DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

HYDROGEOLOGIC TESTING PLAN
FOR EXPLORATORY SHAFT MONITORING WELLS,
DEAF SMITH COUNTY SITE, TEXAS

HAS NOT BEEN REVIEWED BY DOE
DRAFT REPORT

Σ²Π

S. S. PAPADOPULOS & ASSOCIATES, INC.
CONSULTING GROUND-WATER HYDROLOGISTS

DRAFT REPORT HAS NOT BEEN REVI... BY DOE

HYDROGEOLOGIC TESTING PLAN

FOR EXPLORATORY SHAFT MONITORING WELLS,

DEAF SMITH COUNTY SITE, TEXAS

TOPICAL REPORT

NOVEMBER 1986

DRAFT REPORT HAS NOT BEEN R... BY DOE

S. S. PAPADOPULOS & ASSOCIATES, INC.
CONSULTING GROUND-WATER HYDROLOGISTS

DISCLAIMER

TECHNICAL STATUS

HYDROGEOLOGIC TESTING PLAN
FOR EXPLORATORY SHAFT MONITORING WELLS,
DEAF SMITH COUNTY SITE, TEXAS

TOPICAL REPORT

NOVEMBER 1986

By

Stavros S. Papadopulos

S. S. PAPADOPULOS & ASSOCIATES, INC.
CONSULTING GROUND-WATER HYDROLOGISTS

12250 ROCKVILLE PIKE, SUITE 290
ROCKVILLE, MARYLAND 20852
TEL. (301) 468-5760

This report was prepared by S.S.Papadopulos & Associates, Inc. under Contract E514-15400 with Battelle Memorial Institute, Project Management Division, under Contract DE-AC06-76RL01830 with the U.S. Department of Energy.

ABSTRACT

As part of site characterization studies, two exploratory shafts will be constructed at the Deaf Smith County, Texas site. Six dual-completion wells have been proposed to monitor potential impacts of shaft construction on water-bearing zones in the Ogallala Formation and Dockum Group. Hydrogeologic tests for these wells have been proposed to determine the hydraulic properties of the water-bearing zones prior to shaft construction.

To develop a plan for these tests, available data were reviewed to determine the hydrogeologic setting and the range of hydraulic parameters for the Ogallala and Dockum. Ground water in the Ogallala is unconfined; transmissivity ranges from 5,000 to 40,000 gpd/ft and specific yield from 0.05 to 0.20. In the principal water-bearing zone of the Dockum, ground water is confined; transmissivity ranges from 100 to 8,740 gpd/ft and storage coefficient from 0.00001 to 0.001.

Based on expected pumping-test responses for the above range of parameters and review of the proposed monitoring system, a hydrogeologic testing plan was developed. The plan recommends changes in monitoring locations and replacement of each dual-completion well by two separate wells to permit reasonable testing periods and improve the monitoring system. Six-day Ogallala and two-day Dockum pumping tests, followed by equal recovery periods, are recommended at each of the six monitoring locations.

Analyses of Ogallala test data by Neuman's (1975) unconfined aquifer method and of Dockum test data by Theis' (1935) confined aquifer method are demonstrated by application to expected test responses. Other potential responses and applicable analyses are discussed.

DRAFT REPORT
HAS NOT BEEN
BY
DOE

TABLE OF CONTENTS

TABLE OF CONTENTS

(continued)

LIST OF FIGURES

LIST OF FIGURES

(continued)

CONVERSION FACTORS

This report used data from numerous studies by others. In most of these studies, data were reported in U.S. customary units. Therefore, U.S. customary units have been used in this report. Factors for converting U.S. customary units to metric units are presented below.

U.S. Customary Units	Multiply by	Metric Units
feet (ft)	0.3048	meters (m)
gallons (gal)	3.785	liters (L)
gallons per day per foot (gpd/ft)	0.01242	meters squared per day (m^2/d)
gallons per day per square foot (gpd/ft^2)	0.04075	meters per day (m/d)
gallons per minute (gpm)	0.06309	liters per second (L/s)
inches (in)	25.40	millimeters (mm)
miles (mi)	1.609	kilometers (Km)
miles squared (mi^2)	2.589	kilometers squared (Km^2)

