water sample indicated 1435 milligrams per liter. Analyses of water samples from the same well in July and August 1974 revealed TDS concentrations of 2470 milligrams per liter and 2290 milligrams per liter, respectively. Concentrations of all comparable dissolved chemical constituents show dramatic increases in the six year period of basin production. Water samples collected and analyzed in August 1974 from the six wells producing from the basin indicated a total dissolved solids range of from 2150 milligrams per liter to 2470 milligrams per liter. Nitrate ion concentrations in the same samples ranged from 160 to 270 milligrams per liter. Results of water quality analyses in Hougala basin are listed in Appendix C.

THE HOUBAN-HOUGALA WATER QUALITY PROBLEM

At the outset of the present project the water quality conditions existing in the Taiz water system were evaluated to determine trends and characteristics of source areas. It was noted at an early date that extreme deterioration of water quality had occurred since the original construction of source wells and system.

As discussed previously, the present wells producing water supplies for the municipality of Taiz are located in Houban and Hougala basins, and both of these basins lie downgradient and within the direct drainage influence of Taiz. Surface and subsurface waters originating upstream from and within Taiz proper, therefore, migrate toward the well fields. In addition, Wadi Taiz is intensively cultivated (partially irrigated) in the upstream sectors. A United Nations Farm Project is included in this cultivated area, which utilizes chemical fertilizers for test cropping.

Since the original system wells were constructed, total dissolved solids concentrations of the water produced from these basins has increased greatly. Of additional significance is that the nitrate ion content has increased from a minimum of 56.4 milligrams per liter to maximum levels of 270 milligrams per liter. When these, as well as other water quality factors were considered, the conclusion was reached that recharge waters to the existing well field areas were being degraded by return flows from the city of Taiz and Wadi Taiz. In effect, a closed system has developed wherein waters are circulating from the well fields to Taiz, then returning to the basins with added increments of dissolved solids in surface and subsurface flows.

TABLE 6-3

SUMMARY OF PUMP TESTING
HOUBAN AND HOUGALA WELL FIELDS

Well Designation	Date Tested	Static Water Level	Max. Pumping Level	Maximum Drawdown	Q l/s / gpm	Specific Capacity l/s/m / gpm/ft
Houban No. 2	8/10/74	18.6 m / 61 ft	19.6 m / 64.3 ft	1.0 m / 3.3 ft	3.8 / 60	3.8 / 18.2
Houban No. 4	10/9/74	12.3 m / 40.3 ft	16.5 m / 54.0 ft	4.2 m / 13.7 ft	4.4 / 70	1.04 / 5.1
Houban No. 6	8/11/74	16.4 m / 54 ft	20.3 m / 66.6 ft	3.9 m / 12.8 ft	5 / 80	6.3 / 6.3
Houban No. 11	7/30/74	20.5 m / 67.[illegible] ft	22.0 m / 72.2 ft	1.5 m / 4.9 ft	7.6 / 120	5.0 / 24
Houban No. 14	7/30/74	28.5 m / 93.5 ft			13.9 / 220	
Hougala No. 2	7/22/74	*9.7 m / 31.9 ft	11.6 m / 38.0 ft	1.9 m / 6.1 ft	12 / 190	6.3 / 31.1
Hougala No. 3	7/22/74	*9.0 m / 29.5 ft	10.2 m / 33.3 ft	1.2 m / 3.8 ft	13.6 / 215	11.3 / 56.6
Hougala No. 4	7/17/74	5.4 m / 17.8 ft	7.6 m / 25.0 ft	2.2 m / 7.2 ft	13.9 / 220	6.3 / 30.6
Hougala No. 6	7/23/74	8.2 m / 27.0 ft	9.5 m / 31.1 ft	1.3 m / 4.1 ft	12.6 / 200	9.7 / 48.8
Hougala No. 7	8/25/74	11.52m / 37.8 ft	14.0 m / 45.9 ft	2.5 m / 8.2 ft	11.4 / 180	4.6 / 22.0

* Note: Static Water Level Measurements Made 7/23/74 After 2 Hour Power Failure.

Hydrogeologic Features of Existing Production Areas

It may be assumed that continued utilization of the present water source areas will cause additional build-up of total dissolved solids and continued degradation of the quality of water produced to the Taiz water system.

The conclusion was reached that it was mandatory to locate another feasible source of water for the city and that these new source areas should be located either upgradient from or out of the drainage area of Taiz.

EXISTING WELL PRODUCTION EQUIPMENT

Power supplies, prime movers, well pumps and related well field equipment were examined in the course of the project water resources evaluation. Available information regarding such equipment was gathered both from KMWS files and direct field observations. These data are included on Table 6-4. General information regarding well construction is listed on Table 6-5. Volume I of this report discusses, in detail, features and condition of the existing well field equipment.

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TABLE 6-4

EXISTING WATER WELL EQUIPMENT
HOUBAN AND HOUGALA WELL FIELDS
TAIZ, YEMEN ARAB REPUBLIC, NOVEMBER 1974

Well Designation	Date Drilled	Casing Diam. Inches	Pump Type & Number	Date Installed	Pump Setting Meters	Pump Hp	Gear Head Type & Number	Drive Type & Horsepower	Drive Number
Houban #1	1962	8-5/8	Peerless #00730	U	40	10	Rt. Angle Peerless #028109	Ruston Diesel HP 25 BHP	1062-0168-226
Houban #2	1962	8-5/8	Peerless #00744	U	26	7.5	Peerless Rt. Angle Dr. #J28170	Louis-Allis Co. Electric Motor 7.5 HP	1823966
Houban #6	1962	8-5/8	Peerless #00700	U	24	10	Rt. Angle Peerless	Wagner Electric Co. 7.5 HP	C#7W9723
Houban #11	11/68	8	U	U	30	7.5	Fairbanks-Morse	5.5 HP	
Houban-Hougfa #14	1/1/69	8	U	U	44	25			
Hougala #1	7/18/69	10 In to 8 In to 7 In Screen	Peerless #00728	12/70	U	U	Peerless Rt. Angle #J28135	Newman Electric Co. 15 HP	J103910
Hougala #2	8/4/69	10 In to 8 In to 7 In Screen	Submersible Pleuger	12/70	27	27			
Hougala #3	6/23/69	10 In to 8 In to 7 In Screen	Submersible Pleuger	12/70	27	27			
Hougala #4	7/25/69	10 In to 8 In to 7 In Screen	Submersible Pleuger	12/70	27	27			
Hougala #5	9/25/69	10 In to 8 In to 7 In Screen	Submersible Pleuger	12/70	27	27			
Hougala #6	8/4/69	10 In to 8 In to 7 In Screen	Submersible Pleuger	12/70	27	27			
Hougala #7	12/69	10	U	U	U	U			

Note: U = Unknown

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TABLE 6-5

WELL DATA
HOUBAN AND HOUGALA WELL FIELDS

Well Designation	Well Head Elevation Meters	Date Complete	Elevation of Perforations Meters	Total Depth Meters	Casing Diameter Inches	Perforation Size Inches
Houban Field						
No. 1	1122	1962	1098 - 1092	38.1	8 5/8 OD	8 5/8 OD w/1/4 x 8 openings
No. 1A	1122	1962				
No. 2	1112	1962	1096 - 1087	28.6	8 5/8 OD	8 5/8 OD
No. 2A	1112	1962				
No. 3	1099	1962	1089 - 1079	23.1	10 3/4 OD	8 5/8 OD w/1/4 x 6 slots
No. 4	1103	1962	1090 - 1076	24.3	8 5/8 OD	8 5/8 OD w/3/8 x 6 slots
No. 4A	1097	1974				
No. 5	1103	1962	1087 - 1077.5	24.6	8 5/8 OD	
No. 6	1094	1962	1082 - 1071	28.9	8 5/8 OD	
No. 11	1101	11-68	1077 - 1066	33.5	8	
Hougfa						
No. 14	1145	1-69	1115 - 1100	48.8	8	
No. 16	1150	4-69	- -	34.7	Abandoned	
Hougala Field						
No. 1	1023	6-69	No Data	30.8		
No. 2	1027	6-69	No Data	26.2	(	(
No. 3	1025	6-69	No Data	29.9	(	(
No. 4	1019	6-69	999 - 988	30.0	(10 to 8 to 7	(10 w/vert slots
No. 5	1021	7-69	No Data	24.7	(Screen	(7 screen
No. 6	1022		No Data		(	(
No. 7	1031	12-69	1019 - 1011		10	

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CHAPTER 7

CHAPTER 7

HYDROGEOLOGIC FEATURES OF NEW POTENTIAL PRODUCTION AREAS

GENERAL FEATURES

Six new potential source areas for production of water to the Taiz Water System were defined in the course of the project water resources evaluation. The new source areas are located in alluviated valleys along wadi trends and are designated as follows:

Basin Name	Test Area Location
Wadi Salah Basin	IV
Wadi Amed Basin	VIII
Dh'bab Basin	X
Mikbaba Basin	XVI
El Hiama Basin	XVII - XVIII
Upper Wadi Houban Basin	XIX

Additionally, Hougfa, Houban and Hougala basins, which currently supply the city system will, in about 1991, again become useful source areas.

Ground water basins in the vicinity of Taiz are formed primarily along zones of structural weakness, i.e., faults or formation contacts in the underlying bedrock. Alluvial debris, consisting of sediments ranging from clay to boulder size, have been deposited within the valleys throughout Tertiary and Quaternary times. During exploration drilling these alluvial deposits were confirmed to exceed depths of 80 meters (260 ft) at some locations. Additionally, it was determined that most valley basins are relatively narrow and frequently have irregular bottom configurations based on buried bedrock surfaces. Table 7-1 lists the pertinent data regarding test well construction completed during the project.

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TABLE 7-1

PROJECT TEST WELL CONSTRUCTION DATA

TAIZ, YEMEN ARAB REPUBLIC

Test Well Designation	Well Head Elevation Meters	Date Complete	Total Depth Meters	Drilling Method	Test Area Designation
TH 1	1158	7-74	28.6	Cable Tool	I
TH 2	1168	8-74	64.9	Cable Tool	II
TH 3	1172	8-74	48.8	Cable Tool	III
TH 4	1212	8-74	79.2	Cable Tool	IV
TH 5	1178	8-74	141.2	Rotary	V
TH 8	990	9-74	79.2	Cable Tool	X
TH 9	993	10-74	42.7	Cable Tool	X
TH10	997	10-74	29.0	Cable Tool	X
TH11	1033	11-74	22.2	Cable Tool	X
TH11A	1034	11-74	21.3	Cable Tool	X
TH12	1031	11-74	19.8	Cable Tool	IX
TH13	1136	10-74	21.9	Cable Tool	VIII
TH14	1320	9-74	183.8	Rotary	XI
TH14A	1225	9-74	61.0	Rotary	XIX
TH14B	1230	9-74	77.1	Rotary	XIX
TH15	1373	10-74	60.9	Rotary	XVIII
TH16	1383	11-74	53.3	Rotary	XVIII
TH19	1293	11-74	18.9	Cable Tool	XVII
TH20				Cable Tool	XVII

Each valley basin explored has a unique combination of hydrogeologic characteristics, the individual features of which are described in the following text and summarized on Table 8-1.

WADI SALAH BASIN

This basin is formed along a drainage system which rises on the north flank of the Jabel Sabir massif. The wadi courses through a broad flat-bottomed valley with precipitous flanks incising the eastern extent of the alluvail fan upon which greater Taiz is founded. This basin lies approximately one kilometer east of the KMWS headquarters.

Surface alluvium in Wadi Salah basin grades from boulder and gravel deposits in the upstream areas to interbedded thick clay and thin sand-gravel zones in the downstream sector. Project Test Hole No. 4 was drilled into the basin to a depth of 79.2 meters and encountered water bearing sands and gravels from 38.4 meters to the total depth of the boring. The results of this test hole indicate that a significant aquifer is present within Wadi Salah basin. Recharge of the Wadi Salah aquifer appears to occur in the coarse alluvium located at the upstream extent of the basin, then moves downgradient beneath a confining blanket of fine grained materials. Downstream the confining zone thickens until sand and gravel zones are extremely sparse, as found in Test Hole No. 2 at the downstream extent of the basin. In this test hole water was not encountered until a depth of 61.9 meters of predominantly fine grained materials were penetrated. The confined water then rose to a static level of 44.2 meters below ground surface. Low permeability of the water bearing zone was demonstrated later when a bailer test (10 bails) emptied the test bore. Water production and quality in the Hougfa area, downstream from Wadi Salah basin, indicates that a buried stream channel or significant aquifer zone not encountered in test drilling must exist to hydraulically link the two areas.

The availability of ground water sources in Wadi Salah is reinforced by the reported existence of a well previously drilled in the basin which was used to supply the "American Camp" prior to completion of the present KMWS system. It was reported by the driller of the well that good production was obtained at this location until a pump failure resulted. Attempts to remove the pump for repair were unsuccessful and the well was later backfilled when system water became available to the Camp facility.

A water sample was obtained from Test Hole No. 4 in Wadi Salah basin upon completion of the well. The analyzed sample indicated a TDS of 1000 mg/l with NO_3 content of 34 mg/l. Other constituent content shows the water to be of good potable quality (see Appendix C).

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Potential production rates from Test Hole 4, unfortunately, could not be tested because local inhabitants pried the welded cap from the casing head and filled the well with large rocks before a test pump could be installed. Nevertheless, geologic and ground water conditions in Test Area IV appear extremely favorable for development of moderate quantities of water to the Taiz system.

WADI AMED BASIN

This basin is located along the course of Wadi Amed approximately 2 kilometers west of the city of Taiz. The basin lies within the area of the dissected alluvial fan that commences at the toe of the Jabel Sabir escarpment. Drainage to the basin is derived from two minor stream courses on the north flank of Jabel Sabir which encompass a total catchment area of approximately 8 square kilometers. Resources in this relatively minor wadi basin were explored to locate a possible source of peak demand water along a proposed pipeline alignment running from a more remote area (Dh'bab Basin), 9 kilometers west of Taiz.

Test Hole 13 penetrated 22 meters of alluvial sediments before reaching the igneous bedrock of the basin bottom. Bore hole samples obtained during drilling indicate coarse grained aquifer material to be present locally from 13.7 to 22 meters. Greater depths of alluvium are considered to exist within the wadi course upstream, as well as in alluvial fan deposits in lateral hydraulic continuity with the wadi aquifer.

On completion of Test Hole No. 13, a water sample was collected and analyzed. This sample was found to contain 710 mg/l TDS and 80 mg/l NO_3 ion. Although the NO_3 content is considered high, this water, if blended with Dh'bab basin waters, will produce a potable high quality supply source (see Appendix C).

Throughout a 9-hour pumping test the test hole indicated a specific capacity of 50 at a pumping rate of 65 gallons per minute. In addition to providing a modest production for system peaking demand, this basin could provide well water for pipeline installation and testing during the construction phase of the project. Results of subsurface investigation in this test area are shown on Tables 7-2, 7-3, and Appendix B.

DH'BAB BASIN

Dh'bab basin is a relatively long and wide stream valley basin located approximately 9 kilometers west of Taiz. Tributary drainage to the

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TABLE 7-2

STATIC WATER LEVEL MEASUREMENTS
IN 1974 PROJECT TEST HOLES AND EXISTING
SHALLOW WELLS, VICINITY OF TAIZ, YEMEN ARAB REPUBLIC

Test Area Designation	General Location	Well Designation	Date Measured / Depth in Meters to Water Surface
I	Middle Wadi Houban	TH No. 1	7/4/74 / 1.5
II	Near Taiz	TH No. 2	7/24/74 / 44.2
III	Near Taiz	TH No. 3	7/27/74 / 20.4
IV	Wadi Salah	TH No. 4	10/74 / 38.4
V	Northeast Taiz	TH No. 5	9/4/74 / 9.1
X	Dh'bab Basin	TH No. 8	9/29/74 / 0.3
X	Dh'bab Basin	TH No. 9	10/74 / 2.4
X	Dh'bab Basin	TH No. 10	10/74 / 1.0
X	Dh'bab Basin	TH No. 11 (P11)	11/12/74 / 12.8
X	Dh'bab basin	TH No. 11A	11/22/74 / 12.8
X	Dh'bab Basin	ESW 2-2	11/18/74 / 19
X	Dh'bab Basin	ESW 2-3	11/18/74 / 28.9

Note: ESW - Existing Shallow Well

13
6
18
221
279
240
50
320

297
88
209
6
215
12 O
227
4 M
231
22 D
253
32
221
253
16
237
64

TABLE 7-2 (Continued)

Test Area Designation	General Location	Well Designation	Date Measured / Depth in Meters to Water Surface
IX	2 KM NE of Dh'bab Basin	TH No. 12	10/13/74 / 11
VIII	Wadi Amad	TH No. 13	10/28/74 / 14.3
XI	Upper Wadi Houban	TH No. 14	9/8/74 / 7.9
XIX	Near Taiz Biscuit Factory	TH No. 14A	9/23/74 / 3.4
XIX	Near Taiz Biscuit Factory	TH No. 14B	10/1/74 / 9
XIX	Near Taiz Biscuit Factory	ESW 1-1	10/74 / 2.9
XIX	Near Taiz Biscuit Factory	ESW 1-2	10/74 / 5.6
XIX	Near Taiz Biscuit Factory	ESW 1-3	10/74 / 6.5
XIX	Near Taiz Biscuit Factory	ESW 1-5	10/74 / 7
XIX	Near Taiz Biscuit Factory	ESW 1-6	10/74 / 6.9
XIX	Near Taiz Biscuit Factory	ESW 1-8	10/74 / 13.7
XIX	Near Taiz Biscuit Factory	ESW 1-9	10/74 / 9.7

Note: ESW - Existing Shallow Well

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TABLE 7-2 (Continued)

Test Area Designation	General Location	Well Designation	Date Measured / Depth in Meters to Water Surface
XIX	Near Taiz Biscuit Factory	ESW 1-10	10/74 / 12.2
XIX	Near Taiz Biscuit Factory	ESW 1-11	10/74 / 12.8
XVIII	Wadi El Hiama	TH No. 15	11/7/74 / 4
XVIII	Wadi El Hiama	TH No. 16	11/16/74 / 12.8
XVIII	Wadi El Hiama	ESW 3-1	11/18/74 / 2
XVIII	Wadi El Hiama	ESW 3-2	11/18/74 / 7.2
XVIII	Wadi El Hiama	ESW 3-4	11/18/74 / 21.5
XVIII	Wadi El Hiama	ESW 3-6	11/18/74 / 17.3
XVIII	Wadi El Hiama	ESW 3-7	11/18/74 / 7.6
XVIII	Wadi El Hiama	ESW 3-8	11/18/74 / 9.3
XVIII	Wadi El Hiama	ESW 3-9	11/18/74 / 9.2
XVIII	Wadi El Hiama	ESW 3-10	11/18/74 / 7.2
XVI	Wadi Mikbaba	TH No. 19	11/17/74 / 3.3
XVI	Wadi Mikbaba	TH No. 20	11/20/74 / 2.8

Note: ESW - Existing Shallow Well

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TABLE 7-3

SUMMARY OF PROJECT TEST HOLE PUMP TESTING
VICINITY OF TAIZ, YEMEN ARAB REPUBLIC

Well Designation	Date Tested	Static Water Level	Maximum Pumping Level	Maximum Drawdown	Q l/s / gpm	Specific Capacity l/s/m / gpm/ft
TH No. 1	7/14/74	1.2 m / 3.9 ft	19.8 m / 64.9 ft	18.6 m / 61 ft	2.6 / 41	0.1 / 0.6
TH No. 2	6/24/74	44.2 m / 145 ft	62 m / 203 ft	17.7 m / 58 ft	1.9 / 30	0.1 / 0.5
TH No. 3	7/27/74	20.4 m / 67 ft	33.23 m / 109 ft	12.8 m / 42 ft	1.3 / 20	0.1 / 0.5
TH No. 10	11/11/74	2.3 m / 7.5 ft	4.9 m / 16 ft	2.6 m / 8.5 ft	23.7 / 375	9.1 / 44
TH No. 11A	12/7/74	13. m / 42.6 ft	14.3 m / 47 ft	1.3 m / 4.3 ft	25.2 / 400	19.4 / 93
TH No. 13	11/17/74	14.5 m / 47.5 ft	14.9 m / 48.8 ft	0.4 m / 1.3 ft	4.1 / 65	10.3 / 50.0
TH No. 14A	10/29/74	3.3 m / 10.8 ft	4.7 m / 15.4 ft	1.4 m / 4.6 ft	18.6 / 295	13.3 / 64.1
TH No. 14B*	10/13/74	9.0 m / 29.5 ft	–	–	23.7 / 375	–
TH No. 15	11/30/74	4.2 m / 13.7 ft	8.2 m / 27 ft	4 m / 13.1 ft	25.2 / 400	6.3 / 30.5
TH No. 16*	11/21/74	10.7m / 35 ft	–	–	31.5 / 500	–

*Well Air Tested Could Not Measure.

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basin is derived from stream systems on the south and west of Dh'bab. The catchment area tributary to the basin includes some 145 square kilometers.

Rocks of igneous origin form the abrupt flanks and bottom of the basin and are prevalent throughout the upstream drainage system. Terrace deposits of older alluvium occur at some locations along the flanks of the basin. These eroded remnants of a former basin surface rise as much as 100 meters above the present valley floor and possibly overly water bearing deposits in hydraulic continuity with aquifers beneath the existing wadi valley. Geologic conditions existing in Dh'bab are delineated on Figures 5-4 and 7-1.

The main basin follows a general north-south trend which is interrupted at the northern basin extent by a continuation of the Jabel Sabir fault zone. Approximately 0.5 kilometers south of this latter fault zone, a west branching wadi joins the main basin. Then, again, 2 kilometers upstream, a second major wadi enters main Dh'bab basin. These secondary wadis both show evidence of having courses controlled by subsurface geologic structure.

Five test borings were made into the alluvium of Dh'bab basin. Test Hole 8 penetrated to the maximum depth of 79 meters without reaching basement rocks. Lithologic logs of the test holes are included in Appendix B and Table 7-1 summarizes test well construction.

Although aquifer material is continuous throughout the basin, silt and clay fractions increase dramatically downstream within the tested sector. Test Hole 8 near the northern limit of the basin penetrated a continuous clayey zone from 52 to 79 meters depth. This condition reveals the probability that a lacustrine environment existed in the lower basin in past geologic time. The presence of two shallow bedrock narrows, located along the Jabel Sabir fault zone at the northern extent of the basin, strongly suggest that fault damming resulted in impoundment of flows upstream, thus providing a still-water depositional environment. Recent down cutting in the narrows has resulted in removal of basin sediments as streams have adjusted to induced gradient changes.

Test Hole 11A, located the greatest distance upstream from the narrows, was drilled to a depth of 32 meters. From 13.7 meters to the total depth of the bore sand and gravel aquifer material is present. It appears probable that in this upstream area a greater thickness of coarse grained alluvium is present. Test Hole 11A was subsequently test pumped at a rate of 400 gallons per minute for 24 hours. The specific capacity

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obtained from this test was 93 gallons per minute per foot of drawdown, indicating the potentially high productivity of the Dh'bab basin aquifer.

Aquifer and/or pump tests were conducted at all wells constructed in Dh'bab basin. Results of these tests are shown on Table 7-3 and Appendix D. These tests indicate the Dh'bab Basin to contain aquifers of moderate to high transmissibility from which wells can produce 400 to 600 gallons of water per minute on a continuous basis.

Transmissibility coefficients obtained ranged from 76,000 to 190,000 gallons per day per foot in the most reliable tests completed. Higher ranges were obtained in other tests; however, pumping interruptions and other sources of errors within the test procedures were considered to adversely influence calculation results and therefore were not included in the basin evaluation.