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

REPORT

REPORT

DRAFT REPORT
HAS NOT BEEN R
BY
DOE

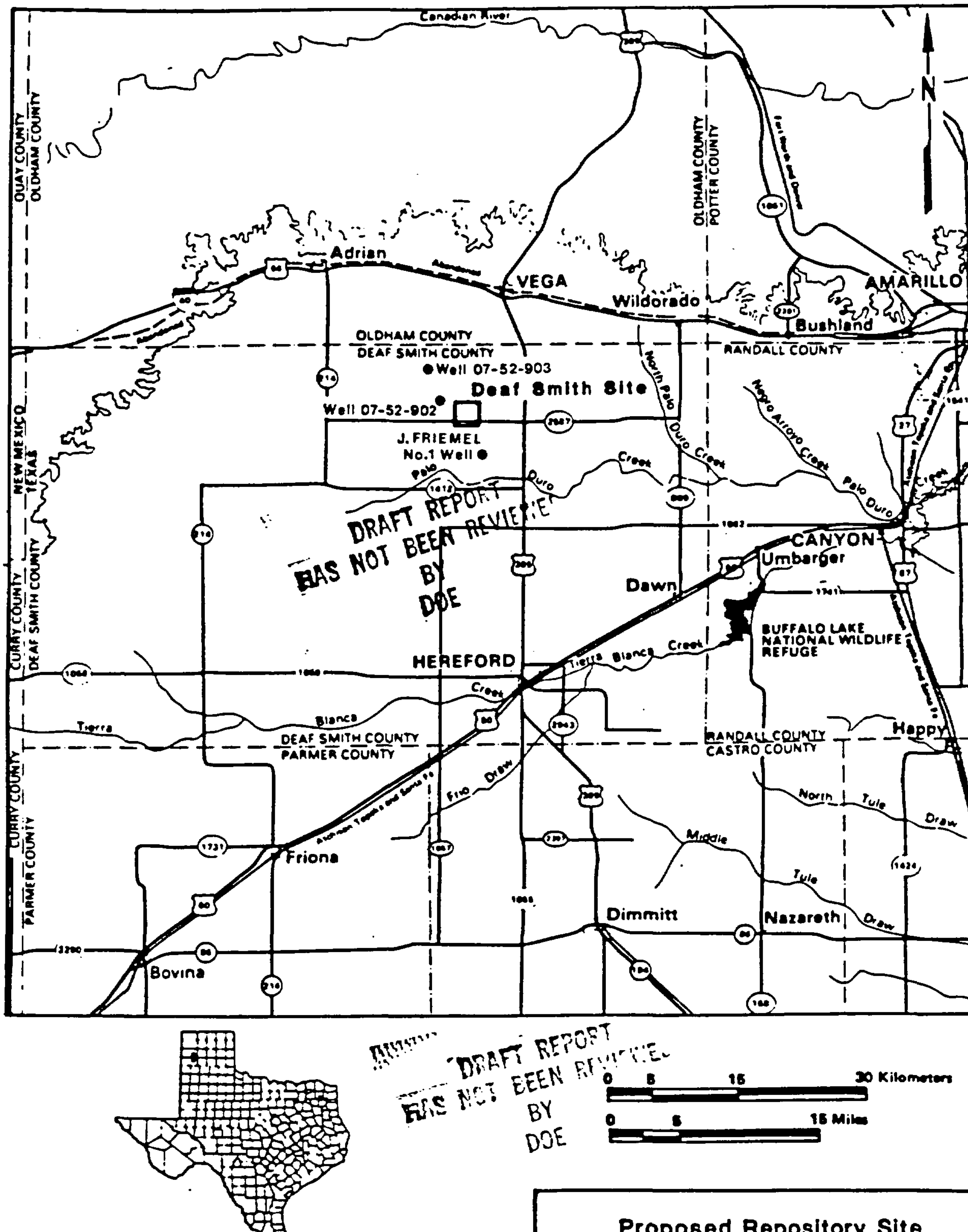
1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Department of Energy (DOE) identified a nine square mile area in Deaf Smith County, Texas (Figure 1-1) as a potentially acceptable site for the development of a high-level radioactive waste repository (DOE, 1986). Geologically, the site lies within the Palo Duro Basin. The basement materials in the Palo Duro Basin consist of igneous and metamorphic rocks; the basement is overlain by a thick sequence of sedimentary rocks. Three hydrogeologic units have been identified within the sedimentary sequence (Bair, 1985; Bair, O'Donnell and Picking, 1985; DOE, 1986). The uppermost unit consists of water-bearing zones within the Ogallala Formation and the Dockum Group, and contains potable water; the unit is often referred to as the High Plains Aquifer. The middle unit is an aquitard consisting of beds of shale and evaporite of Permian age. The proposed host rock for the repository, the Lower San Andres Unit 4 salt, lies within this aquitard. The lowermost hydrogeologic unit, consisting of older Paleozoic rocks, is a deep-basin flow system of brine aquifers.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