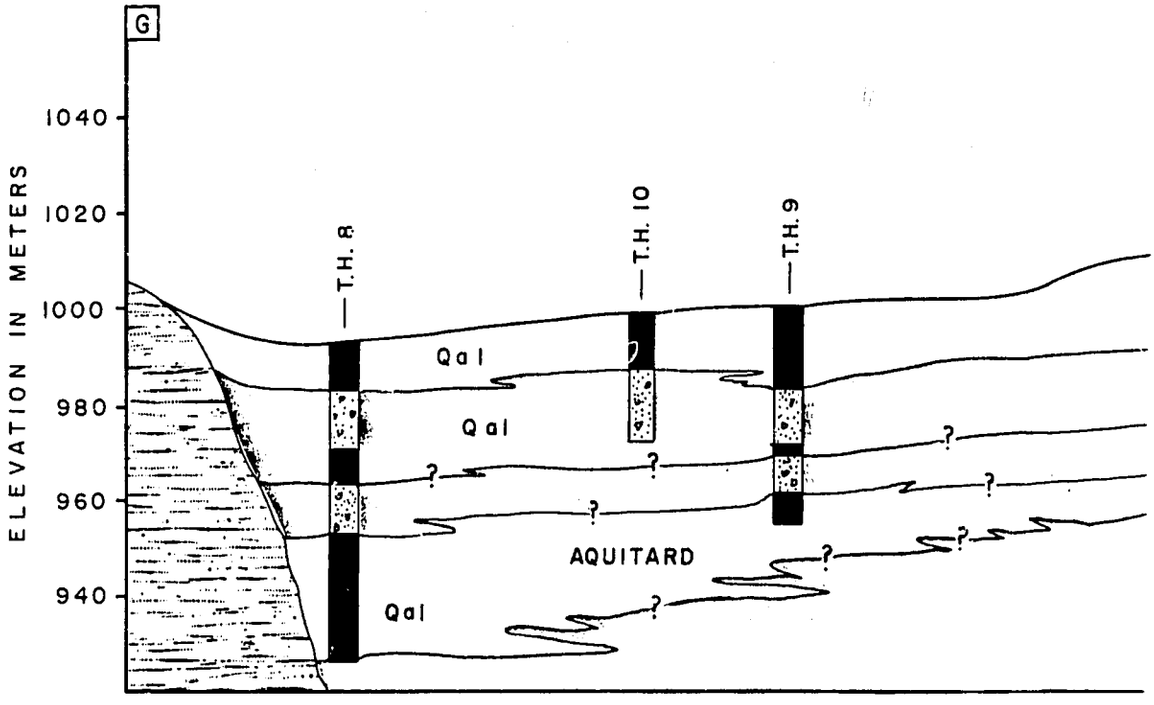
Ground water resources in the basin occur under both free and confined conditions. In the downstream sector water levels are very near the surface over large areas, sometimes causing boggy ground. Near the narrows, at the extreme northern limit of the ground water basin, rising water conditions prevail throughout most years. Geologic cross-sections G-G' and H-H' on Figure 7-1 indicate the probable subsurface hydrogeologic conditions in the basin.

Field investigation determined that a perennial surface stream enters and flows over a portion of the upstream basin. The upstream surface deposits are characteristically comprised of gravel and boulder deposits of high permeability, and probably represent the forebay area for confined aquifers downstream. Portions of the stream flow crossing the forebay are intercepted by local irrigators in a complex system of unlined ditches for flood irrigation of cultivated terraces. This method of irrigation effectively provdies some recharge to shallow underlying aquifers.

During periods of major flooding it appears that uncontrolled surface waters flow across the entire reach of the valley in primary and secondary wadi channels which are undisturbed by cultivation.

The quality of water within Dh'bab basin was determined from four test well samples and was found to be of excellent to good quality in all cases. Total dissolved solids ranged from 480 to 790 mg/l and NO_3, 14.2 to 29 mg/l in the samples analyzed.

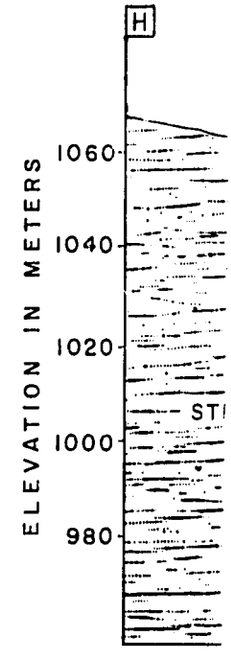
From aspects of both quantity and quality, the waters within Dh'bab basin can be considered a potentially valuable source area for the future

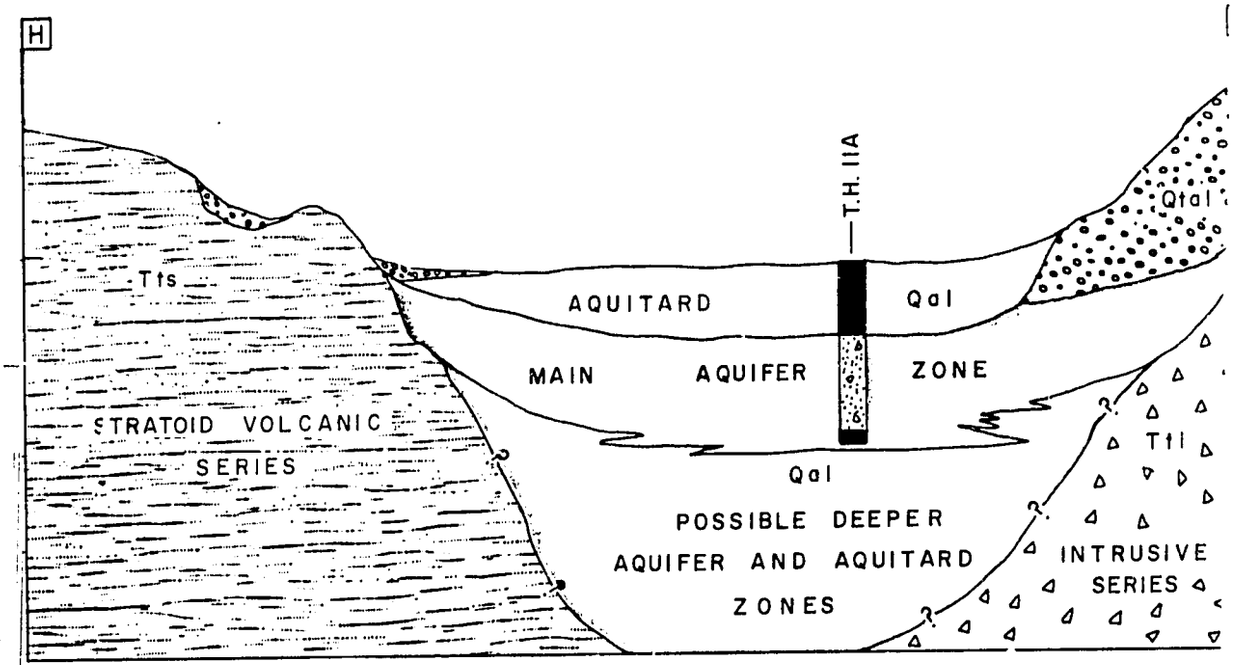


LEGEND

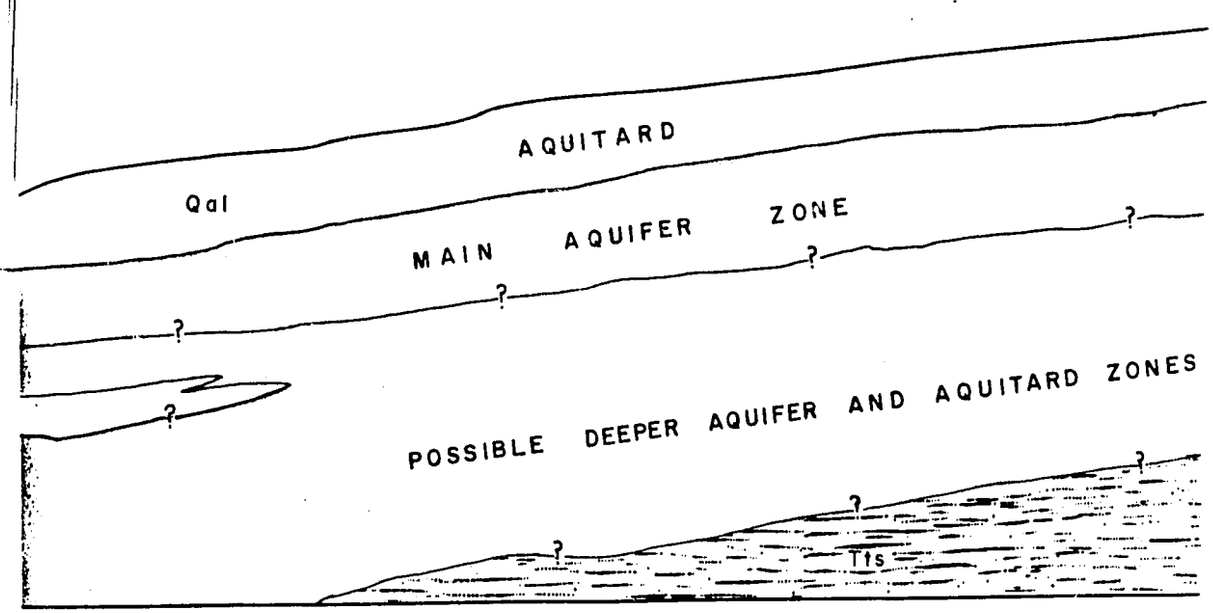
- AQUITARD - CLAYS. SILTS,
- AQUIFER - COARSE SANDS AND GRAVELS
- TERRACE DEPOSITS
- STRATOID VOLCANIC AND CHAOTIC SERIES
- INTRUSIVE SERIES

T.H. IIA - PROJECT TEST WELL





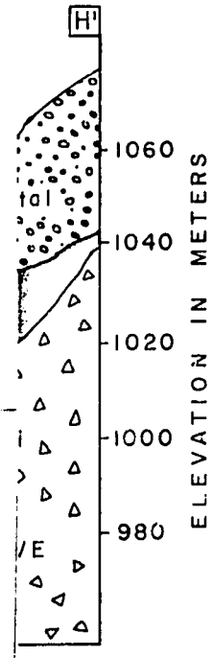
SECTION H - H'



SECTION G - G'

DH' BAB BASIN
GEOLOGIC
CROSS SECTIONS

HORIZONTAL SCALE
1cm = 30m



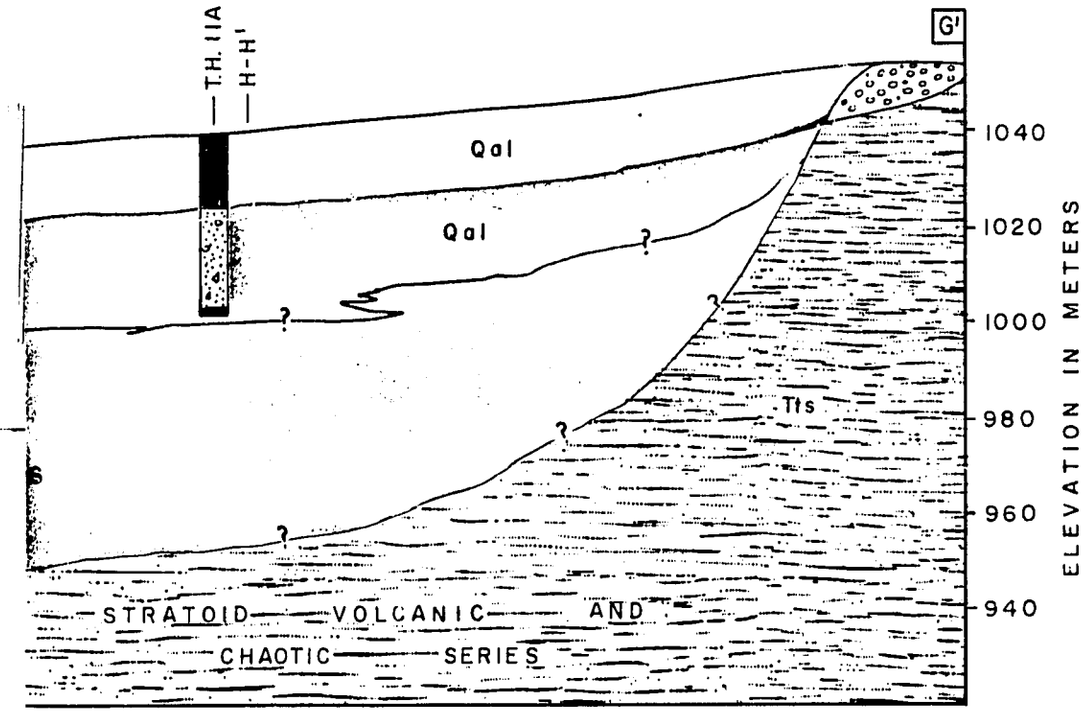


FIGURE 7-1

supply requirements of Taiz. Hydrogeologic data obtained in the course of surface and subsurface investigation of the basin are summarized on Table 8-1.

MIKBABA BASIN

Mikbaba basin is located approximately 14 kilometers southeast of Taiz. The total drainage area tributary to the basin includes more than 300 square kilometers. This potential new source area lies downstream from El Hiama basin which, from water resources considerations, effectively eliminates any catchment area upstream from the Mikbaba-Hiama basin boundary. Therefore, the direct drainage area to Mikbaba is considered to include only 73 square kilometers. All flows leaving Mikbaba continue into a deep bedrock ravine at the southern limit of the basin.

The alluviated portion of this tested basin lies at the intersection of two valleys which trend north-south and east-west respectively. Rocks forming the flanking and bottom boundaries of the alluvium are fine grained igneous types, both acidic and basic, which display well defined flow plane layering. Flow planes dip southeasterly 6 to 11 degrees from the southern limits of the basin and northeasterly 10 to 12 degrees from the northern boundary; suggesting that the basin alluvium has aggraded in a valley along the faulted axis of an eastward plunging anticline (see Figures 5-5 and 7-2). The north-south valley, crossing the anticline axis at right angles, is formed along a fault zone that follows the alignment of El Hiama basin to the north.

Test Holes 19 and 20 were completed in Test Area XVI, one of which penetrated to a depth of more than 29 meters of alluvial material without reaching bedrock. During drilling at Test Hole No. 19 water was encountered at 8 meters and rose in the bore to a static level of 3 meters below the surface.

An analysis of a water sample from Test Hole No. 19 in Mikbaba basin indicated a content of 1000 mg/l TDS with only 18 mg/l NO_3. All other constitutents analyzed (see Appendix C) are within World Health Organization Standards for municipal water supplies.

Ground and surface water recharge to Mikbaba enters the basin from El Hiama basin through a bedrock narrows on the north, and from the two valleys which trend away to the east and west of Mikbaba. A portion of the surface water entering at the Mikbaba-El Hiama narrows is diverted into open ditches to areas of use within the lower reaches of the

basin. The presence of a major, well-defined, stream channel across the entire stretch of the basin attests that flood flows pass through the basin with some frequency. Although lush irrigated vegetation covers most of the central valley sector, naturally wetted surfaces are sparse on the valley floor.

Because of project time and equipment limitations, no pumping tests were conducted in the Mikbaba basin test holes. However, test hole findings, the presence of a confined aquifer, water quality characteristics, and the hydrologic similarities of the basin to the El Hiama basin upstream indicate Mikbaba to be favorable as a new source area for the Taiz water system.

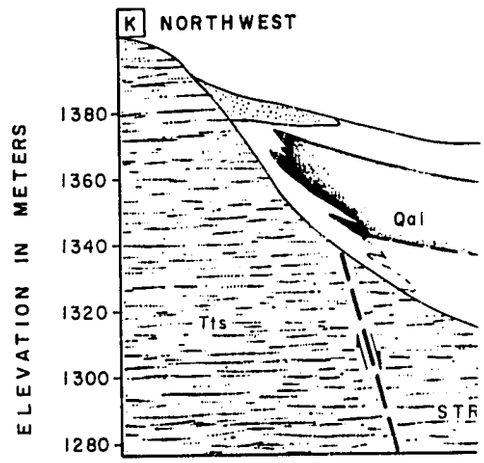
EL HIAMA BASIN

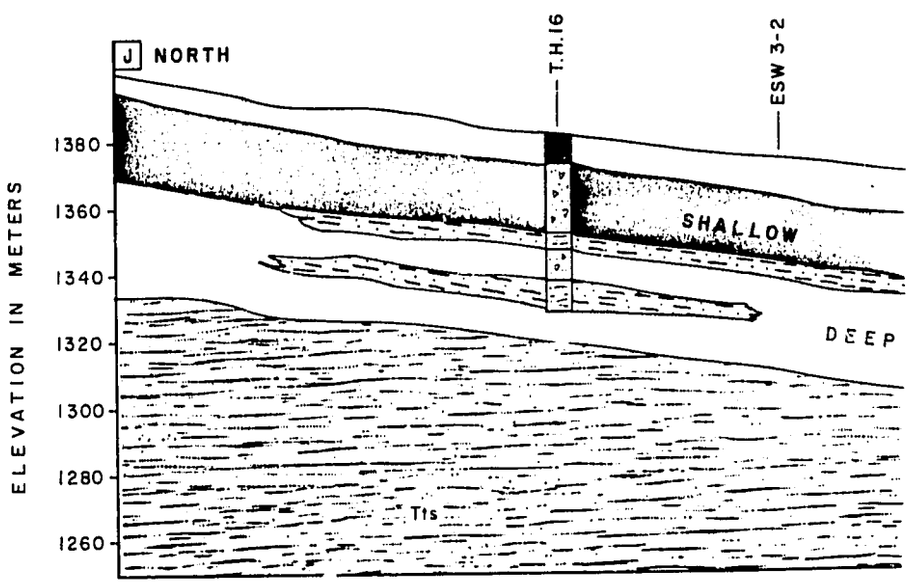
Both test areas XVII and XVIII lie within the basin designated as El Hiama which is located approximately 18 kilometers northeast of Taiz. The floor of the basin valley is more than 10 kilometers long and is 1.5 kilometers wide in some sectors.

Catchment area tributary to El Hiama is on the order of 231 square kilometers, most of which is barren, high mountainous terrain. Surface water enters the basin as a perennial stream from the north. Portions of this flow are diverted through open ditches and directed to lower elevations of irrigated cultivation. The remainder of the surface flows either percolate into the forebay of the ground water basin or flow out on the valley floor to be lost to natural evapotranspiration.

Local inhabitants report that during flood periods large areas of the valley surface are inundated with up to a meter of water. Although the frequency and rates of flooding have not been recorded, the widths and depths of local stream channels suggest that high volume runoff is not uncommon.

Throughout many sectors of the valley floor, crop irrigation is practiced. Field observations reveal that over-irrigation is common and that control of diverted water is somewhat inefficient. These irrigation activities coupled with rising water in the downstream basin sector form a large boggy surface upstream from the Mikbaba-El Hiama narrows. This condition results in an area of excessive water loss from natural and induced evapotranspiration. Both surface and subsurface flows move downstream into Mikbaba basin through the narrows that form the southern extent of El Hiama basin.


K NORTHWEST
ELEVATION IN METERS
1380
1360
1340
1320
1300
1280
Qal
Tts
STR


J NORTH
T.H.16
ESW 3-2
ELEVATION IN METERS
1380
1360
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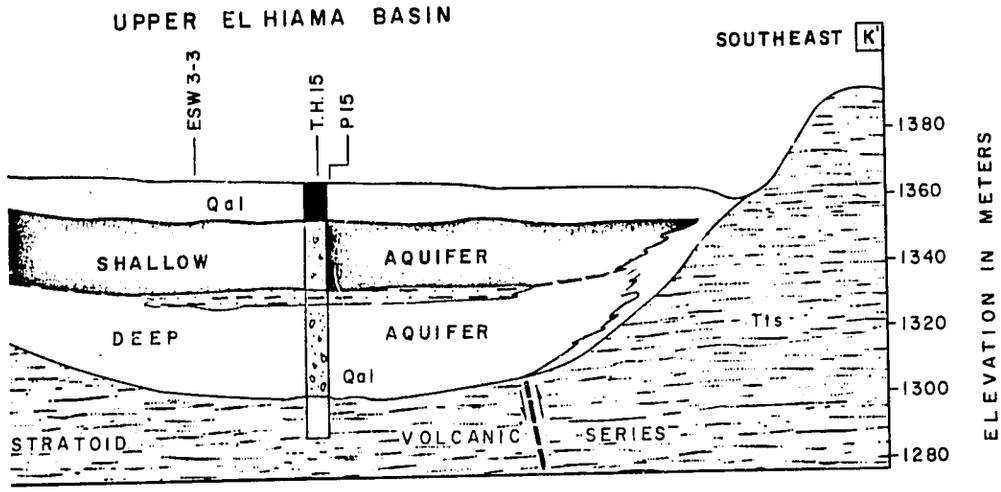
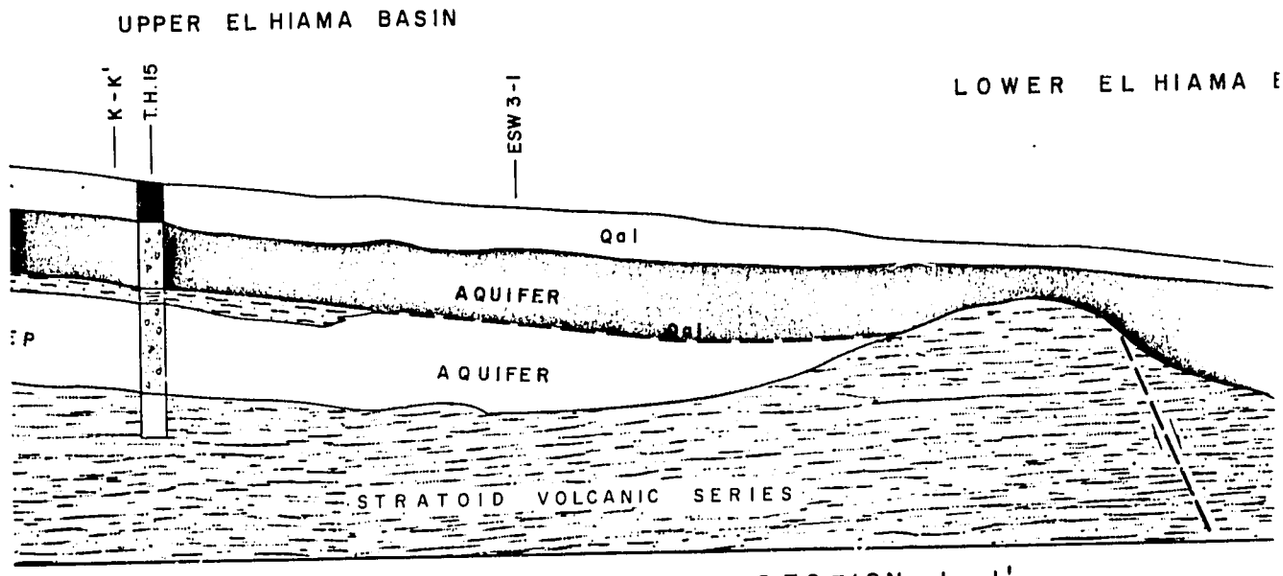
1260
SHALLOW
DEEP
Tts



SECTION K-K'



SECTION J-J'

LEGEND

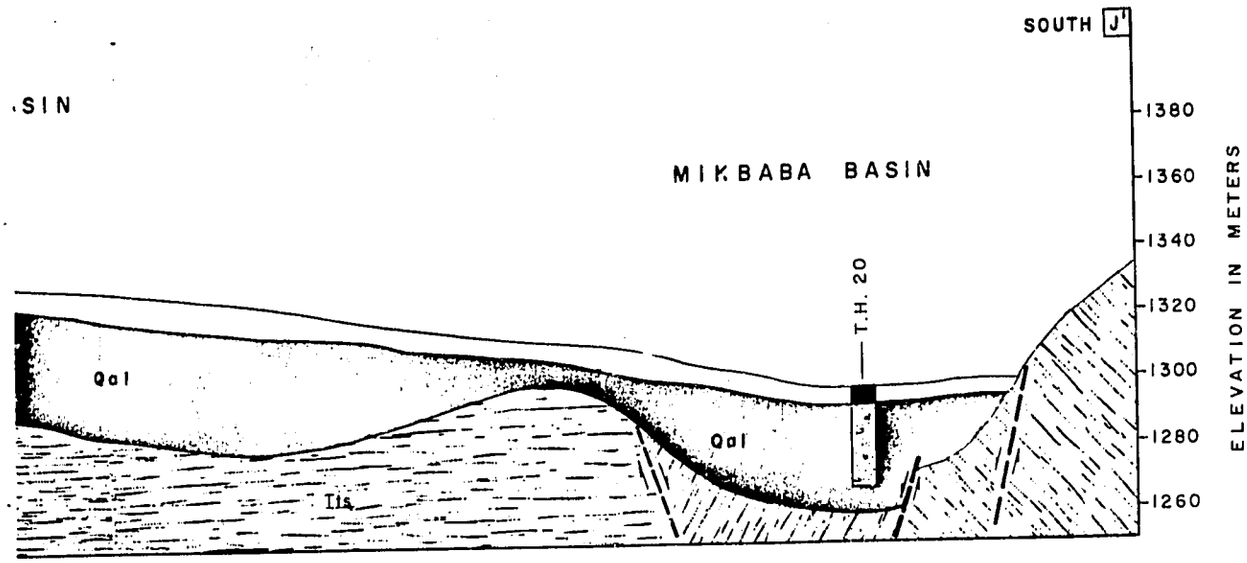
- AQUITARD-CLAY, SILTS,
- SHALLOW AQUIFER-SANDS AND GRAVELS
- DEEP AQUIFER-SANDS AND GRAVEL
- BASALT FLOW
- STRATOID VOLCANIC SERIES
- 16 PROJECT TEST HOLE
- V 3-1 EXIST SHALLOW WELL

UPPER AND LOWER EL HIAMA BASIN

GEOLOGIC CROSS SECTIONS

HORIZONTAL SCALE

1cm = 30m



FIGURE

INC.

7-2

Hydrogeologic Features of New Potential Production Areas

As with many other valleys in the Taiz region, El Hiama follows the trace of a fault zone. This geologic structure is continuous throughout the basin from north to south, strikes through the Mikbaba-El Hiama narrows and becomes obscured south of Mikbaba basin (Test Area XVI).

Test Holes 15 and 16 drilled in El Hiama valley indicate alluvial fill to extend to depths of at least 65 meters. A large section of the alluvium tested consists of sand and gravel zones which are potentially excellent aquifers. Rocks flanking and underlying the valley alluvium are predominantly of fine grained igneous types. These acidic and basic rock types occur in well-defined flow layers which have a general strike of northwest and a dip of 10 degrees north. Formation attitudes appear to be only slightly disrupted from the east to west flanks of the valley fault zone. During test drilling, water was encountered at depths of 4.5 to 10.6 meters below ground surface. Aquifer testing later confirmed that ground water occurs under confined conditions and that highly productive water bearing zones are present in El Hiama basin. Figure 5-5 delineates surface geologic features and Figure 7-2 shows generalized subsurface cross sections through the basin.

Pumping tests performed at Test Holes 15 and 16 show the El Hiama aquifer to be capable of producing moderate to high quantities of water from wells. Tested specific capacity at Test Hole No. 15 was 14.8 gallons per minute per foot of drawdown. Test Hole No. 16 was tested by air lift pumping and produced 500 gallons per minute for a period of 37 hours; however, water levels could not be measured because of the pumping method employed.

An aquifer recovery test was conducted at Test Holes 15 and 16 that resulted in transmissibility coefficients of 93,400 and 206,000 gallons per day per foot respectively (see Appendix D). The test at Test Hole No. 15 would appear to be most representative of aquifer characteristics in view of the specific capacity obtained at the well.

Quality analyses were made of water samples from Test Holes 15 and 16. Total dissolved solids were found to be 600 and 500 mg/l respectively, with a maximum NO_3 content of 9.7 mg/l (see Appendix C). These analyses reveal ground waters in the basin to be of a quality well suited for municipal use.

All surface and subsurface information obtained during the investigation of El Hiama basin indicates that this area has the potential to produce large quantities of water to the proposed new Taiz water system. Table 8-1 summarizes the production potential determined.

UPPER WADI HOUBAN BASIN

Upper Houban basin was added to the recommended test drilling program of August, 1974, after further field surveys indicated that potential water resources were present in the vicinity. The general location of the test area is along the road to the airport approximately 10 kilometers east of Taiz as shown on the revised test drilling program location map (Figure 5-1).

Tributary drainage to Upper Houban basin includes some 30 square kilometers of moderately steep to low rolling topography. Numerous shallow wadis and residual soil covered sectors are present in the lower catchment area. These latter two conditions tend to both decrease surface runoff and increase subsurface inflow to the basin.

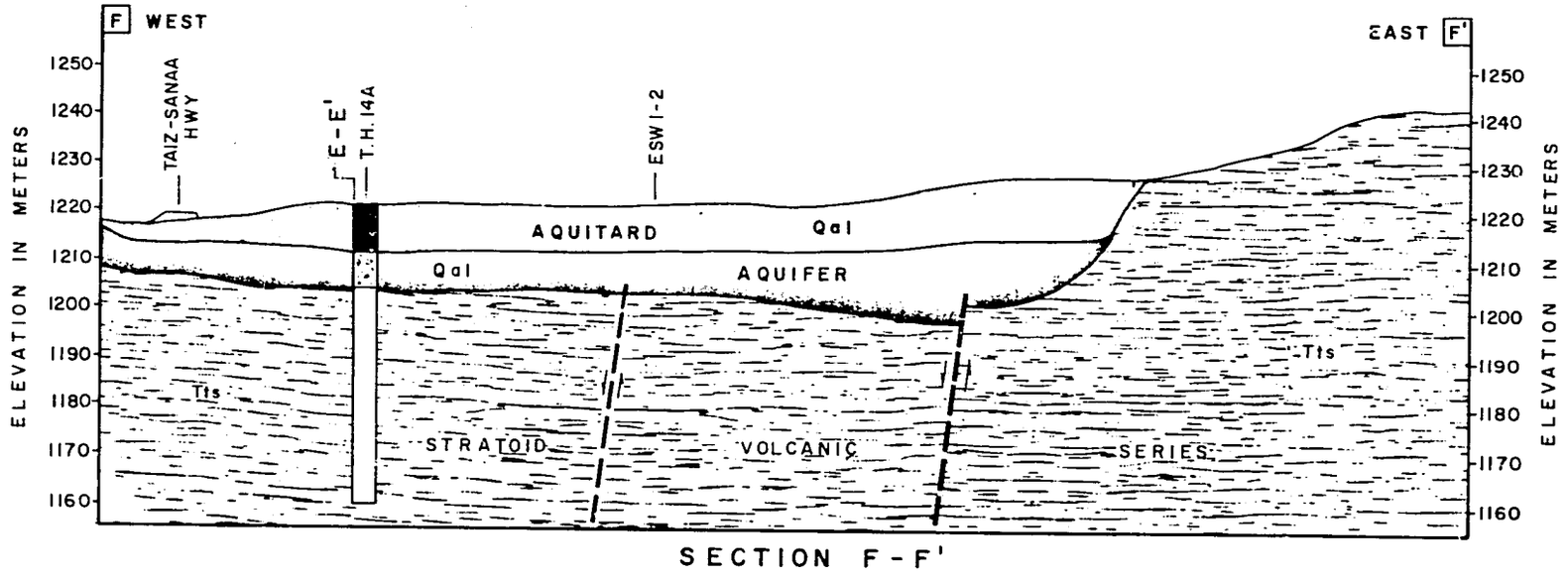
Geologic fault structures apparently control the erosional and depositional patterns in the general region of this basin, but the overall disrupted nature of the locality masks most structural trends. Throughout the vicinity, alluvium mantled surfaces are considered to be underlain by an irregular undulating bedrock surface.

Rocks forming the basin flanks and bottom are primarily of basic igneous origin which have been emplaced at shallow depth or in surface environments. These rocks are regionally referred to as the Trap Series of Tertiary Age. Attitudes obtained on well-defined flow layers in the vicinity indicate regional northeastern striking formations with dips ranging from 8 to 15 degrees south (see Figure 5-3).

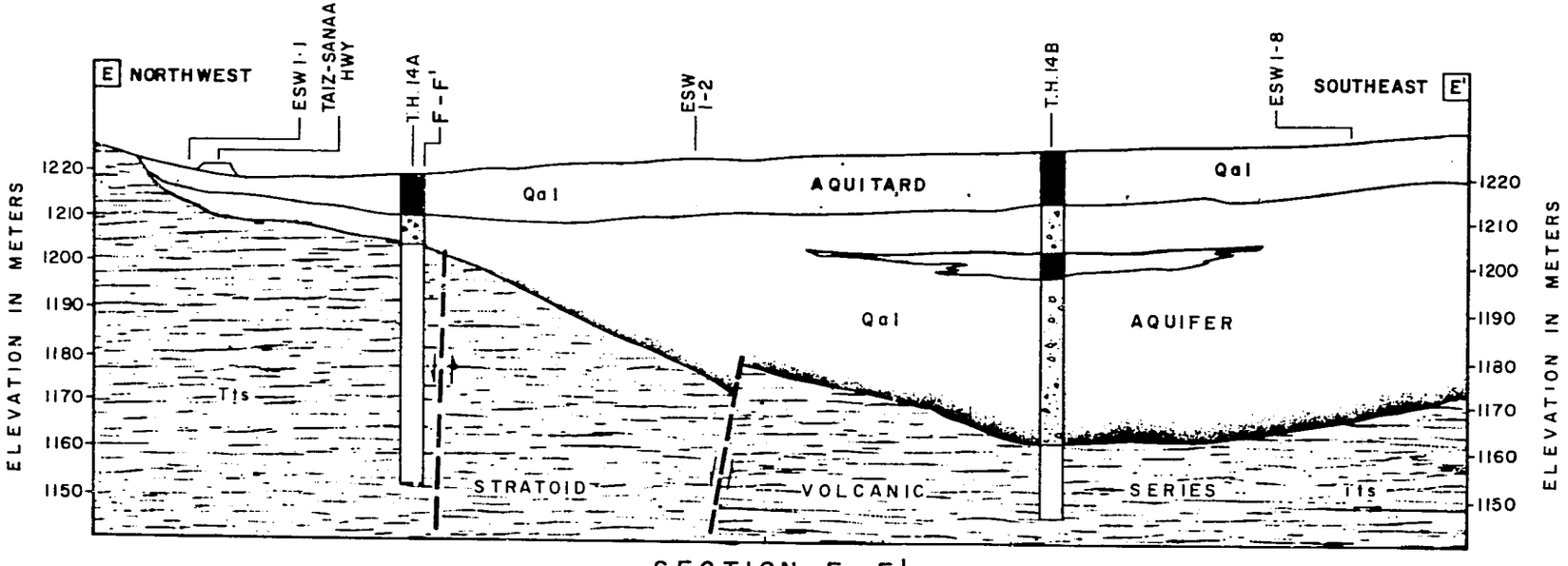
Surface and ground waters enter Upper Wadi Houban from valleys to the north and east, and leave the basin through Wadi Houban (Khowban) which courses south toward Taiz. Rising water and wetted lands occur at and below the narrows which lead from the basin to Wadi Houban.

Agriculture within the basin locality primarily employs dry farming methods. Only a minor area of approximately 10 hectares is currently under irrigated cultivation.

Test Holes No. 14A and 14B were drilled in the basin to total depths of 61 and 77.1 meters respectively; both penetrated bedrock. The static water level in Test Hole No. 14A was 3 meters below ground surface and Test Hole No. 14B, 12.8 meters. Test Hole No. 14B encountered 42 meters of productive aquifer sands and gravels which were developed and test pumped. Geologic cross sections E-E' and F-F' on Figure 7-3 were prepared on bases of project test drilling information.



SECTION F-F'



SECTION E-E'

UPPER WADI HOUBAN GEOLOGIC CROSS SECTIONS

HORIZONTAL SCALE
1cm = 30m

LEGEND

- AQUITARD - CLAYS, SILTS,
- MAIN AQUIFER - COARSE SANDS AND GRAVELS
- STRATOID VOLCANIC SERIES
- T.H. 14A PROJECT TEST HOLE
- ESW I-1 EXISTING SHALLOW WELL

Hydrogeologic Features of New Potential Production Areas

Pump tests were conducted at both Test Holes 14A and 14B to determine potential production and specific capacities to be expected from future system wells. Test Hole No. 14A was produced at a rate of 295 gallons per minute with a resulting specific capacity of 64.1 gallons per minute per foot of drawdown. Test Hole No. 14B was air lift pumped at a rate of 375 gallons per minute, but because of the pumping method, drawdown could not be measured. The quantities of water produced during testing and the specific capacity obtained at Test Hole No. 14A confirm that a useful resource can be derived from the Upper Wadi Houban basin.

Water quality analyses of samples from Test Holes No. 14A and 14B contained 1,000 and 860 mg/l TDS respectively. In the same samples NO_3 ion content was 62 and 48 mg/l. Although these waters contain excessive NO_3 concentrations by World Health Organization Standards, blending with other potential city water sources will result in quality suitable for use in the Taiz system.

Upper Wadi Houban is considered to have only moderate potential as a water source area, but should be capable of producing peak requirement water as well as a small continuous increment to the Taiz water supply. Table 8-1 summarizes the perennial yield of this basin.

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CHAPTER 8

CHAPTER 8

POTENTIAL NEW WATER RESOURCES

In the "Recommended Water Resources Exploration and Test Drilling Program," August, 1974 (Appendix E), it was stated that because of the physical environment, the water economy in the vicinity of Taiz is marginal to slightly surplus. It has subsequently been determined that there is no evidence to indicate any single large surplus surface or ground water resource available for development in the Taiz vicinity. Climatic conditions result in relatively meager perennial stream flows and prevailing geologic features produce only narrow and shallow stream valley ground water basins. Furthermore, test exploration throughout the course of this project has demonstrated that hydrogeologic conditions are regionally unfavorable for the existence or development of large potable water supplies from deep bedrock environments. New water supplies for Taiz must, therefore, be derived from several stream valley basins within a reasonable distance of the city.

During the long history of Yemen, land and water supplies traditionally have been sources of wealth and power. Inhabitants of fertile valleys with surface streams, through the distant past, have developed these resources into relatively rich agricultural areas. The leveling and terracing of land surfaces has increased arable areas while the diversion of surface streams has somewhat improved the dependability of irrigation water supplies. Limitations of gravity flows along open ditches, however, restricts irrigation to the lower sectors of valley bottoms as well as the control of excess flows entering the valley basins. Consequently, in many valleys over-irrigation and inefficient utilization of waters result in excessive consumptive use, evaporation from saturated land areas, and perennial surface and subsurface water outflows.

Within the alluvaited stream valleys evaluated, ground water resources are presently utilized to a very slight extent. As previously stated, current practice is to divert a portion of the surface flows entering a basin and, through open ditches, deliver water to points of use. Undiverted waters percolate into the underlying ground water basin or are lost to evapotranspiration. The few irrigation wells existing in the stream valley basins near Taiz are usually hand-dug, rarely exceed 15 meters in depth, and generally produce less than 100 gallons per minute on discontinuous pumping schedules.

Undeveloped ground water resources contained in the alluvium of the valley basins can, if properly produced, provide additional sources to the city of Taiz without seriously affecting current agricultural activities. In some cases, increased crop yields may even be anticipated through reduction of excessively wetted root zones and the cultivation of presently wetted land surfaces.

BASIN WATER RESOURCE SUMMARIES

Essentially no hydrologic or geologic information had been collected in the potential new source areas prior to the initiation of this project. Therefore, in order to evaluate the potential productivity of the stream valley basins investigated, it was necessary to make original field survey and data collection efforts. The type of information required for such evaluations is usually based on long-term knowledge of physical conditions in a locality. In the absence of such background data many assumptions, based on brief field studies and experience elsewhere, were necessary to perform analyses of the basins.

Using this approach, water resources analysis summaries were prepared for each of the new potential source areas. The Water Resources Analysis Summaries (see Table 8-1) indicate under heading C, the water losses from each basin. Values for these items are based on a number of criteria judgements related to local climatic, hydrologic and geologic observations. It is from these basin water loss surpluses that waters for the Taiz system will be largely derived. The Water Resources Analysis Summaries include ground water basin yield summaries for each source area under heading D.

The results of the basin yield summaries are predicated on six major assumptions:

1. Water will be derived from wells penetrating the deeper basin aquifers.

2. Well production will lower water levels over large portions of the basins, thus inducing resources conservation.

3. With lowered water levels a small decrease in basin storage will occur over long periods (several years) until hydrologic equilibrium is reached whereby natural water supply inflow will equal natural basin losses plus export extraction.

4. Conservation of basin water resources will result from lowered basin water levels by reducing surface outflow, subsurface

outflow, natural evapotranspiration and excessive irrigation evapotranspiration.

5. Conservation of available waters will occur during periods of excessive surface inflow by allowing recharge of storage volume depleted by ground water production.

6. Conserved waters represent the perennial yield of each basin that is possible without causing significant alterations of existing cultivation practices.

If these six assumptions are considered valid, the potential average daily ground water yields for each of the basin areas will be approximately as follows:

Basin Designation	Test Area Designation	Potential Average Daily Basin Yield
Wadi Salah	IV	0.32 mgd / 1210 cu m/d ± 10%
Wadi Amed	VIII	0.12 mgd / 454 cu m/d ± 20%
Dh'bab	X	1.8 mgd / 6808 cu m/d ± 10%
Mikbaba	XVI	1.1 mgd / 4160 cu m/d ± 10%
El Hiama	XVII-XVIII	4.2 mgd / 15880 cu m/d ± 10%
Upper Wadi Houban	XIX	0.33 mgd / 1248 cu m/d ± 10%

The quantities listed above were taken from Table 8-1, line D-6.

Table 8-1 summarizes hydrogeologic features of each potential new ground water source area explored. Values of listed items were determined for all areas in the following manner:

A. Available Recharge

1. Drainage tributary to basin - Planimeter of drainage outlines as determined on 1:65000 scale air photos.

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2. Estimated average precipitation - Comparison of general features of elevation, topography, and orographic characteristics with Taiz.

3. Estimated percent tributary runoff to basin - Comparison and judgement with areas outside Yemen where runoff factors have been developed for similar terrain and rainfall characteristics.

4. Estimated volume of runoff available for recharge - Item 1 x Item 2 x Item 3.

5. Estimated subsurface inflow - Percent of Item 4 judged appropriate to rock type and attitudes surrounding each basin.

6. Estimated volume available to basin recharge - Item 4 + Item 5.

B. Available Basin Storage

1. Basin surface area - Planimeter of mapped alluvial surface.

2. Estimated average thickness saturated sediments - From test hole data and basin configuration.

3. Estimated average specific yield of sediments - From characteristics of formation samples collected from test holes.

4. Estimated total developable water in storage - Item 1 x Item 2 x Item 3.

C. Water Losses from Basin

1. Estimated surface outflow - From observations of stream flows throughout the rainfall season. Value does not include excessive flood outflow.

2. Estimated subsurface outflow - From estimates of subsurface aquifer cross-section, aquifer permeability and water level gradient of a lower portion of basin.

3. Estimated loss to natural evapotranspiration - Losses from seasonally and perennial naturally wetted surfaces in the basin due to evaporation and excess vegetation transpiration.

4. Estimated loss to irrigation evapotranspiration - Losses induced from over-irrigation practices within basin irrigation systems.

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5. Estimated total losses from basin - Total Items 1 + 2 + 3 + 4.

D. Ground Water Basin Yield

1. Conserved yield from surface outflow - Estimated quantity of Item C-1 which would infiltrate basin under proper operating conditions.

2. Conserved yield from subsurface outflow - Estimated quantity of Item C-2 which could be captured by wells before leaving basin as ground water flow.

3. Conserved yield from evapotranspiration - Estimated quantity of Item C-3 which could be conserved by lowering excessively high water levels and reducing wetted surface areas in basin.

4. Conserved yield from irrigation evapotranspiration - Estimated quantity of Item C-4 which could be conserved by lowering water levels in forebay and shallow aquifer areas, thus reducing over-irrigation.

5. Potential perennial ground water yield - Total Items 1 + 2 + 3 + 4.

6. Potential average daily ground water yield - Item 5 + 365.

RECOMMENDED APPROACH TO PRODUCTION DRILLING PROGRAM - TAIZ WATER PROJECT

GENERAL

It should be emphasized that the water resources evaluation was performed as only one part of an overall feasibility study for a water supply and sewerage system for Taiz. The water resources portion of the study was therefore subject to the same time and budget constraints, and level of objectives sought for other areas of the total project program, i.e. feasibility of developing additional water supply and sewerage systems for the city.

The feasibility of developing additional water resources within a reasonable distance of Taiz has been demonstrated, but the level of investigation can be considered to have produced only general conclusions regarding physical characteristics of new resource areas. Therefore, all conclusions are subject to further verification and refinement before final facilities design can be completed.

TABLE 8-1

WATER RESOURCES ANALYSIS SUMMARIES
OF NEW SOURCE AREAS

TEST AREA IV
WADI SALAH BASIN

A.	**AVAILABLE RECHARGE**	
1.	Drainage Tributary to Basin	22 km^2
2.	Estimated Average Precipitation	600 mm/yr
3.	Estimated % Tributary Runoff to Basin	7 %
4.	Estimated Volume of Runoff Available for Recharge	924,000 m^3/yr
5.	Estimated Subsurface Inflow (6% Item 4)	50,000 m^3/yr
6.	Estimated Volume Available to Basin Recharge	974,000 m^3/yr
B.	**AVAILABLE BASIN STORAGE**	
1.	Basin Surface Area	0.4 km^2
2.	Estimated Average Thickness Saturated Sediments	30 m
3.	Estimated Average Specific Yield of Sediments	12 %
4.	Estimated Total Water in Storage	1,440,000 m^3
C.	**WATER LOSSES FROM BASIN**	
1.	Estimated Surface Outflow	262,000 m^3/yr
2.	Estimated Subsurface Outflow (based on wq)	250,000 m^3/yr
3.	Estimated Loss to Natural Evapotranspiration	120,000 m^3/yr
4.	Estimated Loss to Irrigation Evapo-transpiration	320,000 m^3/yr
		952,000 m^3/yr
	Balance Error = 3% (+)	
D.	**GROUND WATER BASIN YIELD**	
1.	Conserved Yield from Surface Outflow	150,000 m^3/yr
2.	Conserved Yield from Subsurface Outflow	150,000 m^3/yr
3.	Conserved Yield from Natural Evapo-transpiration	20,000 m^3/yr
4.	Conserved Yield from Irrigation Evapo-transpiration	120,000 m^3/yr
5.	Potential Perennial Ground Water Yield	440,000 m^3/yr
6.	Potential Average Daily G.W. Yield	.32 mgd avg ± 10% 1211 m^3/day

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TABLE 8-1 (Continued)

TEST AREA VIII
WADI AMAD BASIN

A.	**AVAILABLE RECHARGE**	
1.	Drainage Area Tributary to Basin	8.0 km^2
2.	Estimated Average Precipitation	650 mm
3.	Estimated % Tributary Runoff to Basin	7%
4.	Estimated Volume Available to Basin Recharge	364,000 m^3/yr
B.	**AVAILABLE BASIN STORAGE**	
1.	Basin Surface Area	0.2 km^2
2.	Estimated Average Thickness Saturated Sediments	10 m
3.	Estimated Average Specific Yield of Sediments	12%
4.	Estimated Total Water in Storage	240,000 m^3
C.	**WATER LOSSES FROM BASIN**	
1.	Estimated Surface Outflow	105,000 m^3/yr
2.	Estimated Subsurface Outflow	10,000 m^3/yr
3.	Estimated Evaporation and Transpiration	160,000 m^3/yr
4.	Estimated Irrigation Evapotranspiration	60,000 m^3/yr
5.	Estimated Total Basin Losses	326,000 m^3/yr
	Balance Error = 11% (+)	
D.	**GROUND WATER BASIN YIELD**	
1.	Conserved Yield from Surface Outflow	75,000 m^3/yr
2.	Conserved Yield from Subsurface Outflow	5,000 m^3/yr
3.	Conserved Yield from Natural Evapotranspiration	60,000 m^3/yr
4.	Conserved Yield from Irrigation Evapotranspiration	20,000 m^3/yr
5.	Potential Perennial Ground Water Yield	160,000 m^3/yr
6.	Potential Average Daily G. W. Yield	0.12 mgd avg ± 20% 454 m^3/day

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TABLE 8-1 (Continued)

TEST AREA X
DH'BAB BASIN

A.	**AVAILABLE RECHARGE**	
1.	Drainage Area Tributary to Basin	145 km^2
2.	Estimated Average Precipitation	600 mm/yr
3.	Estimated % Tributary Runoff to Basin	7 %
4.	Estimated Volume of Runoff Available for Recharge to Basin	6,090,000 m^3/yr
5.	Estimated Percentage Lost to Irrigation Diversion	20%
6.	Estimated Surface Inflow Available for Recharge	4,870,000 m^3/yr
7.	Estimated Subsurface Inflow (4% Item 4)	250,000 m^3/yr
8.	Estimated Volume Available to Basin Recharge	5,120,000 m^3/yr
B.	**AVAILABLE BASIN STORAGE**	
1.	Basin Surface Area	3.6 km^2
2.	Estimated Average Thickness Saturated Sediments	30 m
3.	Estimated Average Specific Yield of Sediments	12 %
4.	Estimated Total Water in Storage	12,960,000 m^3
C.	**WATER LOSSES FROM BASIN**	
1.	Estimated Surface Outflow (rising and tail waters)	1,790,000 m^3/yr
2.	Estimated Subsurface Outflow	274,000 m^3/yr
3.	Estimated Natural Evaporation and Transpiration	1,860,000 m^3/yr
4.	Estimated Irrigation Evaporation and Transpiration	1,220,000 m^3/yr
		5,144,000 m^3/yr
	Balance Error = 1% (-)	
D.	**GROUND WATER BASIN YIELD**	
1.	Conserved Yield from Surface Outflow	1,300,000 m^3/yr
2.	Conserved Yield from Subsurface Outflow	200,000 m^3/yr
3.	Conserved Yield from Natural Evapo-transpiration	600,000 m^3/yr
4.	Conserved Yield from Irrigation Evapo-transpiration	400,000 m^3/yr
5.	Potential Perennial Ground Water Yield	2,500,000 m^3/yr
6.	Potential Average Daily G. W. Yield	1.8 mgd avg ± 10% 6813 m^3/day