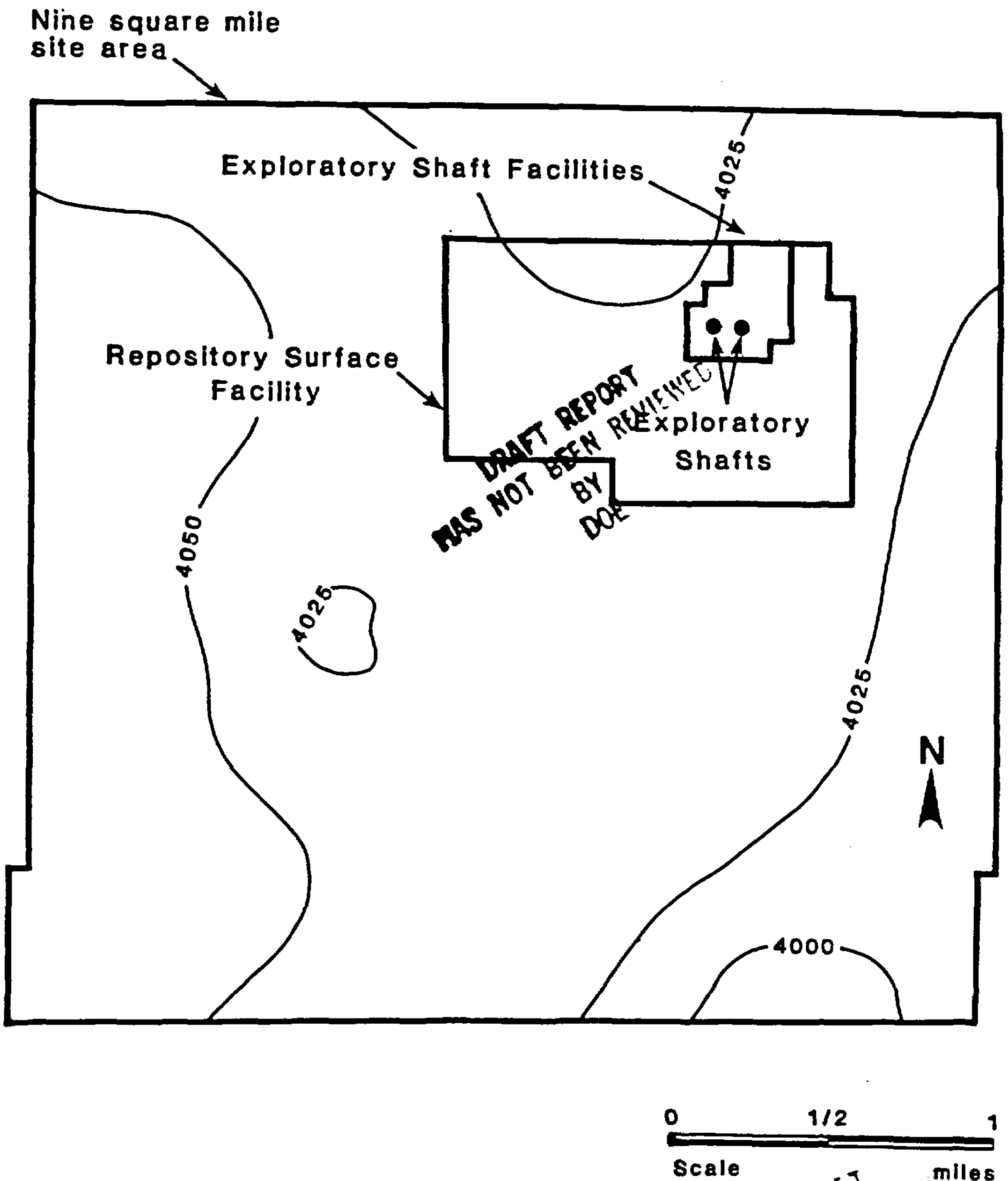
As part of the site characterization program two exploratory shafts are planned for construction (DOE, 1986) at the northeastern part of the proposed site (Figure 1-2). The shafts will extend into the Lower San Andres Unit 4 salt (DOE, 1986), which is estimated to lie between about 2,370 and 2,600 feet below land surface [DOE, Salt Repository Project Office (DOE/SRPO), 1986]. Before the shafts are constructed, an engineering design borehole (EDBH) will be drilled through the Unit 4 salt to the underlying Lower San Andres Unit 3 salt at each of the shaft locations.