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TABLE 8-1 (Continued)

TEST AREA XVI
MIKBABA BASIN

A.	**AVAILABLE RECHARGE**	
1.	Drainage Tributary to Basin	73 km^2
2.	Estimated Average Precipitation	600 mm/yr
3.	Estimated % Tributary Runoff to Basin	7 %
4.	Estimated Volume of Runoff Available for Recharge	3,070,000 m^3/yr
5.	Estimated Subsurface Inflow from Haima Basin	500,000 m^3/yr
6.	Estimated Surface Inflow from Haima Basin	3,150,000 m^3/yr
7.	Estimated Volume Available to Basin Recharge	6,720,000 m^3/yr
B.	**AVAILABLE BASIN STORAGE**	
1.	Basin Surface Area	1.2 km^2
2.	Estimated Average Thickness Saturated Sediments	15 m
3.	Estimated Average Specific Yield Sediments	8 %
4.	Estimated Total Water in Storage	1,440,000 m^3
C.	**WATER LOSSES FROM BASIN**	
1.	Estimated Surface Outflow	2,630,000 m^3/yr
2.	Estimated Subsurface Outflow	1,050,000 m^3/yr
3.	Estimated Loss to Natural Evapo-transpiration	1,200,000 m^3/yr
4.	Estimated Loss to Irrigation Evapo-transpiration	1,500,000 m^3/yr
5.	Total Water Losses from Basin	6,380,000 m^3/yr
	Balance Error = 5% (-)	
D.	**GROUND WATER BASIN YIELD**	
1.	Conserved Yield from Surface Outflow	600,000 m^3/yr
2.	Conserved Yield from Subsurface Outflow	300,000 m^3/yr
3.	Conserved Yield from Natural Evapo-transpiration	200,000 m^3/yr
4.	Conserved Yield from Irrigation Evapo-transpiration	400,000 m^3/yr
5.	Potential Perennial Ground Water Yield	1,500,000 m^3/yr
6.	Potential Average Daily G.W. Yield	1.1 mgd avg ± 10% 4164 m^3/day

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TABLE 8-1 (Continued)

TEST AREAS XVII - XVIII
EL HIAMA BASIN

A.	**AVAILABLE RECHARGE**	
1.	Drainage Area Tributary to Basin	231 km^2 (approx)
2.	Estimated Average Precipitation	650 mm/yr
3.	Estimated % Tributary Runoff to Basin	7 %
4.	Estimated Volume of Runoff Available for Recharge to Basin	10,510,000 m^3/yr
5.	Estimated Subsurface Inflow (5% Item 4)	525,000 m^3/yr
6.	Estimated Volume Available to Basin Recharge	11,035,000 m^3/yr
B.	**AVAILABLE BASIN STORAGE**	
1.	Basin Surface Area	13.0 km^2
2.	Estimated Average Thickness Saturated Sediments	40 m
3.	Estimated Average Specific Yield of Sediments	10 %
4.	Estimated Total Water in Storage	52,000,000 m^3
C.	**WATER LOSSES FROM BASIN**	
1.	Estimated Surface Outflow	3,150,000 m^3/yr
2.	Estimated subsurface Outflow	500,000 m^3/yr
3.	Estimated Loss to Natural Evapo-transpiration	4,230,000 m^3/yr
4.	Estimated Loss to Irrigation Evapo-transpiration	3,400,000 m^3/yr
5.	Total Water Losses from Basin	11,280,000 m^3/yr
	Balance Error = 2% (-)	
D.	**GROUND WATER BASIN YIELD**	
1.	Conserved Yield from Surface Outflow	2,000,000 m^3/yr
2.	Conserved Yield from Subsurface Outflow	250,000 m^3/yr
3.	Conserved Yield from Natural Evapo-transpiration	2,200,000 m^3/yr
4.	Conserved Yield from Irrigation Evapo-transpiration	1,400,000 m^3/yr
5.	Potential Perennial Ground Water Yield	5,850,000 m^3/yr
6.	Potential Average Daily G.W. Yield	4.2 mgd avg ± 10% 15897 m^3/day

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TABLE 8-1 (Continued)

TEST AREA XIX
UPPER WADI HOUBAN BASIN

A.	**AVAILABLE RECHARGE**	
1.	Drainage Tributary to Basin	30 km^2
2.	Estimated Average Precipitation	600 mm/yr
3.	Estimated % Tributary Runoff to Basin	5 %
4.	Estimate Volume of Runoff Available for Recharge	900,000 m^3/yr
5.	Estimated Subsurface Inflow (10% Item 4)	90,000 m^3/yr
6.	Estimated Volume Available to Basin Recharge	990,000 m^3/yr
B.	**AVAILABLE BASIN STORAGE**	
1.	Basin Surface Area	1.2 km^2
2.	Estimated Average Thickness Saturated Sediments	15 m
3.	Estimated Average Specific Yield of Sediments	10 %
4.	Estimated Total Water in Storage	1,800,000 m^3
C.	**WATER LOSSES FROM BASIN**	
1.	Estimated Surface Outflow	525,000 m^3/yr
2.	Estimated Subsurface Outflow	7,000 m^3/yr
3.	Estimated Evaporation and Transpiration	360,000 m^3/yr
4.	Estimated Irrigation Evapotranspiration	30,000 m^3/yr
5.	Estimated Total Basin Losses	922,000 m^3/yr
	Balance Error = 2% (+)	
D.	**GROUND WATER BASIN YIELD**	
1.	Conserved Yield from Surface Outflow	325,000 m^3/yr
2.	Conserved Yield from Subsurface Outflow	4,000 m^3/yr
3.	Conserved Yield from Natural Evapo-transpiration	120,000 m^3/yr
4.	Conserved Yield from Irrigation Evapo-transpiration	10,000 m^3/yr
5.	Potential Perennial Ground Water Yield	459,000 m^3/yr
6.	Potential Average Daily G.W. Yield	0.33 mgd avg ± 10% 1249 m^3/day

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It is believed, however, that sufficient information was derived in the course of the water resources evaluation to justify proceeding with efforts to develop the water resources as recommended in this report.

The test drilling program formulated and executed in the course of the project determined that it is feasible to develop ground water resources in at least six new locations in the vicinity of Taiz. Although test bores were completed in these new source areas, test drilling is not considered complete enough to determine final well locations or designs for all production well fields. Further test drilling is therefore recommended in all new source areas prior to production drilling.

Test Drilling

Additional test drilling should be performed in the Phase I source area (El Hiama) at the earliest possible time prior to the commencement of production well and transmission line construction. This additional drilling will better define the most favorable locations for production wells and optimum well designs to be employed. All testing procedures should be conducted under the direction of a qualified hydrogeologist. Equipment provided for testing can be of the percussion (cable tool) or rotary type; however, the latter type is strongly recommended. If possible, under the Phase I production program, an expanded test drilling program should be instituted to include the other potential new water source areas planned for use in later phases of the Taiz Water Supply Project. Of particular value would be additional information in Dh'bab basin, Wadi Salah basin and Mikbaba basin. With such information available later expansions of system water supplies could proceed without preliminary testing programs.

Production Drilling

Production well drilling should directly follow or, if possible, operate concurrently with test drilling. Phase I production drilling and testing for the Taiz Water System should be performed under the direction of a qualified well construction specialist. Only rotary drilling is recommended for system wells since gravel envelope wells will be required. Wells of the rotary gravel pack (envelope) type are considered mandatory because of the drilling environment in the El Hiama source area and the low turbidity requirements of produced waters necessary for proposed water system operations.

It can be assumed that the equipment recommended for drilling production wells must be imported into the Yemen Arab Republic along

with qualified operating personnel. Observations made during the course of the test drilling project revealed major inadequacies of equipment, personnel, logistics, operations control and support of rotary rigs currently deployed in the YAR.

Figure 8-1 depicts a generalized well design which is suited to the ground water environment and production rates to be required for Phase I water supplies.

It should be noted that no special non-corrosive materials are specified. Such precautions are not considered necessary since water well equipment currently operating, as well as water quality characteristics, indicate special materials to be unnecessary.

RECOMMENDED DATA COLLECTION PROGRAM

During the initial period of this project the paucity of basic data regarding existing system sources and regional hydrologic conditions became extremely obvious. During the approximately 10 years of previous system operations only a meager amount of data had been collected, and that occurred either by chance or through the initiative of some dedicated individual.

Currently, there is no known systematic resources data collection or filing program operational within the KMWS. Throughout the current feasibility project, technicians employed by KMWS were consistently encouraged to participate in data collection efforts and, in addition, were made cognizant of the importance of continuing resources data acquisition.

At the time the Taiz Water System is expanded to provide a supply of several million gallons per day, resources data collection, storage, and analysis should become a regular function of system operations.

When well production to the Taiz System is initiated a finite program for resources data handling should be formulated. Until that time, information should be collected by present KMWS technicians from test holes constructed during this project, shallow wells in the vicinity of potential new water sources, and at miscellaneous points as follows:

1. Static water levels in all existing system wells should be measured during the last week of each month.

2. Pumping water levels in all existing system wells should be measured during the last week of each month.

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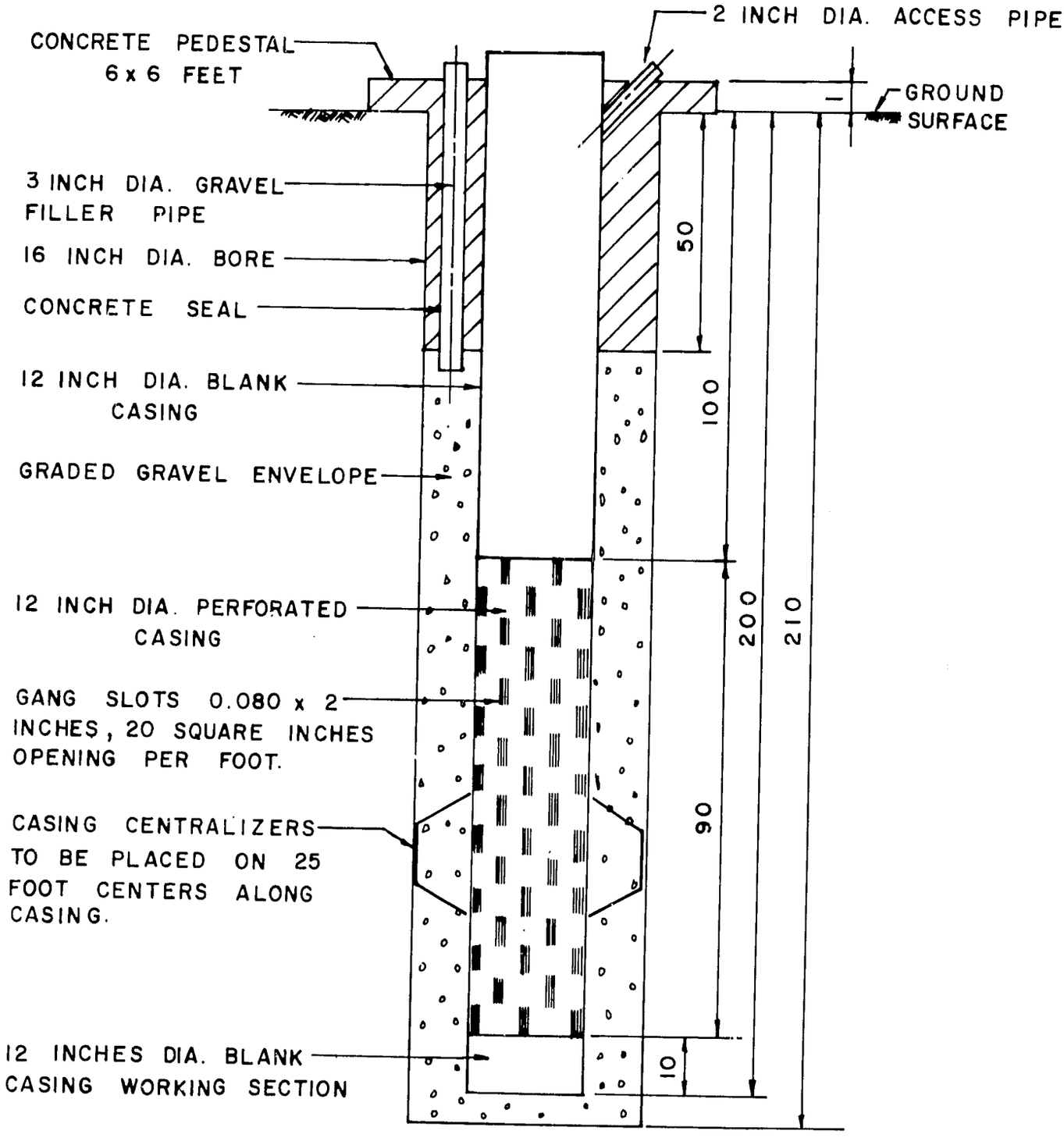
3. Water quality analyses of existing system well waters should be made at the end of March and the end of October each year to determine at least, total dissolved solids, chloride ion, and nitrate ion content.

4. Static water levels in all feasibility project wells where measurement access is still possible.

5. Continuously maintained precipitation and temperature stations should be established at the KMWS offices and at least two other permanent governmental establishments, such as the Taiz airport and the proposed El Hiama well field.

6. All information regarding as-built well designs, equipment installations, equipment changes, well maintenance, well testing and any other items of data pertinent to each system water well should be continuously filed and updated.

The data collection program outlined above is considered minimal, therefore any expansion in this program possible within the current KMWS organization would be considered to be of significant benefit.



NOT TO SCALE

NOTES :

1. ALL MEASUREMENT IN FEET UNLESS OTHERWISE NOTED.
2. ALL MEASUREMENTS ARE APPROXIMATE. FINAL DESIGN OF EACH WELL WILL BE BASED ON TEST BORING INFORMATION.

TAIZ WATER SUPPLY AND SEWERAGE PROJECT

GENERALIZED WATER WELL DESIGN FOR EL HIAMA BASIN

FIGURE 8-1

APPENDIX A

Logs of Houban and Hougala Wells

HOUBAN WELL No. 1

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil and Clay	0 / 0	26 / 7.9	26 / 7.9
Blue Clay	26 / 7.9	59 / 18	33 / 10
Soft Clay and Gravel	59 / 18	63 / 19.2	4 / 1.2
Sand and Gravel	63 / 19.2	71 / 21.6	8 / 2.4
Sand, Gravel, Clay	71 / 21.6	96 / 29.2	25 / 7.6
Broken Basalt	96 / 29.2	100 / 30.5	4 / 1.2
Stratified Rock	100 / 30.5	111 / 33.8	11 / 3.4
Rock with Clay	111 / 33.8	115 / 35.1	4 / 1.2
Marl or Shale	115 / 35.1	125 / 38.1	10 / 3.0

Surface Elevation: 1122.0 m
Static Water Level: 18.3 m BGS
Date Completed: 1962

HOUBAN WELL No. 2

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Sand-Clay with Gravel	0 / 0	33.7 / 10.3	33.7 / 10.3
Vary Hard Sandstone	33.7 / 10.3	38.7 / 11.8	5 / 1.5
Sand-Clay with Gravel	38.7 / 11.8	58.7 / 17.9	20 / 6.1
Sand-Gravel	58.7 / 17.9	63.2 / 19.3	4.5 / 1.4
Sand and Gravel with Small Boulders	63.2 / 19.3	79 / 24.1	15.8 / 4.8
Hard Rock	79 / 24.1	93.7 / 28.6	14.7 / 4.5

Surface Elevation: 1112.7 m
Static Water Level: 12.4 m BGS
Date Completed: 1962

HOUBAN WELL No. 3

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Surface Soil	0 / 0	16 / 4.9	16 / 4.9
Shale and Lime Shells	16 / 4.9	45 / 13.7	29 / 8.8
Water and Sand	45 / 13.7	51 / 15.5	6 / 1.8
Grey Lime	51 / 15.5	57 / 17.4	6 / 1.8
Hard Sandy Shale	57 / 17.4	68 / 20.7	11 / 3.4
Gravel Sand and Small Boulders	68 / 20.7	75 / 22.9	7 / 2.1
Lime	75 / 22.9	76 / 23.1	1 / 0.3

Surface Elevation: 1099.6 m
Static Water Level: 9.3 m BGS
Date Completed: 1962

HOUBAN WELL No. 3A

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	15 / 4.6	15 / 4.6
Coarse Sand	15 / 4.6	35 / 10.7	20 / 6.1
Fine Sand	35 / 10.7	55 / 16.8	20 / 6.1
Sandy Clay	55 / 16.8	65 / 19.8	10 / 3

Surface Elevation: -
Static Water Level: 11.9 m BGS
Date Completed: 1962

Logs of Houban and Hougala Wells

HOUBAN WELL No. 4

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Surface Soil and Clay	0 / 0	18 / 5.5	18 / 5.5
Sticky Grey Shale	18 / 5.5	45 / 13.7	27 / 8.2
Hard Sand	45 / 13.7	51 / 15.5	6 / 1.8
Hard Broken Lime and Sand	51 / 15.5	65 / 19.8	14 / 4.3
Gravel and Sand	65 / 19.8	76 / 23.1	11 / 3.4
Hard Lime	76 / 23.1	80 / 24.3	4 / 1.2

Surface Elevation: 1099.1 m
Static Water Level: 9.7 m BGS
Date Completed: 1962

HOUBAN WELL No. 4A

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Sand with Stones	0 / 0	30 / 9.1	30 / 9.1
Clay with Stones	30 / 9.1	40 / 12.2	10 / 3.0
Black Clay	40 / 12.2	50 / 15.2	10 / 3.0
Clay	50 / 15.2	55 / 16.8	5 / 1.5
White Rock	55 / 16.8	90 / 27.4	35 / 10.7
White and Brown Rock	90 / 27.4	95 / 29	5 / 1.5
White Rock	95 / 29	100 / 30.5	5 / 1.5
Brown Rock	100 / 30.5	110 / 33.5	10 / 3
Brown to Black Rock	110 / 33.5	120 / 36.6	10 / 3
Black Rock	120 / 36.6	130 / 39.6	10 / 3
Brown Rock	130 / 39.6	145 / 44.2	15 / 4.6
Hard Black Rock	145 / 44.2	155 / 47.3	10 / 3

Surface Elevation: -
Static Water Level: 16.8 m BGS
Date Completed: 1962

Logs of Houban and Hougala Wells

HOUBAN WELL No. 5

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil and Clay	0 / 0	21 / 6.4	21 / 6.4
Shale	21 / 6.4	32 / 9.8	11 / 3.4
Gravel	32 / 9.8	36 / 11	4 / 1.2
Silt and Gravel	36 / 11	44 / 13.4	8 / 2.4
Sand and Gravel with Clay	44 / 13.4	56 / 17.1	12 / 3.7
Fine Sand with Gravel	56 / 17.1	60 / 18.3	4 / 1.2
Clay with Gravel	60 / 18.3	65 / 19.8	5 / 1.5
Sand and Medium Rock	65 / 19.8	76 / 23.2	11 / 3.4
Sand and Gravel	76 / 23.2	78.6 / 24	2.6 / 0.8
Rock	78.6 / 24	79 / 24.1	0.4 / 0.1

Surface Elevation: 1103.5 m
Static Water Level: 9.3 m BGS
Date Completed: 1962

HOUBAN WELL No. 5A

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	42 / 12.8	42 / 12.8
Clay and Gravel	42 / 12.8	45 / 13.7	3 / .915
Fine Sand	45 / 13.7	48 / 14.6	3 / .915
Clay	48 / 14.6	54 / 16.5	6 / 1.83
Sandy Clay	54 / 16.5	60 / 18.3	6 / 1.83
Clay	60 / 18.3	70 / 21.3	10 / 3.05
Fine Sand	70 / 21.3	84 / 25.6	14 / 4.27
Coarse Sand	84 / 25.6	96 / 29.3	12 / 3.66
Fine Sand	96 / 29.3	101 / 30.8	5 / 1.52
Sand with Clay	101 / 30.8	107 / 32.6	6 / 1.83

Surface Elevation: -
Static Water Level: 19.2 m BGS
Date Completed: -

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Logs of Houban and Hougala Wells

HOUBAN WELL No. 6

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil and Clay	0 / 0	10 / 3	10 / 3
Clay	10 / 3	20 / 6.1	10 / 3
Rock with Gravel	20 / 6.1	29 / 8.8	9 / 2.7
Clay	29 / 8.8	41 / 12.5	12 / 3.7
Boulders	41 / 12.5	43 / 13.1	2 / 0.6
Clay with Gravel	43 / 13.1	55 / 16.8	12 / 3.7
Sand	55 / 16.8	68 / 20.1	13 / 4
Gravel	68 / 20.1	72 / 22	4 / 1.2
Blue Rock with Clay	72 / 22	75 / 22.9	3 / 0.9
Blue Rock	75 / 22.9	90 / 27.4	15 / 4.6
Red Rock	90 / 27.4	92 / 28	2 / 0.6
White Lime Rock	92 / 28	95 / 29	3 / 0.9

Surface Elevation: 1094.2 m
Static Water Level: 9.2 m BGS
Date Completed: 1962

HOUBAN WELL No. 6A

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	10 / 3	10 / 3
Clay With Sand	10 / 3	16 / 4.9	6 / 1.8
Clay	16 / 4.9	30 / 9.1	14 / 4.3
Clay With Sand	30 / 9.1	65 / 19.8	35 / 10.7
Medium Sand	65 / 19.8	72 / 22	7 / 2.1
Green Clay With Gravel	72 / 22	90 / 27.4	18 / 5.5
Sand and Gravel	90 / 27.4	95 / 29	5 / 1.5
Clay With Fine Sand	95 / 29	100 / 30.5	5 / 1.5
Clay With Gravel	100 / 30.5	105 / 32	5 / 1.5
Clay With Gravel and Sand	105 / 32	115 / 35.1	10 / 3

Surface Elevation: -
Static Water Level: 13.1 m BGS
Date Completed: 1962

HOUBAN WELL No. 11

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	44 / 13.4	44 / 13.4
Clay With Hard Sand	44 / 13.4	46 / 14	2 / 0.6
Clay	46 / 14	52 / 15.9	6 / 1.8
Clay With Gravel	52 / 15.9	54 / 16.5	2 / 0.6
Clay	54 / 16.5	64 / 19.5	10 / 3
Clay With Medium Sand	64 / 19.5	68 / 20.7	4 / 1.2
Clay	68 / 20.7	78 / 23.8	10 / 3
Gravel and Sand	78 / 23.8	83 / 25.3	5 / 1.5
Medium Sand	83 / 25.3	85 / 25.9	2 / 0.6
Sand With Clay	85 / 25.9	95 / 29	10 / 3
Clay	95 / 29	96 / 29.2	1 / 0.3
Clay With Sand and Gravel	96 / 29.2	110 / 33.5	14 / 4.3

Surface Elevation: 1101.0 m
Static Water Level: 21.3 m BGS
Date Completed: 11/68

Logs of Houban and Hougala Wells

HOUBAN WELL No. 12

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	12 / 3.7	12 / 3.7
Clay With Sand and Gravel	12 / 3.7	20 / 6.1	8 / 2.4
Clay With Sand	20 / 6.1	30 / 9.1	10 / 0.9
Sand With Small Stones	30 / 9.1	40 / 12.2	10 / 0.9
Clay With Sand	40 / 12.2	60 / 18.3	20 / 6.1
Clay With Sand and Gravel	60 / 18.3	73 / 22.3	13 / 4
Sand With Gravel	73 / 22.3	75 / 22.9	2 / 0.6
Clay With Sand	75 / 22.9	95 / 29	20 / 6.1
Small Stones With Gravel	95 / 29	97 / 29.6	2 / 0.6
Clay, Sand and Gravel	97 / 29.6	107 / 32.6	10 / 0.9
Clay and Gravel	107 / 32.6	115 / 35.1	8 / 2.4
Clay With Sand	115 / 35.1	128 / 39	13 / 4
Gravel With Sand	128 / 39	130 / 39.6	2 / 0.6
Clay With Gravel and Sand	130 / 39.6	145 / 44.2	15 / 4.6
Hard Black Rock	145 / 44.2	147 / 44.8	2 / 0.6
Clay With Gravel and Sand	147 / 44.8	149 / 45.4	2 / 0.6
Black and White Hard Rock	149 / 45.4	162 / 49.4	13 / 4

Surface Elevation: -
Static Water Level: -
Date Completed: 9/5/69

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Logs of Houban and Hougala Wells

HOUBAN WELL No. 14

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0	20 / 6.1	20 / 6.1
Clay, Sand and Gravel	20 / 6.1	30 / 9.1	10 / 3
Clay	30 / 9.1	50 / 15.2	20 / 6.1
Clay, Sand and Gravel	50 / 15.2	90 / 27.4	40 / 12.2
Sand With Clay	90 / 27.4	100 / 30.5	10 / 3
Gravel and Sand	100 / 30.5	130 / 39.6	30 / 9.1
Clay and Reddish Gravel	130 / 39.6	140 / 42.7	10 / 3
Sand and Gravel	140 / 42.7	160 / 48.8	20 / 6.1

Surface Elevation: -
Static Water Level: 25.9 m BGS
Date Completed: 1/69

HOUBAN WELL No. 15

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	5 / 1.5	5 / 1.5
Clay and Gravel	5 / 1.5	15 / 4.6	10 / 3
Clay	15 / 4.6	23 / 7	8 / 2.4
Gravel With Clay	23 / 7	35 / 10.7	12 / 3.7
Gravel With Sand	35 / 10.7	43 / 13.1	8 / 2.4
Clay With Sand	43 / 13.1	52 / 15.9	9 / 2.7
Gravel With Sand	52 / 15.9	57 / 17.4	5 / 1.5
Clay With Sand	57 / 17.4	73 / 22.3	16 / 4.9
Stones With Clay and Sand	73 / 22.3	78 / 23.8	5 / 1.5
Clay and Sand With Gravel	78 / 23.8	80 / 24.4	2 / 0.6
Stones	80 / 24.4	83 / 25.3	3 / 0.9
Rocks and Colored Sand	83 / 25.3	90 / 27.4	7 / 2.1
Hard Rocks	90 / 27.4	105 / 32	15 / 4.6

Surface Elevation: -
Static Water Level: -
Date Completed: -

Logs of Houban and Hougala Wells

HOUBAN WELL No. 16

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Fine Sand and Clay	0 / 0	46 / 14	46 / 14
Fine Sand With Gravel and Clay	46 / 14	70 / 21.3	24 / 7.3
Clay	70 / 21.3	73 / 22.3	3 / 0.9
Coarse Sand	73 / 22.3	76 / 23.2	3 / 0.9
Clay and Fine Sand	76 / 23.2	80 / 24.4	4 / 1.2
Fine and Coarse Sand	80 / 24.4	85 / 25.9	5 / 1.5
Fine Sand With Medium Stones	85 / 25.9	100 / 30.5	15 / 4.6
Sand and Gravel	100 / 30.5	104 / 31.7	4 / 1.2
Fine Sand With Big Stones	104 / 31.7	107 / 32.6	3 / 0.9
Fine Black Sand	107 / 32.6	112 / 34.1	5 / 1.5
Black Rock	112 / 34.1	115 / 35.1	3 / 0.9

Surface Elevation: -
Static Water Level: - 21.3 m BGS
Date Completed: 4/23/69

HOUBAN WELL No. 17

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	40 / 12.2	40 / 12.2
C' With Stones	40 / 12.2	75 / 22.9	35 / 10.7
Sand With Stones	75 / 22.9	85 / 25.9	10 / 3
Black Rocks	85 / 25.9	100 / 30.4	15 / 4.6
Rocks With Clay	100 / 30.4	120 / 36.6	20 / 6.1
Black Rocks	120 / 36.6	137 / 41.8	17 / 5.2
Black to Red Rocks	137 / 41.8	145 / 44.2	8 / 2.4
Red Rocks	145 / 44.2	150 / 45.7	5 / 1.5
Rocks	150 / 45.7	160 / 48.8	10 / 3
Grey Rocks (Hard)	160 / 48.8	170 / 51.8	10 / 3
Black Rocks (Hard)	170 / 51.8	173 / 52.7	3 / 0.9

Surface Elevation: -
Static Water Level: -
Date Completed: -

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Logs of Houban and Hougala Wells

HOUGALA WELL No. 1

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay and Sand	0 / 0	19.7 / 6	19.7 / 6
Sand and Gravel	19.7 / 6	29.5 / 9	9.8 / 3
Coarse Sand	29.5 / 9	39.3 / 12	9.8 / 3
Gravel With Clay	39.3 / 12	49.2 / 15	9.8 / 3
Sand With Clay	49.2 / 15	64 / 19.5	14.8 / 4.5
Gravel With Rocks	64 / 19.5	68.2 / 20.8	4.3 / 1.3
Sand and Clay	68.2 / 20.8	78.7 / 24	10.5 / 3.2
Dark Rocks	78.7 / 24	101.7 / 31	23 / 7

Surface Elevation: 1023.6 m
Static Water Level: 4.2 m BGS
Date Completed: 7/69

HOUGALA WELL No. 2

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	25 / 7.6	25 / 7.6
Clay With Sand	25 / 7.6	30 / 9.1	5 / 1.5
Fine Sand	30 / 9.1	50 / 15.2	20 / 6.1
Fine to Coarse Sand and Gravel	50 / 15.2	66 / 20.1	16 / 4.9
Fine Sand	66 / 20.1	86 / 26.2	20 / 6.1

Surface Elevation: 1023.0 m
Static Water Level: -
Date Completed: 8/4/69

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HOUGALA WELL No. 3

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Clay	0 / 0	30 / 9.1	30 / 9.1
Clay With Coarse Sand	30 / 9.1	40 / 12.2	10 / 0.9
Clay With Medium Sand	40 / 12.2	57 / 17.4	17 / 5.2
Black and White Coarse Sand	57 / 17.4	67 / 20.4	10 / 0.9
Blue Clay With Gravel	67 / 20.4	75 / 22.9	8 / 2.4
Coarse Gravel With Brown Clay	75 / 22.9	90 / 27.4	15 / 4.6
Clay With Coarse Sand	90 / 27.4	95 / 29	5 / 1.5
Medium Hard Rock	95 / 29	98 / 29.9	3 / 0.9

Surface Elevation: 1024.7 m
Static Water Level: 4.9 m BGS
Date Completed: 6/23/69

HOUGALA WELL No. 4

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Clay	0 / 0	30 / 9.1	30 / 9.1
Clay With White Sand	30 / 9.1	47 / 14.3	17 / 5.2
Sand	47 / 14.3	55 / 16.8	8 / 2.4
Black Clay	55 / 16.8	57 / 17.4	2 / 0.6
Coarse Sand With Black Clay	57 / 17.4	63 / 19.2	6 / 0.9
Medium to Fine Sand	63 / 19.2	99 / 30.2	36 / 11

Surface Elevation: 1018.9 m
Static Water Level: 2.4 m BGS
Date Completed: 7/25/69

Logs of Houban and Hougala Wells

HOUGALA WELL No. 5

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	30 / 9.1	30 / 9.1
Fine Sand With Clay	30 / 9.1	60 / 18.2	30 / 9.1
Coarse Sand With Gravel	60 / 18.2	81 / 24.7	21 / 6.4
Black Rock	81 / 24.7	82 / 25	1 / 0.3

Surface Elevation: 1021.3 m
Static Water Level: 4 m BGS
Date Completed: 8/25/69

HOUGALA WELL No. 6

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay	0 / 0	18 / 5.5	18 / 5.5
Gravel With Coarse Sand	18 / 5.5	25 / 7.6	7 / 2.1
Clay	25 / 7.6	30 / 9.1	5 / 1.5
Medium Sand and Gravel	30 / 9.4	40 / 12.2	10 / 3
Hard Black Rock	40 / 12.2	45 / 13.7	5 / 1.5
Soft Green Rock	45 / 13.7	48 / 14.6	3 / 0.9
Soft Rock	48 / 14.6	58 / 17.7	10 / 3
Coarse Black Sand	58 / 17.7	67 / 20.4	9 / 2.7
Hard Brown and Black Rock	67 / 20.4	102 / 31.1	35 / 10.7

Surface Elevation: 1026.6 m
Static Water Level: 1.8 m BGS
Date Completed: 8/12/68

Logs of Houban and Hougala Wells

HOUGALA WELL No. 7

Formation Description	Depth in Feet / Depth in Meters		
	From	To	Total Thickness
Clay	0 / 0	40 / 12.2	40 / 12.2
Sand With Stones	40 / 12.2	60 / 18.3	20 / 6.1
Fine Sand	60 / 18.3	65 / 19.8	5 / 1.5

Surface Elevation: -
Static Water Level: -
Date Completed: 12/69

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APPENDIX B

APPENDIX B

LITHOLOGIC LOGS OF PROJECT TEST HOLES

Appendix B includes the lithologic logs of all the test holes drilled during the water resources evaluation in the vicinity of Taiz.

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Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 1 (Test Area I)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Clay (Saturated)	0 / 0	53 / 16.2	53 / 16.2
Coarse Sand And Gravel	53 / 16.2	94 / 28.7	41 / 12.5
Matic, Rounded to Angular Some Shell Frags. Felospars And Quartz Grains. Dark Brown Bedrock	94 / 28.7	108 / 32.9	14 / 4.3

Location: 3 KM NE of Taiz on Taiz-Airport Road, 100 Meters North of Road along South Bank of Wadi Khowban.

Surface Elevation: 1157 m (From Topo Map)
Static Water Level: 1.5 m BGS
Date Completed: 7/4/74

PROJECT TEST HOLE NO. 2 (Test Area II)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil	0 / 0	10 / 3	10 / 3
Clay with Gravel and Boulders	10 / 3	30 / 9.1	20 / 6.1
Light Brown Silt and Clay with Rounded Boulders	30 / 9.1	100 / 30.5	70 / 21.3
Grey Clay with Rock Frags.	100 / 30.5	130 / 39.6	30 / 9.1
Grey Clay	130 / 39.6	140 / 42.7	10 / 3
Grey Silt and Clay with Some Gravel Frags.	140 / 42.7	150 / 45.7	10 / 3
Dark Brown Basalt	150 / 45.7	160 / 48.8	10 / 3
Grey Silty Sand with some Gravel Frags.	160 / 48.8	170 / 51.8	10 / 3
Grey Clay	170 / 51.8	190 / 57.9	20 / 6.1
Grey Clay with Rock Frags.	190 / 57.9	200 / 61	10 / 3
Basaltic Tuff, Grey to Black with Glassy Texture.	200 / 61	213 / 64.9	13 / 4

Location: Approx., 1 km East of Taiz, 50 m North of Taiz-Airport Road.

Surface Elevation: 1165 m (From Topo Map)
Static Water Level: 44.2 m BGS
Date Completed: 7/24/74

Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 3 (Test Area III)

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Soil	0 / 0	10 / 3	10 / 3
Red Clay with Angular and Rounded Boulders	10 / 3	110 / 33.5	100 / 30.5
Grey to Red Clay with Rock Frags. Very Hard	110 / 33.5	130 / 39.6	20 / 6.1
Red Clay with Sand	130 / 39.6	142 / 43.3	12 / 3.7
Hardrock	142 / 43.3	146 / 44.5	4 / 1.2

Location: Approx. 0.7 km East of Taiz, 150 M South of Taiz-Airport Road.
Surface Elevation: 1170 m (From Topo Map)
Static Water Level: 20.4 m BGS
Dated Completed: 7/27/74

PROJECT TEST HOLE NO. 4 (Test Area IV)

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Soil	0 / 0	10 / 3	10 / 3
•Light Brown Clay and Silt with some Sand and Gravel	10 / 3	40 / 12.2	30 / 9.1
Coarse Sand with Light Brown Clay and Silt.	40 / 12.2	70 / 21.3	30 / 9.1
Medium Sand with some Gravel and 20% Clay	70 / 2.13	80 / 24.4	10 / 3
Light Brown Sandy Clay	80 / 24.4	90 / 27.4	10 / 3
Light Brown Sand, Clay, and Gravel, 20% Clay	90 / 27.4	120 / 36.6	30 / 9.1
Coarse Sand and Gravel	120 / 36.1	124 / 37.8	4 / 1.2
Boulder	124 / 37.8	126 / 38.4	2 / 0.6
Fine to Medium Sand and Gravel	126 / 38.4	135 / 41.2	9 / 2.7
Light Brown Silt and Clay with Sand and Gravel	135 / 41.2	140 / 42.7	5 / 1.5
Fine to Medium Sand with 20% Light Brown Clay	140 / 42.7	150 / 45.7	10 / 3
Clean Sand and Gravel	150 / 45.7	160 / 48.8	10 / 3
Grey Clay	160 / 48.8	180 / 54.9	20 / 6.1
Grey Clay with Hardrock Frags.	180 / 54.9	240 / 73.2	60 / 18.3
Coarse Grey Sand and Gravel, some Silt.	240 / 73.2	260 / 79.3	20 / 9.1

Location: Upper Wadi Salah.
Surface Elevation: 1206 m
Static Water Level: 36.6 m BGS (Approx.)
Date Completed: 10/3/74

Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 5 (Test Area V)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Coarse Sand and Gravel with Thin Beds of Clay	0 / 0	50 / 15.2	50 / 15.2
Fractured Hard Basalt	50 / 15.2	90 / 27.4	40 / 12.2
Very Hard Basalt	90 / 27.4	125 / 38.1	35 / 10.7
Basalt and Rhyolite	125 / 38.1	135 / 41.2	10 / 3
Black, Very Hard Basalt	135 / 41.2	155 / 47.3	20 / 9.1
Grey Fractured Andesite	155 / 47.3	195 / 59.5	40 / 12.2
Olivine Basalt (Fractured)	195 / 59.5	205 / 62.5	10 / 3
Grey Hard Andesite with Secondary Quartz	205 / 62.5	255 / 77.7	50 / 15.2
Grey Andesite with Fault Gouge	255 / 77.7	260 / 79.3	5 / 1.5
Fractured Basalt	260 / 79.3	270 / 82.3	10 / 3
Rhyolite	270 / 82.3	300 / 91.5	30 / 9.1
Basalt	300 / 91.5	310 / 94.5	10 / 3
Rhyolite	310 / 94.5	340 / 103.7	30 / 9.1
Very Hard Basalt with Secondary Quartz	340 / 103.7	463 / 141.2	123 / 37.5

Location: Upper Wadi Kolabat, 0.7 km North of Taiz on Taiz-Airport Road
Approx. 10 Meters North of Sharp Bend in Road.
Surface Elevation: 1175 m (From Topo Map)
Static Water Level: 10 m BGS
Date Completed: 9/4/74

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Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 8 (Test Area X)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil	0 / 0	36 / 11	36 / 11
Coarse Sand and Gravel	36 / 11	75.4 / 23	39.4 / 12
Grey Clay	75.4 / 23	90.2 / 27.5	14.8 / 4.5
Sandy Clay	90.2 / 27.5	100 / 30.5	10 / 3
Sand and Gravel with Small Percent Clay	100 / 30.5	110 / 33.5	10 / 3
Clay	110 / 33.5	131 / 40	21.3 / 6.5
Coarse Sand and Gravel with some Silt and Clay	131 / 40	170.6 / 52	39.3 / 12
Sandy Clay	170.6 / 52	190.2 / 58	19.7 / 6
Clay	190.2 / 58	21[illegible] / 64	19.7 / 6
Sandy Clay	210 / 64	249 / 76	39.3 / 12
Clay	249 / 76	260 / 79	10 / 3

Location: Dh'bab Basin
Surface Elevation: 980 m (Approx)
Static Water Level: 0.2 m BGS
Date Completed: 9/29/74

PROJECT TEST HOLE NO. 9 (Test Area X)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil	0 / 0	10 / 3	10 / 3
Clay and Sand	10 / 3	49.9 / 15.2	40 / 12.2
Coarse Sand and Gravel with some Silt and Clay	49.9 / 15.2	59.7 / 18.2	10 / 3
Grey Sandy Clay	59.7 / 18.2	85.3 / 26	25.6 / 7.8
Fine to Medium Sand	85.3 / 26	90.2 / 27.5	4.9 / 1.5
Buff to Black Coarse Sand and Gravel	90.2 / 27.5	119.7 / 36.5	29.5 / 9
Light Brown Clay	119.7 / 36.5	140 / 42.7	20.3 / 6.2

Location: Dh'bab Basin
Surface Elevation: 993 m
Static Water Level: 2.4 m BGS
Date Completed: 10/74

Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 10 (Test Area X)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil	0 / 0	10 / 3	10 / 3
Light Brown Sandy Clay	10 / 3	50 / 15.2	40 / 12.2
Fine to Medium Sand and Gravel	50 / 15.2	60 / 18.3	10 / 3
Fine Sand and Gravel	60 / 18.3	75 / 22.9	15 / 15.5

Location: Dh'bab Basin
Surface Elevation: 997 M (Approx.)
Static Water Level: 3.0 m BGS
Date Completed: 10/74

PROJECT TEST HOLE NO. 11-P11 (Test Area X)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Silty Clay with Some Coarse Sand and Gravel	0 / 0	40 / 12.2	40 / 12.2
Coarse Sand and Medium to Coarse Dark Colored Gravel, Very Clean	40 / 12.2	60 / 18.3	20 / 6.1
Light Brown to Black Running Fine Sand	60 / 18.3	73 / 22.3	13 / 4

Location: Dh'bab Basin
Surface Elevation: 1033 m
Static Water Level: 12.8 m BGS
Date Completed: 11/12/74

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Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 11A (Test Area X)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Light Brown Silty Clay With Thin Lenses of Sand and Gravel	0 / 0	40 / 12.2	40 / 12.2
Coarse Sand and Gravel	40 / 12.2	50 / 15.2	10 / 3
Fine Running Sand	50 / 15.2	72 / 22	22 / 6.7
Large Boulder	72 / 22	80 / 24.4	8 / 2.4
Coarse Sand and Gravel	80 / 24.4	105 / 32	25 / 7.6

Location: Upper Wadi Dh'bab Basin
Surface Elevation: 1034 m
Static Water Level: 15.2 m BGS
Date Completed: 11/24/74

PROJECT TEST HOLE NO. 12 (Test Area IX)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Soil	0 / 0	10 / 3	10 / 3
Brown Clay and Silt	10 / 3	40 / 12.2	30 / 9.1
Light Brown Sand, Silt, and Clay	40 / 12.2	52 / 15.8	12 / 3.7
Dark Brown to Black Basalt	52 / 15.8	65 / 19.8	13 / 4

Location: 2 km North of Dh'bab Basin and 100 m West of Taiz Turba Road in Cultivated Field
Surface Elevation: 1031 m (Approx.)
Static Water Level: 13 m BGS
Date Completed: 10/23/74

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PROJECT TEST HOLE NO. 13 (Test Area VIII)

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Clay with Sand and Gravel	0 / 0	45 / 13.7	45 / 13.7
Coarse Sand and Gravel	45 / 13.7	70 / 21.3	25 / 7.6
Basalt	70 / 21.3	72 / 22	2 / 0.6

Location: Wadi Amad, 6 km West of Taiz, 1 km South of Taiz Hodeida Road
Surface Elevation: 1136 m
Static Water Level: 14.3 m BGS
Date Completed: 11/13/74

PROJECT TEST HOLE NO. 14 (Test Area XI)

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Medium Sand with Some Grey to Black Gravel	0 / 0	50 / 15.2	50 / 15.2
Brown Clay with Basalt Fragments	50 / 15.2	60 / 18.3	10 / 3
Grey Andesite Quartz Purphyry Hard to Very Hard Drilling	60 / 18.3	120 / 36.6	60 / 18.3
Green Tuffaceous Clay	120 / 36.6	130 / 39.6	10 / 3
Basalt	130 / 39.6	150 / 45.7	20 / 6.1
Olivine Basalt, Very Hard Drilling	150 / 45.7	160 / 48.8	10 / 3
Fractured Basalt	160 / 48.8	180 / 54.9	20 / 6.1
Green Tuffaceous Clay	180 / 54.9	200 / 61	20 / 6.1
Green, Buff, and Red Welded Tuff	200 / 61	270 / 82.3	70 / 21.3
Grey Dacite	270 / 82.3	280 / 85.4	10 / 3

PROJECT TEST HOLE NO. 14 (Test Area XI)
(Continued)

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Red-Grey to Black Andesite	280 / 85.4	320 / 97.6	40 / 12.2
Rhyolite	320 / 97.6	340 / 103.7	20 / 6.1
Olivine Basalt	340 / 103.7	360 / 109.8	20 / 6.1
Mixed Fractured Volcanic Rock Fragments	360 / 109.8	400 / 122	40 / 12.2
Light Grey Dacite Porphyry with Some Basalt Streaks	400 / 122	603 / 183.8	203 / 61.9

Location: 1.4 km West of Intersection of Taiz-Sana'a Road and Road to Rawhida Test Area
Surface Elevation: 1320 m
Static Water Level: 8.2 m BGS
Date Completed: 9/14/74

PROJECT TEST HOLE NO. 14A (Test Area XIX)

Formation Description	Depth in Feet / Depth in Meters From	To	Total Thickness
Silty Clay, Sandy Soil	0 / 0	30 / 9.1	30 / 9.1
Fine to Medium Sand and Silt	30 / 9.1	40 / 12.2	10 / 3
Clean Fine Sand and Gravel	40 / 12.2	50 / 15.2	10 / 3
Fractured Hardrock	50 / 15.2	60 / 18.3	10 / 3
Dark Grey Andesite	60 / 18.3	100 / 30.5	40 / 12.2
Dark Grey to Black Olivine Basalt	100 / 30.5	140 / 42.7	40 / 12.2
Grey Andesite	140 / 42.7	190 / 57.9	50 / 15.2
Dark Grey to Black Olivine Basalt	190 / 57.9	200 / 61	10 / 3

Location: 50 m South of Taiz-Sana'a Road, 1.8 KM West of Biscuit Factory
Surface Elevation: 1225 m
Static Water Level: 3.3 m BGS
Date Completed: 9/23/74

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Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 14B (Test Area XIX)

Formation Description	Depth in Feet / Depth in Meters		
	From	To	Total Thickness
No Cuttings	0 / 0	70 / 21.3	70 / 21.3
Rounded and Angular Gravel Fragments With Calcareous Sandy Clay	70 / 21.3	90 / 27.4	20 / 6.1
Coarse Sand and Gravel With Angular Rock Fragments and Abundant Clay	90 / 27.4	100 / 30.5	10 / 3
Mixed Angular Gravel Fragments, Calcareous Sandstone Mixed with Clay	100 / 30.5	160 / 48.8	60 / 18.3
Sand, Gravel, Angular Rock Fragments With Little Clay	160 / 48.8	200 / 61	40 / 12.2
Dark Grey to Black Andesite	200 / 61	253 / 77.1	53 / 16.2

Location: 50 M North of Road to Rawhida, 500 m South of Taiz-Sanna Road
Surface Elevation: 1230 m (Approx.)
Static Water Level: 16.8 m BGS
Date Completed: 10/74

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Lithologic Logs of Project Test Holes

PROJECT TEST HOLE NO. 15 (Test Area XVIII)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Medium to Coarse Sand and Gravel Separated by Clay Lenses	0 / 0	45 / 13.7	45 / 13.7
Grey Medium Sand and Gravel	45 / 13.7	95 / 29	50 / 15.2
Grey Medium Sand with Coarse Grey Gravel and Volcanic Rock Fragments	95 / 29	115 / 35	20 / 6.1
Grey to Black Very Hard Basalt	115 / 35	125 / 38.1	10 / 3
Coarse Grey Sand and Coarse Basalt Gravel	125 / 38.1	135 / 41.2	10 / 3
Fine to Medium Sand and Basalt Gravel	135 / 41.2	145 / 44.2	10 / 3
Fine Sand with Basalt Fragments	145 / 44.2	155 / 47.3	10 / 3
Fine Sand with Basalt Gravel and Fragments	155 / 47.3	195 / 59.5	40 / 12.2
Fine Sand with Basalt Medium to Coarse Gravel	195 / 59.5	205 / 62.5	10 / 3
Fine Sand with Fine Basalt Gravel	205 / 62.5	215 / 65.5	10 / 3
Basalt	215 / 65.5	255 / 78.6	40 / 12.2

Location: Wadi El Hiama (Test Area XVIII)
Surface Elevation: 1373 m (Approx.)
Static Water Level: 3.9 m BGS
Date Completed: 11/7/74

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PROJECT TEST HOLE NO. 16 (Test Area XVIII)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Medium to Coarse Sand and Gravel with Thin Zones of Clay	0 / 0	25 / 7.6	25 / 7.6
Medium Sand with Basalt Gravel	25 / 7.6	100 / 30.5	75 / 22.9
Grey to Black Basalt Flow	100 / 30.5	115 / 35.1	15 / 4.6
Medium Sand with Brown Clay	115 / 35.1	120 / 36.6	5 / 1.5
Grey to Black Basalt Flow	120 / 36.6	125 / 38.1	5 / 1.5
Medium Sand with Brown Clay	125 / 38.1	145 / 44.2	20 / 6.1
Grey to Black Basalt Flow	145 / 44.2	175 / 53.3	30 / 16.2

Location: 1 km North of T H No. 15
Wadi El Hiama Basin
Surface Elevation: 1383 m
Static Water Level: 12.8 m BLS
Date Completed: 11/19/74

PROJECT TEST HOLE NO. 19 (Test Area XVI)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Light Brown Silty Clay with Minor Coarse Sand and Gravel	0 / 0	50 / 15.2	50 / 15.2
Light Brown Medium Sand with Some Gravel	50 / 15.2	58 / 17.7	8 / 2.4
Green Volcanic Clay	58 / 17.7	62 / 18.9	4 / 1.2

Location: Wadi Mikbaba Basin (Test Area XVI)
3.5 km South of T.H. No. 15 in El Haima Basin
Surface Elevation: 1293 m (Approx.)
Static Water Level: 3.3 m BGS.
Date Completed: 11/17/74

PROJECT TEST HOLE NO. 20 (Test Area XVI)

Formation Description	Depth in Feet / Depth in Meters: From	To	Total Thickness
Driller Reported Sand Gravel and Clay to Total Depth of Bore, But Did Not Preserve Cuttings or Prepare Well Log. Because of This Action Description is Considered Unreliable.	0 / 0	95 / 29	95 / 29

Location: Wadi Mikbaba Basin (Test Area XVI)
Surface Elevation: 1292 m
Static Water Level: 2.8 m BGS.
Date Completed: 12/10/74

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APPENDIX C

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APPENDIX C

QUALITY ANALYSES OF WATERS IN THE VICINITY OF THE CITY OF TAIZ, YEMEN ARAB REPUBLIC

Location	Date	Sampled By	Analysis By	pH	E.C. mhos/cm @ 25° C	Milligrams per Liter								Total Solids M/L
						Ca	K	Na	Cl	SO_4	NO_3	Total Hardness	Alkalinity	
UN Farm Springs #1 Wadi Ausscifera	5/27/74	Dewan	Dewan	7.60	2000	221	11.31	230	303.8	600	29.14			
UN Farm Spring #2 Wadi Ausscifera	5/27/74	Dewan	Dewan	7.60	2800	237.2	15.99	220.8	352.0	519.8	52.45			
Houban #1 Well	7/ 6/74	Fahey	Fahey			113	10.5	679	485	519	59.8	540	523	2230
Houban #2 Well	7/ 6/74	Fahey	Fahey			125			495	522	62.51	609	524	2270
	8/25/74	Fahey	Fahey	7.3		125			501	535	64	580	475	2220
Houban #3 Well	app. 1/64	USAID	-	7.2		110	21	258	224	264		358	(HCO_3) 238	996
Houban #4 Well	app. 1/64	USAID	-	7.4	-	120	23	270	238	290		383	(HCO_3) 255	1057
Houban #4A Well	10/ 5/74	Ramsey	Fahey		3750	120			540	610	89	700	520	2400
Houban #5 Well	12/21/64	Salih	Salih	7.3	-							446	498	1660
	app. 1/64	USAID	-	7.2		124	26	280	246	302		394	(HCO_3) 264	1094
Houban #6 Well	app. 1/64			7.2		118	23	256	232	280		376	(HCO_3) 252	1050
	12/22/64			7.6								408	493	1646
	7/ 9/66			7.6					328			462	497	1509
	6/ 6/74					129	10.5	644	499	500	56.4	607	509	2270
	8/25/74			7.1		123			492	509	65	590	455	2190
Houban #11 Well	7/ 6/74					128		598	490	498	63.3	620	560	2260
	8/25/74			7.2		124			493	504	65	593	460	2190
Houban #14 Well	7/ 6/74	Fahey	Fahey			108		230	179	230	56.4	441	317	960
	8/25/74			7.2		81.4			136	210	56	327	280	975
Hougfa-Wadi Khowban Surface Flow	7/14/74	Ramsey	Fahey						545	568	56.7	457		2650
Hougala #1 Well	7/ 6/74	Fahey	Fahey			254	10.5	335	459	679	210	1170	335	2580
	8/25/74			7.0		239	12	425	500	688	260	1110	300	2420

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Quality Analyses of Waters

Location	Date	Sampled By	Analysis By	pH	E.C. mhos/cm @ 25° C	Milligrams per Liter								Total Solids M/L
						Ca	K	Na	Cl	SO_4	NO_3	Total Hardness	Alka-linity	
Hougala #2 Well	6/22/69			7.8		124			272		NH_4NO_3 .01	411	345	1435
	7/ 6/74	Fahey				267	10.1	328	431	625	203	1140	325	2470
	8/25/74			7.2		256	11	483	413	649	270	1080	295	2290
Hougala #3 Well	7/18/69			7.8		140.5			355	300		446	586	
	7/ 6/74					109	11.3	748	478	536	127	686	461	2350
	8/25/74			7.2		119	12	460	506	546	160	725	425	2340
Hougala #4 Well	7/74					151	11.3	690	493	658	172	880	392	2590
	8/25/74			7.2		142	12	563	475	653	240	914	360	2470
Hougala #5 Well														
Hougala #6 Well	7/ 6/74	Fahey	Fahey			209	10.9	736	468	681	202	1170	333	2560
	8/25/74			7.0		231	13	437	440	-	270	1120	440	2470
Hougala #7 Well	8/25/74					248					270	1060	295	2150
Test Hole #1 Well	7/15/74	Ramsey	Fahey						403	477	99.7	474		2640
Test Hole #2 Well	7/15/74	Ramsey	Fahey		3100	30	17.6	437	320	430	0.4	210	660	2000
Surface Well 15 Km No. of Hougala	8/ 3/74	Ramsey	Fahey		1250	29			77.5		78.8	243	339	1000
Wadi Dinakhai 25 Km No. of Taiz Surface Flow	8/21/74	Fahey	Fahey	7.8		79.4			70.8	60.7	12.0	331	240	576
Hougfa Surface Flow	7/14/74	Ramsey	Fahey						545	568	56.7	457		2650
Test Area X														
Spring Near TH10	7/24/74	Ramsey	Fahey		900	87.8	2.0	102	42.5	45.3	30.1	365	305	596
*ESW 2-2	11/26/74	Ramsey	Fahey		750	77			43	38	26	320	370	460
Test Area XII														
Surface flow	9/22/74	Ramsey	Fahey	7.5	2480	91			225	480	20	580	440	1570
Shallow hand dug well in airport drainage area	11/ 4/74	Ramsey	Fahey			1800			1350	3100	89	1650	530	7500

*ESW - Existing shallow well

Quality Analyses of Waters

Location	Date	Sampled By	Analysis By	pH	E.C. mhos/cm @ 25° C	Milligrams per Liter								Total Solids M/L
						Ca	K	Na	Cl	SO_4	NO_3	Total Hardness	Alkalinity	
Test Area XIII														
Surface flow	9/22/74	Ramsey	Fahey	7.7	2950	88			320	270	22.2	670	590	1870
Test Area XIV														
Brohi Wadi	8/ 3/74	Ramsey	Fahey		3100	61.0			352	611	9.7	647	537	2040
Test Area XVI														
Surface flow	9/22/74	Ramsey	Fahey	7.7	1310	74			113	108	11	430	495	830
Test Area XVIII														
*ESW 3-1	11/20/74	Ramsey	Fahey		860	57			42	51	15	300	340	490
ESW 3-2	11/20/74	Ramsey	Fahey		820	67			38	85	7.5	310	350	520
ESW 3-4	11/18/74	Ramsey	Fahey		1070	74			110	99	19	390	360	690
ESW 3-9	11/21/74	Ramsey	Fahey		840	74			74	38	8.3	330	360	490
Surface flow Upper Haima	9/24/74	Ramsey	Fahey	7.5	910	67			50	50	10.6	340	350	492
Test Area XIX														
ESW 1-2	10/24/74	Ramsey	Fahey	7.6	1700	34			130	140	49	270	500	1100
ESW 1-3	10/24/74	Ramsey	Fahey	7.5	1150	36			45	43	19	360	450	570
ESW 1-5	11/11/74	Ramsey	Fahey		2300	63			240	380	52	450	490	1600
ESW 1-10	10/27/74	Ramsey	Fahey	7.5	1500	43			120	130	54	350	450	930
ESW 1-11	10/27/74	Ramsey	Fahey	7.5	1650	37			140	170	39	430	500	1100
ESW 1-12	10/24/74	Ramsey	Fahey	7.7	2700	32			290	290	91	480	710	1700
ESW 1-13	10/24/74	Ramsey	Fahey	7.4	1850	61			140	220	230	500	340	1200
ESW 1-14	10/24/74	Ramsey	Fahey	7.5	3150	49			360	650	170	460	560	2000
Test Hole #3	7/27/74	Ramsey	Fahey		6750	49.2	17.1	150	1340	1390	4.4	330	838	5450
Test Hole #4	9/ 5/74	Ramsey	Fahey	7.3	1080	89			85	150	34	320	280	1000
Test Hole #5	9/ 3/74	Ramsey	Fahey						4080					8490
Test Hole #8	8/27/74	Ramsey	Fahey						79.5		14.2	280		594
Test Hole #9	10/13/74	Ramsey	Fahey	8.2	790	56			54	49	21	200	290	480
Test Hole #10	10/10/74	Ramsey	Fahey	7.8	890	82			53	120	29	370	340	520

*ESW - Existing shallow well

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Quality Analyses of Waters

Location	Date	Sampled By	Analysis By	pH	E.C. mhos/cm @ 25° C	Milligrams per Liter								Total Solids M/L
						Ca	K	Na	Cl	SO_4	NO_3	Total Hardness	Alka-linity	
Test Hole #11A	11/25/74	Ramsey	Fahey		790	80			44	95	25	360	370	790
Test Hole #12	10/22/74	Ramsey	Fahey	7.6	3000	73			360	370	380	930	380	2400
Test Hole #13	10/30/74	Ramsey	Fahey		1160	88			120	120	80	350	260	710
Test Hole #14	9/14/74	Ramsey	Fahey						875	1210				3570
Test Hole #14A	9/30/74	Ramsey	Fahey	7.5	1720	40			170	190	62	350	440	1000
Test Hole #14B	10/ 1/74	Ramsey	Fahey	7.6	1500	30			150	150	44	210	330	890
	10/ 1/74	Ramsey	Fahey	7.8	1420	28			150	150	48	200	310	860
Test Hole #15	11/ 2/74	Ramsey	Fahey		850	70			51	49	7.8	330	400	600
Test Hole #16	11/16/74	Ramsey	Fahey		900	58			38	58	9.7	290	380	500
Test Hole #19	11/17/74	Ramsey	Fahey		1500	47			120	130	18	440	510	1000

Note: TDS obtained by evaporation method

APPENDIX D

APPENDIX D

RESULTS OF PROJECT AQUIFER TESTING
VICINITY OF TAIZ, Y.A.R.
1974-1975

Appendix D includes aquifer test curves developed during the test drilling portion of the project. The calculations made to determine aquifer transmissibility coefficients utilizing the curves, are also shown for each test performed.

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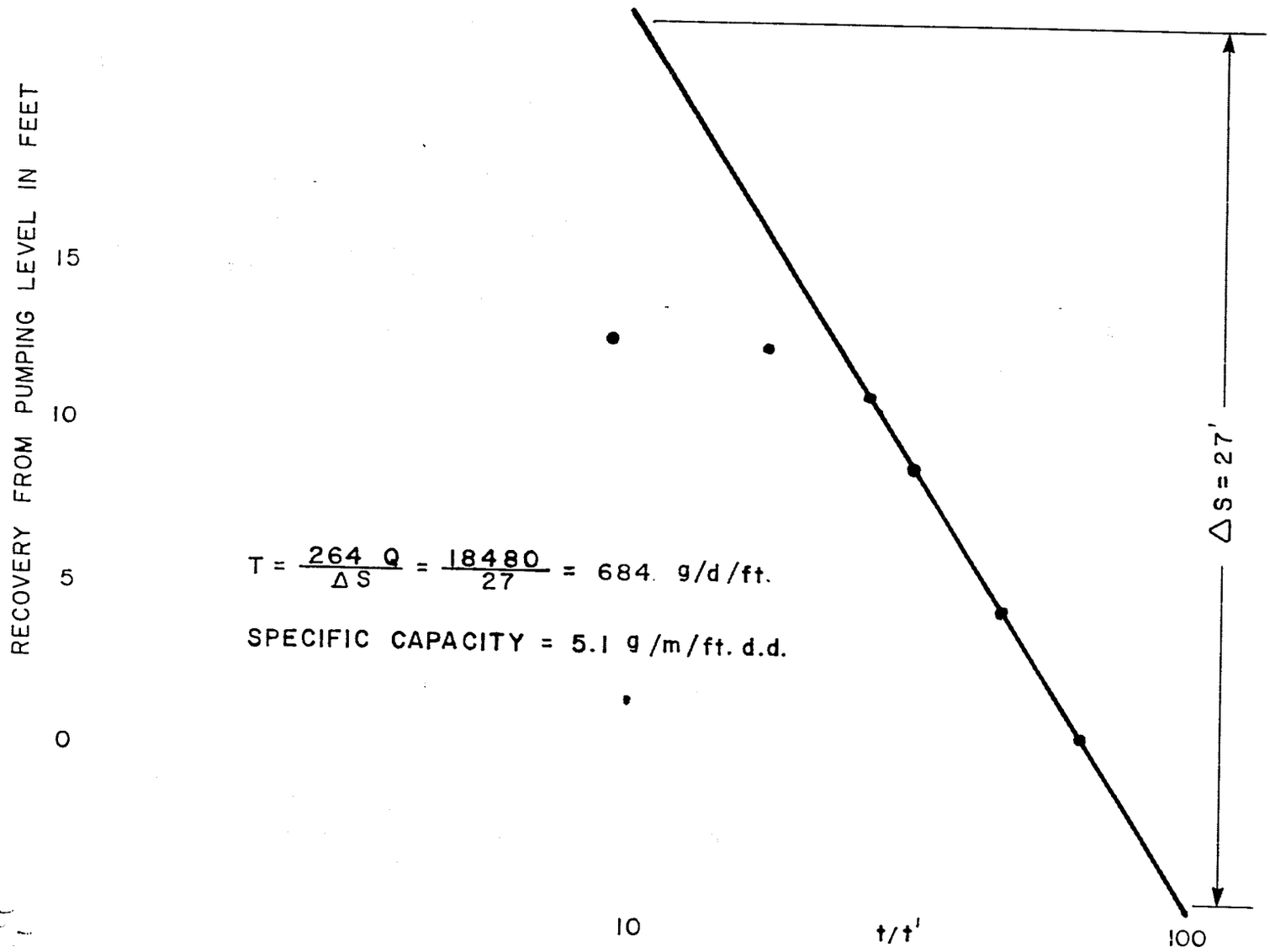
OCT. 9, 1974
PRODUCTION RATE (Q) = 70 GPM
STATIC WATER LEVEL - 40.25' B.G.S.

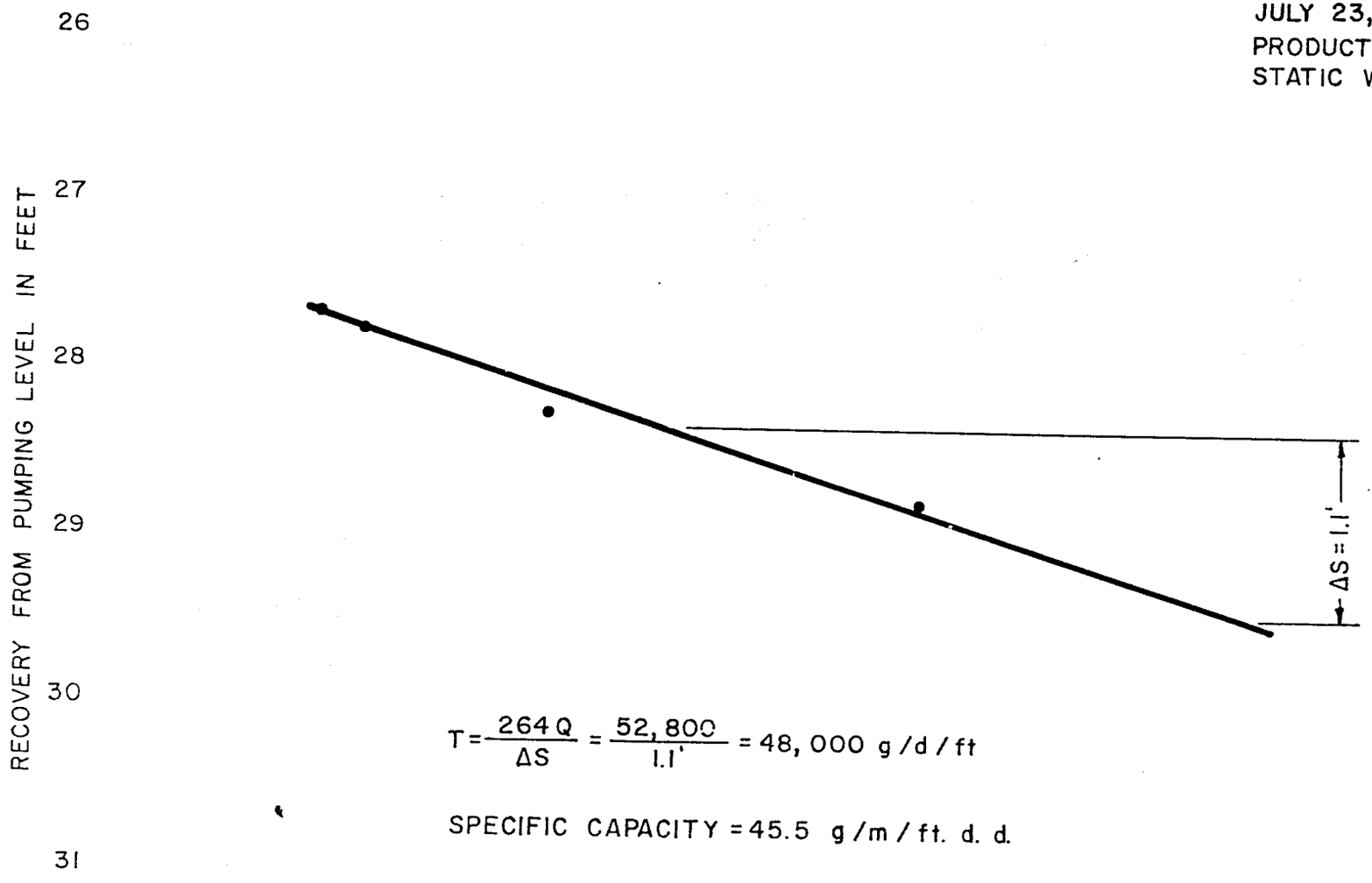


$$T = \frac{264\ Q}{\Delta S} = \frac{18480}{27} = 684.\ g/d/ft.$$

SPECIFIC CAPACITY = 5.1 g/m/ft. d.d.

HOUBAN WELL NO.4
RECOVERY PUMP TEST
FIGURE D-1

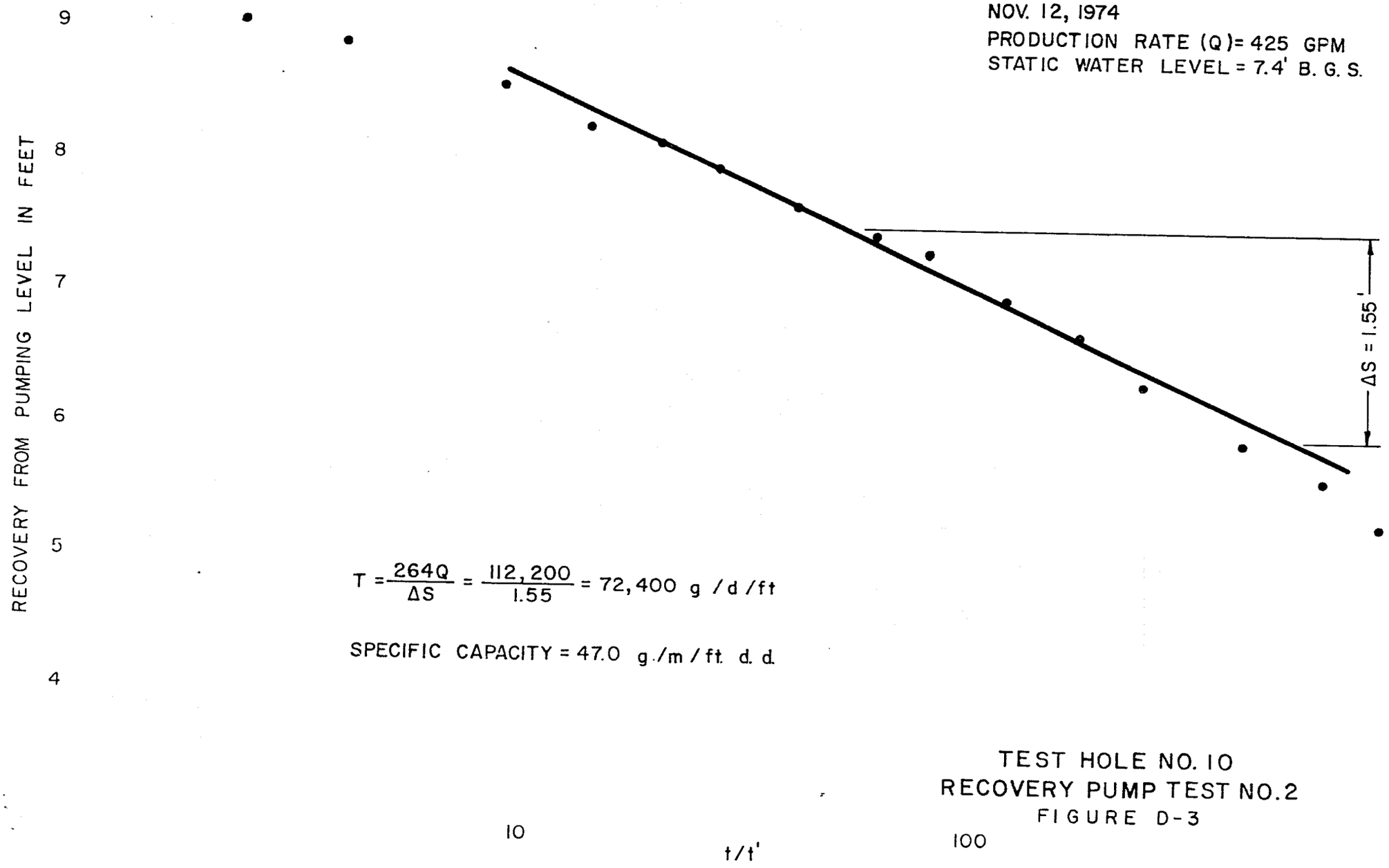
JULY 23, 1974
PRODUCTION RATE (Q) = 200 GPM
STATIC WATER LEVEL = 26.8' B. G. S.



$$T = \frac{264\,Q}{\Delta S} = \frac{52,800}{1.1'} = 48,000 \text{ g/d/ft}$$

SPECIFIC CAPACITY = 45.5 g/m/ft. d. d.

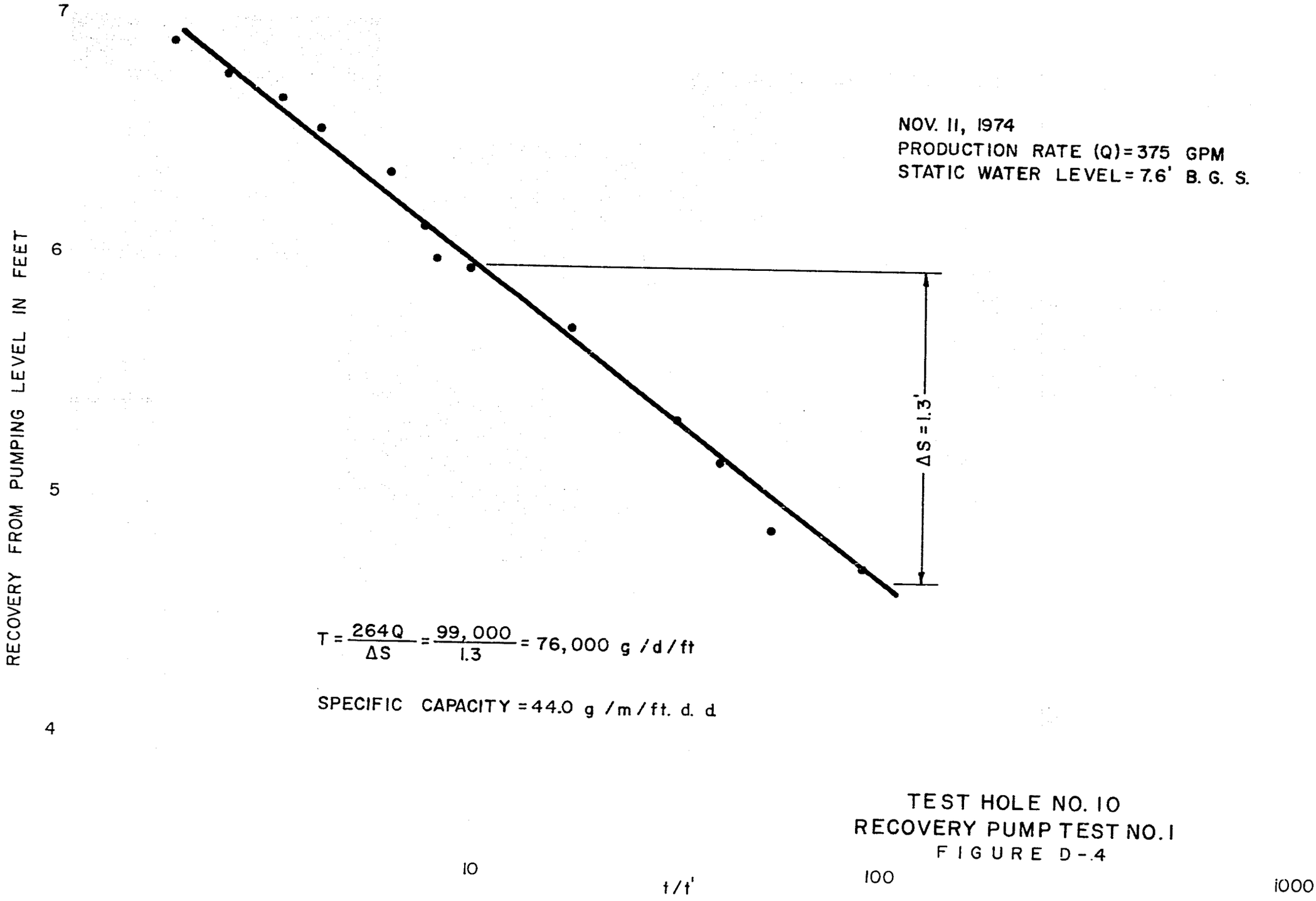
HOUGALA WELL NO.6
RECOVERY PUMP TEST
FIGURE D - 2



$$T = \frac{264Q}{\Delta S} = \frac{112,200}{1.55} = 72,400 \text{ g/d/ft}$$

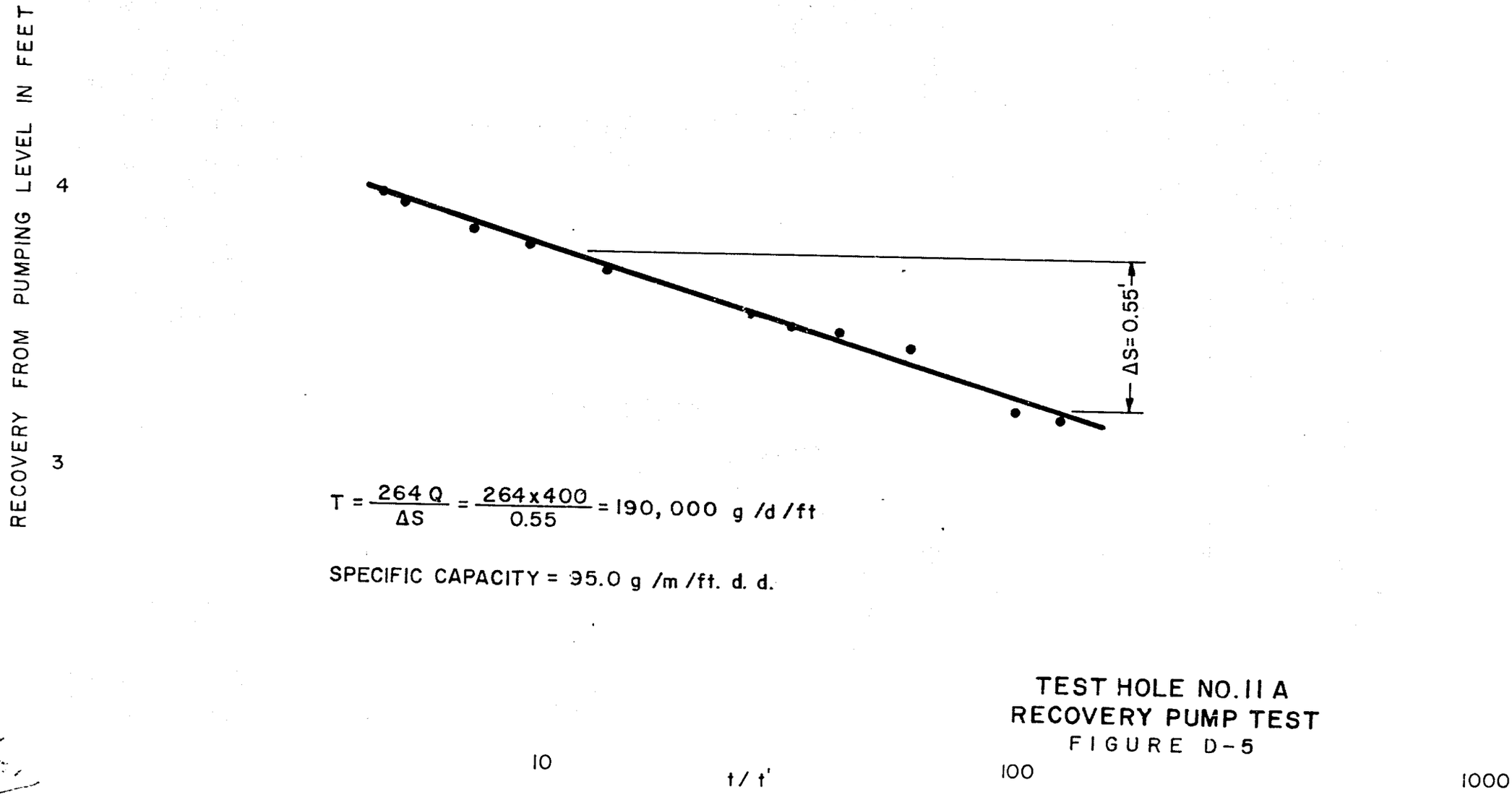
SPECIFIC CAPACITY = 47.0 g./m/ft. d. d.

TEST HOLE NO. 10
RECOVERY PUMP TEST NO. 2
FIGURE D-3



TEST HOLE NO. 10
RECOVERY PUMP TEST NO. 1
FIGURE D-4

DEC. 7, 1974
PRODUCTION RATE (Q)= 400 GPM
STATIC WATER LEVEL = 42.2' B. G. S.

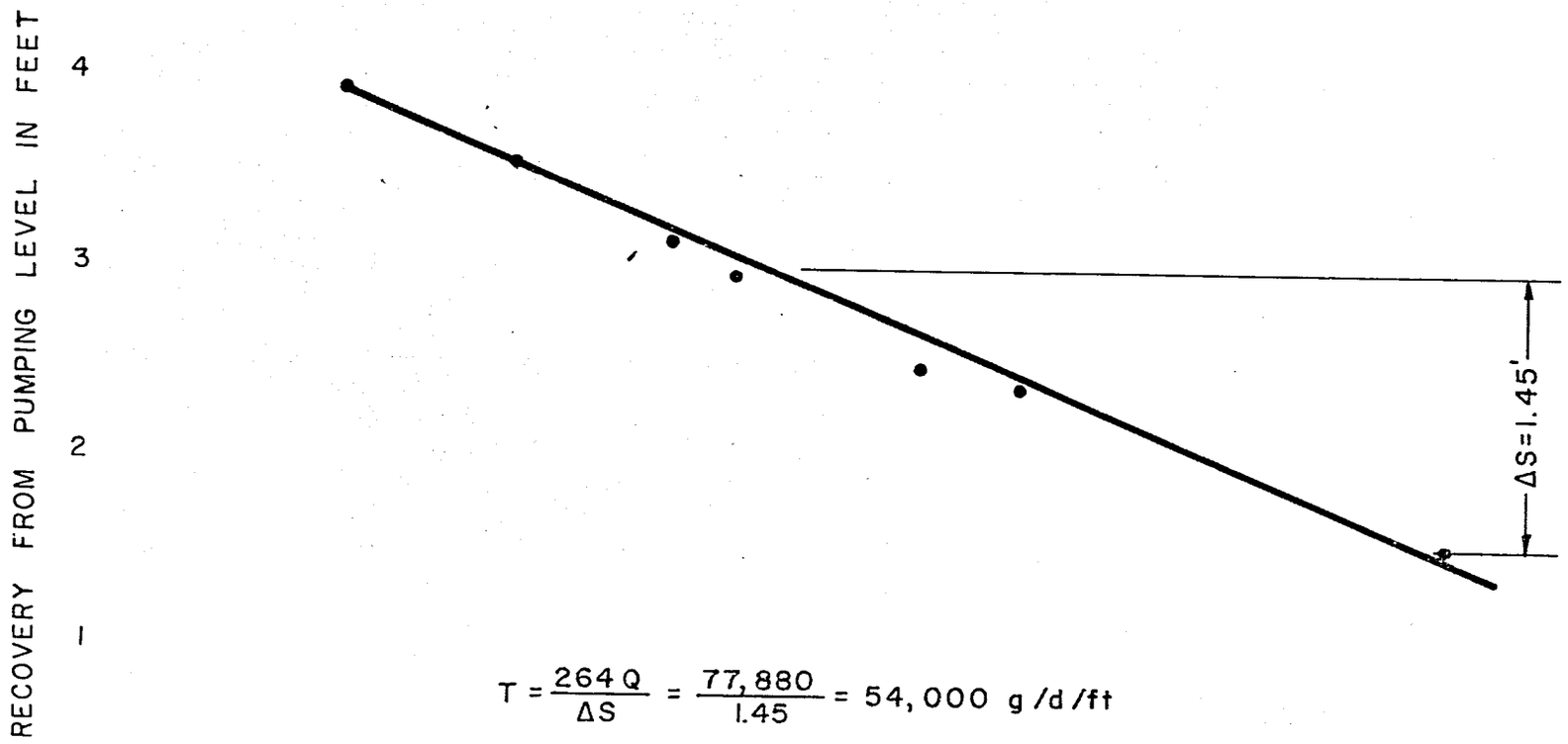


$$T = \frac{264\,Q}{\Delta S} = \frac{264 \times 400}{0.55} = 190,000 \text{ g /d /ft}$$

SPECIFIC CAPACITY = 95.0 g /m /ft. d. d.

TEST HOLE NO. 11 A
RECOVERY PUMP TEST
FIGURE D-5

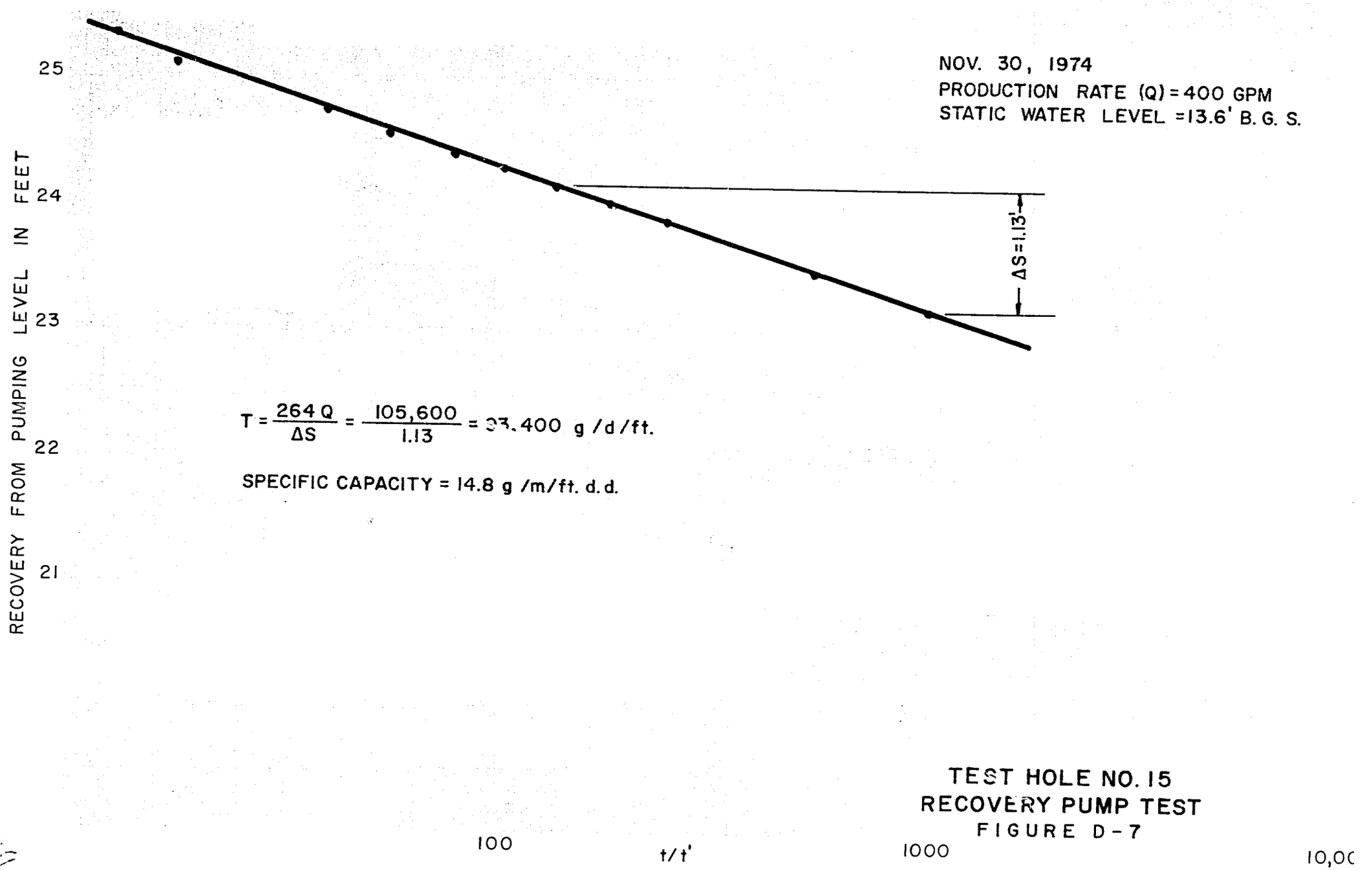
OCT. 29, 1974
PRODUCTION RATE (Q) = 295 GPM
STATIC WATER LEVEL = 10.2' B. G. S.



$$T = \frac{264\,Q}{\Delta S} = \frac{77,880}{1.45} = 54,000 \text{ g/d/ft}$$

SPECIFIC CAPACITY = 63.8 g/m/ft. d.d.

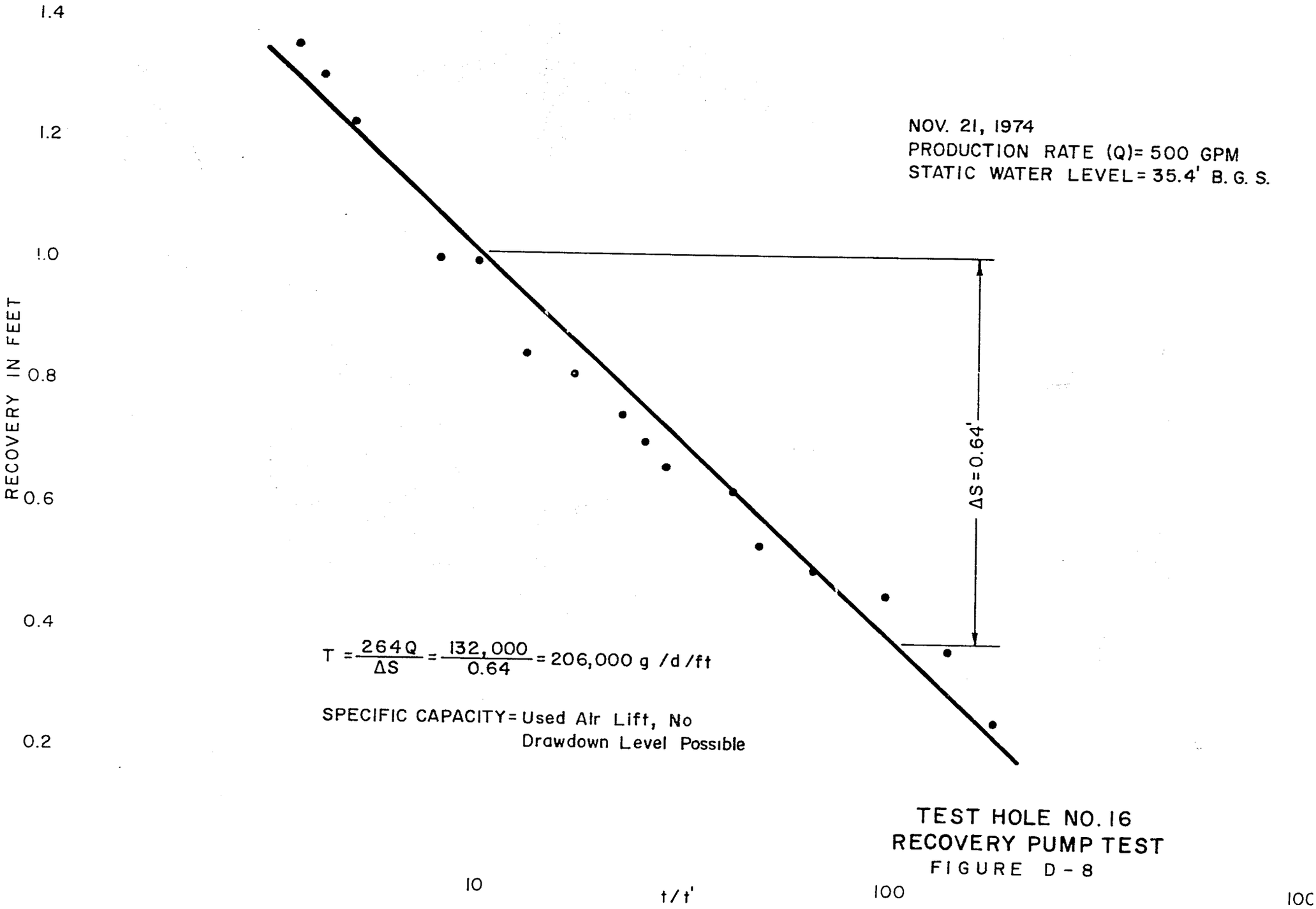
TEST HOLE NO. 14A
RECOVERY PUMP TEST
FIGURE D-6



$$T = \frac{264\,Q}{\Delta S} = \frac{105{,}600}{1.13} = 93{,}400 \text{ g/d/ft.}$$

SPECIFIC CAPACITY = 14.8 g/m/ft. d.d.

TEST HOLE NO. 15
RECOVERY PUMP TEST
FIGURE D-7



TEST HOLE NO. 16
RECOVERY PUMP TEST
FIGURE D - 8

APPENDIX E

APPENDIX E

RECOMMENDED WATER RESOURCES EXPLORATION AND TEST DRILLING PROGRAM CITY OF TAIZ AND VICINITY YEMEN ARAB REPUBLIC

(Retype of Report Presented in August 1974)

PURPOSE AND SCOPE

The test program herein recommended was formulated to provide a systematic approach for the exploration and confirmation of water resources within an 18 kilometer radius of Taiz. This radius for evaluation was selected as the maximum distance which it could, at this time, be considered economically feasible to transmit a water supply through pipeline(s) to the city. Aerial accessibility, topographic conditions and comparative elevations were factors of consideration in confining the analysis to this 18 kilometer limitation. Further, a study of air photos extending far beyond the radius of determined feasibility indicated no large potential water source which would justify expanded investigation.

At the outset of the project the feasibility of developing surface water sources was considered. However, analyses of climate, runoff characteristics, watershed areas, and topography demonstrated a restricted potential for surface supply capture and storage. The location and development of ground water resources was therefore considered the most feasible approach to satisfying the future water needs of Taiz City.

The exploration and testing program recommended is intended to serve as a guideline for determining equipment and materials requirements, exploration costs, project alternatives, project timing and a general priority for exploration of potential resources.

GENERAL PHYSICAL ENVIRONMENT

Topographic, geologic and climatic features all combine to limit the availability of reliable water resources in the Taiz vicinity.

Taiz lies at the foot of the East-West trending escarpment of the Jabel Sabir massif, the jagged peaks of which rise steeply to the south of the city. Moderate to rugged hills and narrow valleys form a broad vista

lying below and away to the north of the city. Igneous rocks of Tertiary and older, dominate the aerial terrain. Exposures of these rocks reflect an intensive post-emplacement structural activity of faulting, folding, jointing and general regional upheaval. Superimposed over these older rocks and features is an erratic and largely dendritic drainage pattern. Stream valleys incising the steep Jabel Sabir north of the city are sharply "V" cut and are essentially devoid of alluvial fill. From the foot of the Jabel Sabir escarpment and continuing north, the stream valleys (wadis) occur as ribbons of Quaternary alluvium; filling narrow valleys eroded in the older basement complex. Soil covered surfaces in the wadis are intensely cultivated, primarily by dry-farming methods. Soils on the slopes of the basement complex hills are either poorly developed or non-existent.

Precipitation in the vicinity of Taiz occurs predominantly throughout the months of June through August. Rainfall is derived generally from conventional or narrow storm fronts of high intensity and short duration. High natural and artificial consumptive use, i.e., evaporation and transpiration, coupled with soil moisture deficiencies incurred throughout the long dry season appear to limit direct deep percolation from precipitation throughout the region.

Because of the above factors of physical environment, the water economy in the vicinity of Taiz is marginal to slightly surplus.

APPROACH TO GROUND WATER EXPLORATION

In the subject area, two avenues of approach appear available for exploration of resources. One is, as in the past, the possibility of locating additional resources in the Quaternary alluvial fill of wadi basins. The second is the exploration of the older consolidated rocks where the geologic environment appears conducive to accumulation, transmission and storage of sufficient quantities of suitable quality water. There are positive and negative aspects to both of these approaches, and both require drilling-testing programs for confirmation. Information test borings are also recommended to study subsurfaces conditions near and in Taiz.

Wadi Basin Exploration

The current Taiz water supply is derived primarily from the wadi basins of Houban and Hougala with a minor contribution from Hougfa basin. Presently, approximately 1.2 million US gallons per day are derived from these combined sources. The Houban basin is in apparent overdraft at current extraction rates, while it is possible the production could be increased slightly from Hougala and Hougfa. Water quality,

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however, has become progressively degraded in these basins throughout time to the point where, if continued, these sources will be completely nonpotable within a few years. It is strongly suspected that development of any additional wadi sources within the drainage influence of the city will result in a similar degradation. Additional wadis outside the Taiz drainage that appear suitable for source development are few. South of the city lie the steep slopes and sharp valleys of Jabel Sabir; to the northeast are rugged hills with only minor shallow valley courses; to the near north and northwest is the Taiz city drainage. Only to the west and distant north does it appear likely that a water source of satisfactory quantity and quality can be located. The test locations recommended in wadis throughout the vicinity are shown on Plate I and pertinent data upon which to base alternatives and priorities are listed in Table E-1.

Wadi test drilling in all cases, anticipated to be shallow (maximum 200 feet), can be accomplished by percussion or rotary drilling techniques in a relatively short time, and completed at low cost.

Consolidated Rock Exploration

To date the water resources potential of consolidated rocks (hardrock) in the vicinity of Taiz has not been explored. That these rocks are locally water bearing is demonstrated by the numerous springs issuing from the Jabel Sabir massiff and other locations throughout the region. Such water sources are generally associated with fracture zones and/or bedding planes oriented on attitudes favorable to collection and storage of percolating waters. Consolidated rock sources are usually discovered at greater depths than the near-surface wadi sources and frequently not subject to pollution or contamination as are the shallow wadi supplies. Upon the basis of surface evidence alone, there are in the area of evaluation several locations which exhibit water bearing potential. Once again, these locations are limited by natural physical conditions in the vicinity of Taiz. The areas south of the city are dominated by the inaccessible slopes of Jabel Sabir. With the exception of one location approximately three kilometers north of the new Taiz airport, the area northeast of the city appears unsuitable as a source area because of structural deformation and formation characteristics. In the sector between 10 and 18 kilometers due north of Taiz at least six potential consolidated rock prospects have been located. All of these locations are associated with rocks having favorably dipping bedding planes intersecting fault zones. Wetted wadis adjacent to the test sites suggest seepage from the dipping formations, therefore shallow test holes are also recommended along stream courses near the consolidated rock test bores. One test hole is recommended near the city where at least two major faults intersect. These structural features may provide

TABLE E-1

GENERAL FEATURES OF TEST AREAS

Test Area Designation	Accessibility	Water Quality	Geologic Environment	Pipeline Distance (Approx km)	Elevation (Approx m)	Testing Priority Rating
I	Good Road	Tested Poor	Wadi Alluvium to Volcanic Bedrock	N.A.	1165	1
II	Good Road	Tested Poor	Wadi Alluvium	N.A.	1170	2
III	Good Road		Wadi Alluvium to Volcanic Bedrock	N.A.	1170	3
IV	Good Road	Probable Very Good	Wadi Alluvium to Igneous Bedrock	1.5	1220	5
V	Good Road	Probable Very Good	Intersecting Faults in Fractured Bedrock	0.8	1175	6
VI	Fair Road	Probable Good	Alluvial Fan to Fractured Igneous Bedrock	N.A.		13
VII	Fair Road	Probable Good	Alluvial Fan to Fractured Bedrock	N.A.		14
VIII	Poor Road	Probable Good	Wadi Alluvium to Bedrock	5.8		9
IX	Poor Road	Probable Good	Wadi Alluvium to Bedrock	7.6		10
X	Poor Road	Tested Very Good	Alluviated Wadi Basin to Bedrock	11.8		4
XI	Poor Road To No Road	Probable Potable	Fractured Zone in NW Striking, South Dipping Formation	15.6		7
XII	Poor Road To No Road	Probable Good	Fracture Zone in NW Striking, South Dipping Formation and Alluviated Wadi	18.3		15
XIII	Poor Road To No Road	Probable Good	Fracture Zone in NW Striking, South Dipping Formation and Alluviated Wadi	18.3		12
XIV	Fair Road	Probable Good	Fracture Zone in NW Striking, South Dipping Formation and Alluviated Wadi	15.0		8
XV	Fair Road	Probable Poor	Alluviated Wadi Basin to Bedrock	9.5		11
XVI	Poor Road To No Road	Probable Good	Fracture Zone in NW Striking, South Dipping Formation. Alluviated Wadi to Bedrock	21.0		16
XVII	Poor Road To No Road	Probable Good	Fracture Zone in NW Striking, South Dipping Formation. Alluviated Wadi to Bedrock	23.0		17
XVIII	Poor Road To No Road	Probable Good	Fracture Zone in NW Striking, South Dipping Formation. Alluviated Wadi to Bedrock	25.2		18

flow channels from Jabel Sabir, beneath the city and into a related crush zone. Surface evidence suggests stream sapping may have occurred in the past at this location. Plate I depicts the locations of suggested rock test points and Tables E-1 and E-2 list pertinent information regarding each site.

Consolidated rock drilling will require conventional rotary or downhole pneumatic equipment to penetrate to depths and at rates necessary for a test program. Maximum drilling depths of 600 feet are expected at most site locations. Drilling of this type may be anticipated to be relatively expensive and time consuming.

Information Test Drilling

In addition to the shallow wadi and consolidated rock test drilling, a number of information test wells are recommended. Such wells are sited at locations where conditions regarding aquilen continuity, underflow rates and/or water quality trends should be investigated. Suggested sites for the information borings are shown on Plate I and Table E-2 describes the purpose of each test point. All information wells are anticipated to be drilled into alluvial or soft rock sediments to depths of 200 feet or less. Either percussion or rotary drilling may be employed in drilling and construction at the information test locations.

IMPLEMENTATION AND EXECUTION OF DRILLING AND TESTING

The test program recommended includes a number of alternative potential supply sources, and upon bases of location, accessibility, drilling conditions, probable water quality, and several project economics, establishes a numerical sequence priority rating for exploration in each area. For example, the area with priority rating number 1 should be the first area investigated, number 2 second, etcetera. At the time during the project that a sufficient water supply for the project is confirmed the test drilling program should be discontinued and design of facilities initiated.

Because of the potential expense, importance of the test drilling to the overall project, and the specialized knowledge required to evaluate ground water resources, it is recommended that a qualified water resources consultant be present to direct testing activities and analyze data throughout the course of the program.

TABLE E-2

TEST HOLE INFORMATION

Test Area Designation	Direction from Taiz	Distance from Taiz (km)	Test Hole Designation	Drilling Conditions	Test Bore Depths (m)	Purpose of Testing	Well Testing Required
I	Northeast	2.5	TH 1	Alluvial	50	Lithology Underflow	Production, Quality Transmissivity
II	Northeast	2.0	TH 2	Alluvial	50	Lithology	Quality Transmissivity
III	Northeast	1.0	TH 3	Alluvial	50	Lithology Underflow	Quality Transmissivity
IV	East	1.5	TH 4	Alluvial	60	Lithology New Source	Production, Quality Transmissivity
V	North	1.0	TH 5	Hard Rock (Fracture Zone)	180	New Source	Production, Quality
VI	Southwest City Sector	Within	TH 6 and Alternate TH 6A	Alluvial	60	Water Quality Unknown	Production, Quality Transmissivity
VII	Western City Sector	Within	TH 7	Alluvial	60	Water Quality Unknown	Production, Quality Transmissivity
VIII	West	5.0	TH 13	Alluvial	50	New Source	Production, Quality Transmissivity
IX	West	7.0	TH 12	Alluvial	50	New Source	Production, Quality Transmissivity
X	West	9.5	TH 8 TH 9 TH 10 TH 11	Alluvial Alluvial Alluvial Alluvial	60 60 60 60	New Source (Piezometer) New Source (Test Well) New Source (Information) New Source (Information)	Production, Quality, Transmissivity, Storage, Recharge
XI	Northeast	13.5	TH 14	Hard Rock (Structure)	180	New Source	Production, Quality
XII	North	11.0	TH 20 TH 21	Alluvial Hard Rock (Structure)	50 180	New Source New Source	Production, Quality Production, Quality
XIII	North	10.5	TH 22 TH 23	Alluvial Hard Rock (Structure)	60 180	New Source New Source	Production, Quality Production, Quality
XIV	North	10.0	TH 24 TH 25	Alluvial Hard Rock (Structure)	50 180	New Source New Source	Production, Quality Production, Quality
XV	Northwest	8.0	TH 26 TH 27	Alluvial Alluvial	60 60	New Source New Source Sewage Disposal	Production, Quality Transmissivity
XVI	North	13.0	TH 19 TH 20	Alluvial Hard Rock (Structure)	50 180	New Source New Source	Production, Quality Production, Quality
XVII	North	15.0	TH 17 TH 18	Alluvial Hard Rock (Structure)	60 180	New Source New Source	Production, Quality Production, Quality
XVIII	North	17.0	TH 15 TH 16	Alluvial Hard Rock (Structure)	50 180	New Source New Source	Production, Quality Production, Quality

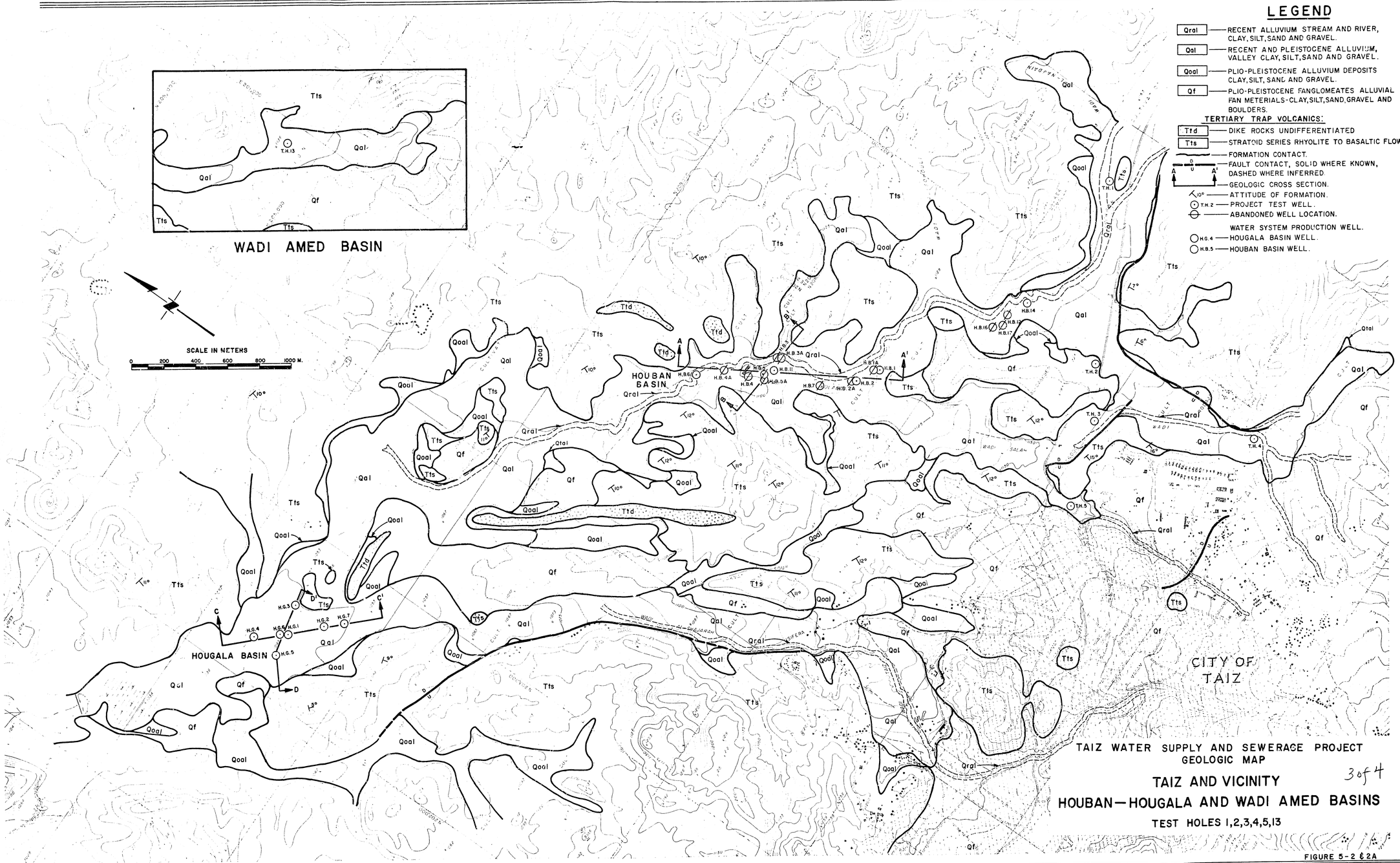

FIGURE 5-2 & 2A

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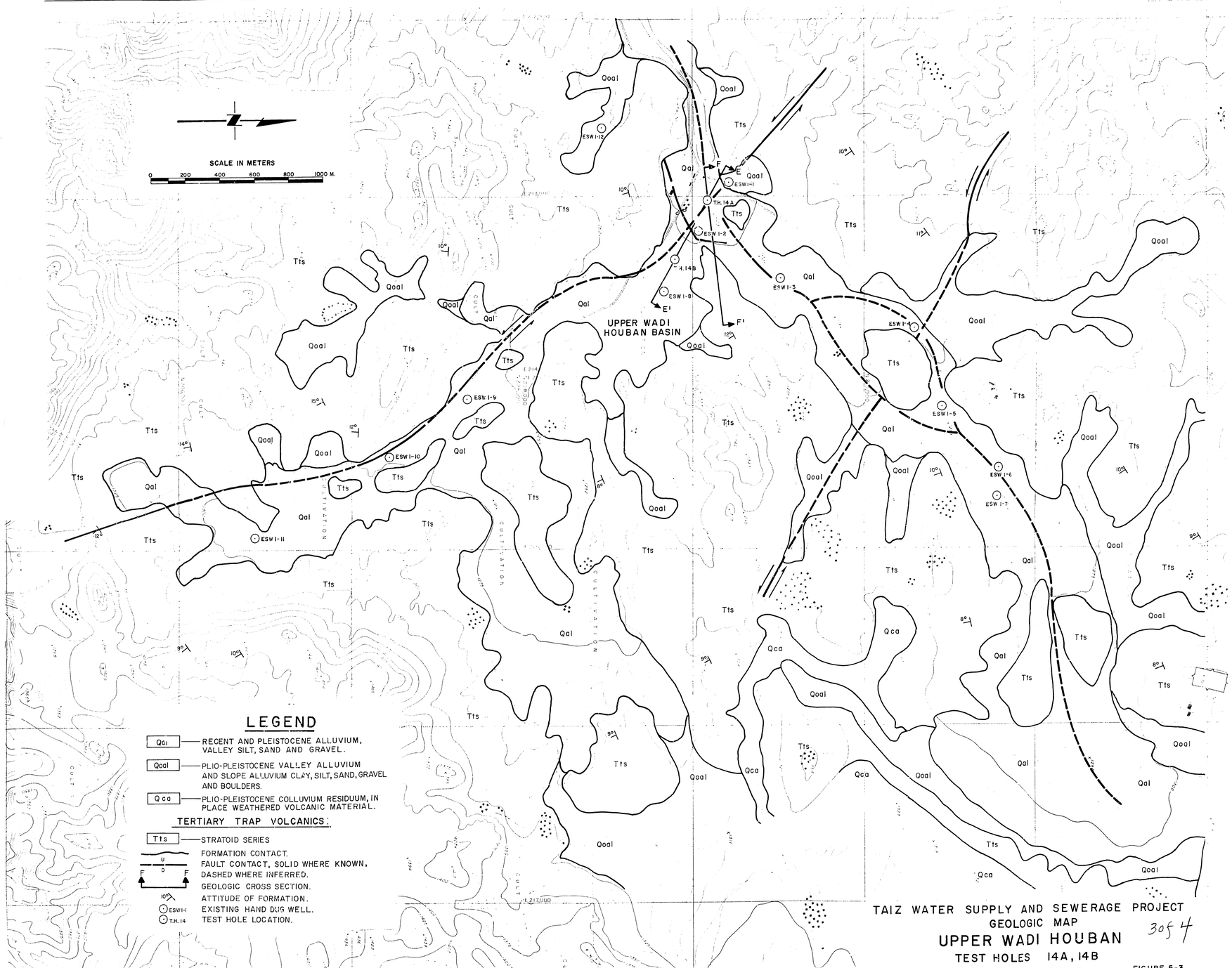
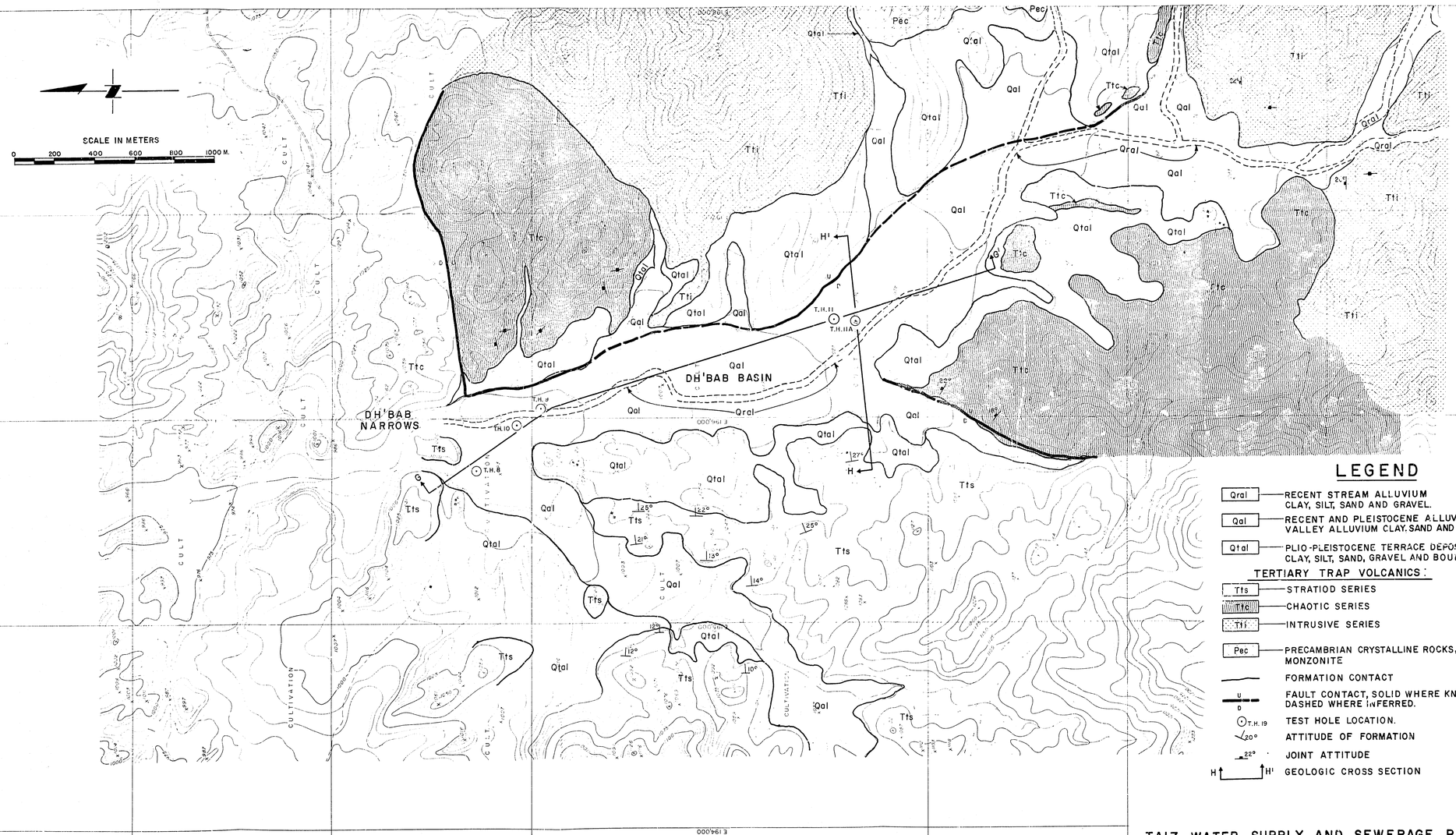


TAIZ WATER SUPPLY AND SEWERAGE PROJECT
GEOLOGIC MAP
UPPER WADI HOUBAN
TEST HOLES 14A, 14B

FIGURE 5-3

JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.

1.0 1.1 1.25 1.4 1.6 2.8 3.2 2.5 2.2 2.0
24X



LEGEND

Qral	RECENT STREAM ALLUVIUM CLAY, SILT, SAND AND GRAVEL.
Qal	RECENT AND PLEISTOCENE ALLUVIUM, VALLEY ALLUVIUM CLAY, SAND AND GRAVEL.
Qtal	PLIO-PLEISTOCENE TERRACE DEPOSITS CLAY, SILT, SAND, GRAVEL AND BOULDERS.

TERTIARY TRAP VOLCANICS:

Tts	STRATIOD SERIES
Ttc	CHAOTIC SERIES
Tti	INTRUSIVE SERIES
Pec	PRECAMBRIAN CRYSTALLINE ROCKS, QUARTZ MONZONITE
	FORMATION CONTACT
	FAULT CONTACT, SOLID WHERE KNOWN, DASHED WHERE INFERRED.
T.H. 19	TEST HOLE LOCATION.
20°	ATTITUDE OF FORMATION
22°	JOINT ATTITUDE
H H'	GEOLOGIC CROSS SECTION

TAIZ WATER SUPPLY AND SEWERAGE PROJECT
GEOLOGIC MAP

DH'BAB BASIN

TEST HOLES 8,9,10,11,11A

3 of 4

FIGURE 5-4

JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.

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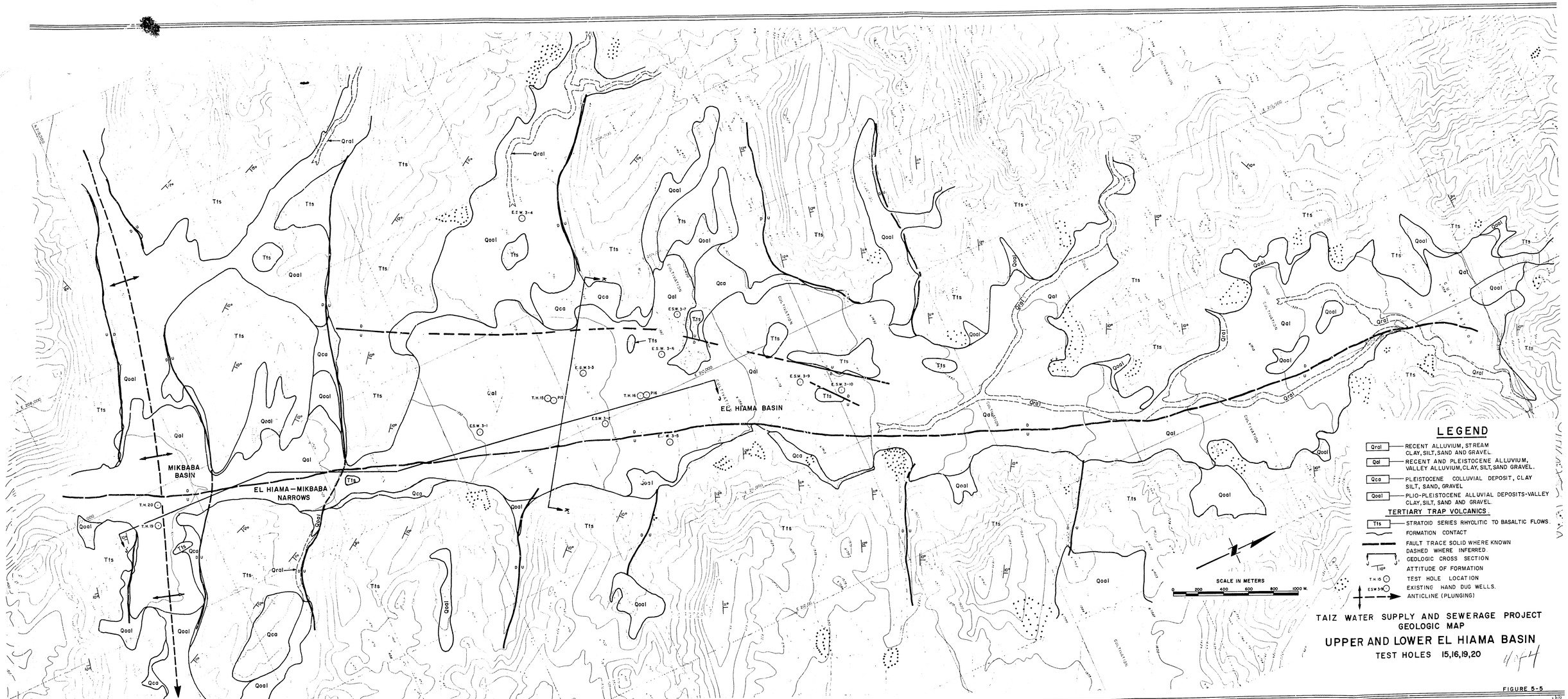
EL HIAMA BASIN
MIKBABA BASIN
EL HIAMA – MIKBABA NARROWS
LEGEND
Qral — RECENT ALLUVIUM, STREAM CLAY, SILT, SAND AND GRAVEL.
Qal — RECENT AND PLEISTOCENE ALLUVIUM, VALLEY ALLUVIUM, CLAY, SILT, SAND GRAVEL.
Qca — PLEISTOCENE COLLUVIAL DEPOSIT, CLAY SILT, SAND, GRAVEL
Qoal — PLIO-PLEISTOCENE ALLUVIAL DEPOSITS-VALLEY CLAY, SILT, SAND AND GRAVEL.
TERTIARY TRAP VOLCANICS.
Tts — STRATOID SERIES RHYOLITIC TO BASALTIC FLOWS.
FORMATION CONTACT
FAULT TRACE SOLID WHERE KNOWN DASHED WHERE INFERRED.
GEOLOGIC CROSS SECTION
ATTITUDE OF FORMATION
T.H. 15 TEST HOLE LOCATION
E.S.W. 3-9 EXISTING HAND DUG WELLS.
ANTICLINE (PLUNGING)
SCALE IN METERS
0 200 400 600 800 1000 M.
TAIZ WATER SUPPLY AND SEWERAGE PROJECT
GEOLOGIC MAP
UPPER AND LOWER EL HIAMA BASIN
TEST HOLES 15,16,19,20
JAMES M. MONTGOMERY, CONSULTING ENGINEERS, INC.

FIGURE 5-5

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
30X