Source : Enviromental Assessment, Deaf Smith County Site, Texas, USDOE, May, 1986, Figure 2

Proposed Repository Site
Deaf Smith County, Texas

Figure 1-1



DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

EXPLANATION

—4025— Line of equal altitude of land surface, in feet above MSL

Adapted from Environmental Assessment, Deaf Smith County Site, Texas, USDOE, May 1986, Figures 4-2 and 4-5

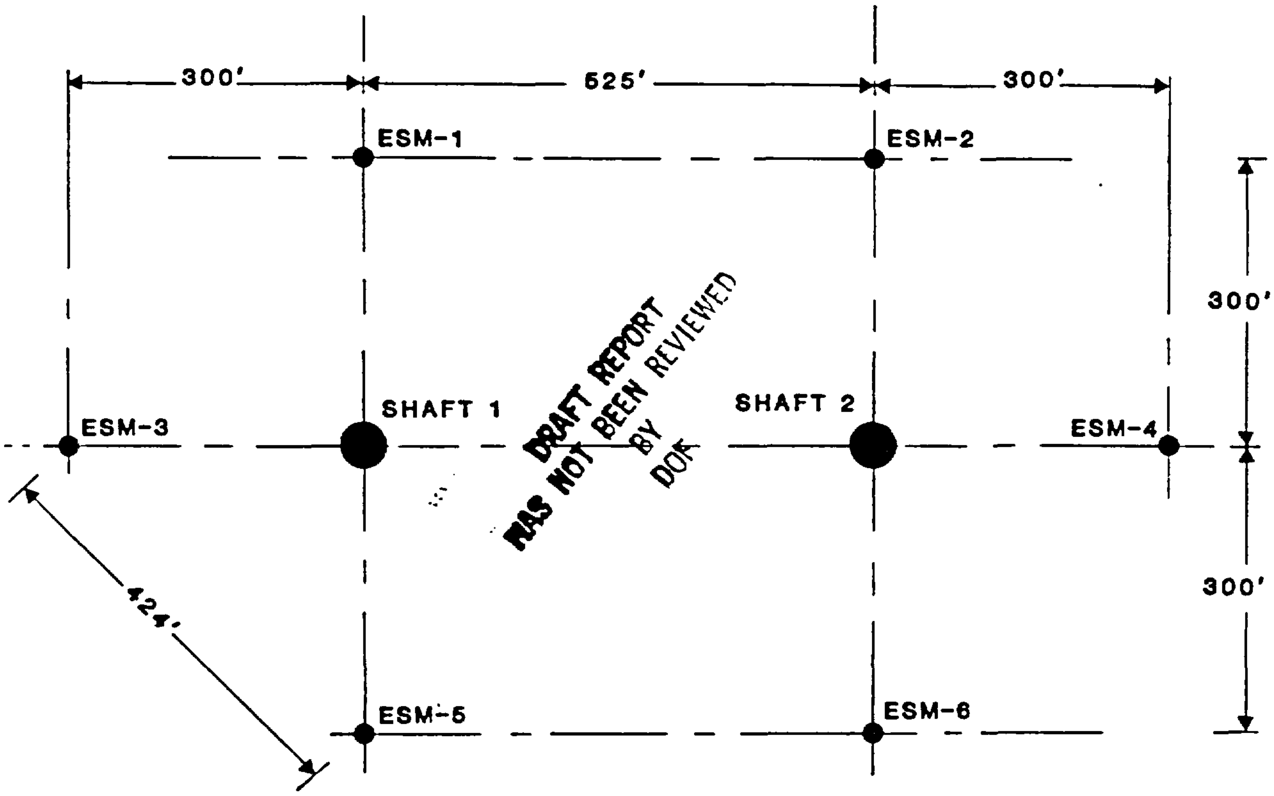
Location of the Exploratory Shaft Facility

Figure 1-2

To reduce ground-water inflow during shaft construction and to stabilize unconsolidated materials, a freeze-wall will be developed around each shaft location by freezing the Ogallala Formation and, in part, the underlying Dockum Group. The Ogallala extends to a depth of about 340 feet and the Dockum to about 960 feet at the shaft locations. The hydraulic properties of water-bearing zones within the Ogallala Formation and the Dockum Group are among the parameters that must be known for the design of the freeze wall and for shaft construction. These hydraulic properties are also needed for the overall characterization of the suitability of the site as a repository.

Six monitoring wells will be installed around the two shaft sites (DOE, 1986) to determine baseline water-level and water-quality conditions in the Ogallala Formation and the Dockum Group prior to shaft construction, and to monitor these conditions during and after shaft construction. The installation of these wells will begin simultaneously with that of the EDBHs [Stone & Webster Engineering Corporation (SWEC), 1985e, Attachment 11]. Preliminary plans for the location and completion of these wells were developed by SWEC (1985e). The locations proposed in these plans are shown on Figure 1-3. These plans also call for the dual completion of the monitoring wells with screened intervals both in the saturated part of the Ogallala Formation and in the principal water-bearing zone of the Dockum Group (Figure 1-4).

Although the primary purpose of these monitoring wells will be to detect water-level and/or water-quality changes that may be caused by shaft construction activities, the wells will also be available for the conduct of hydrogeologic tests prior to shaft construction. Thus, the hydraulic



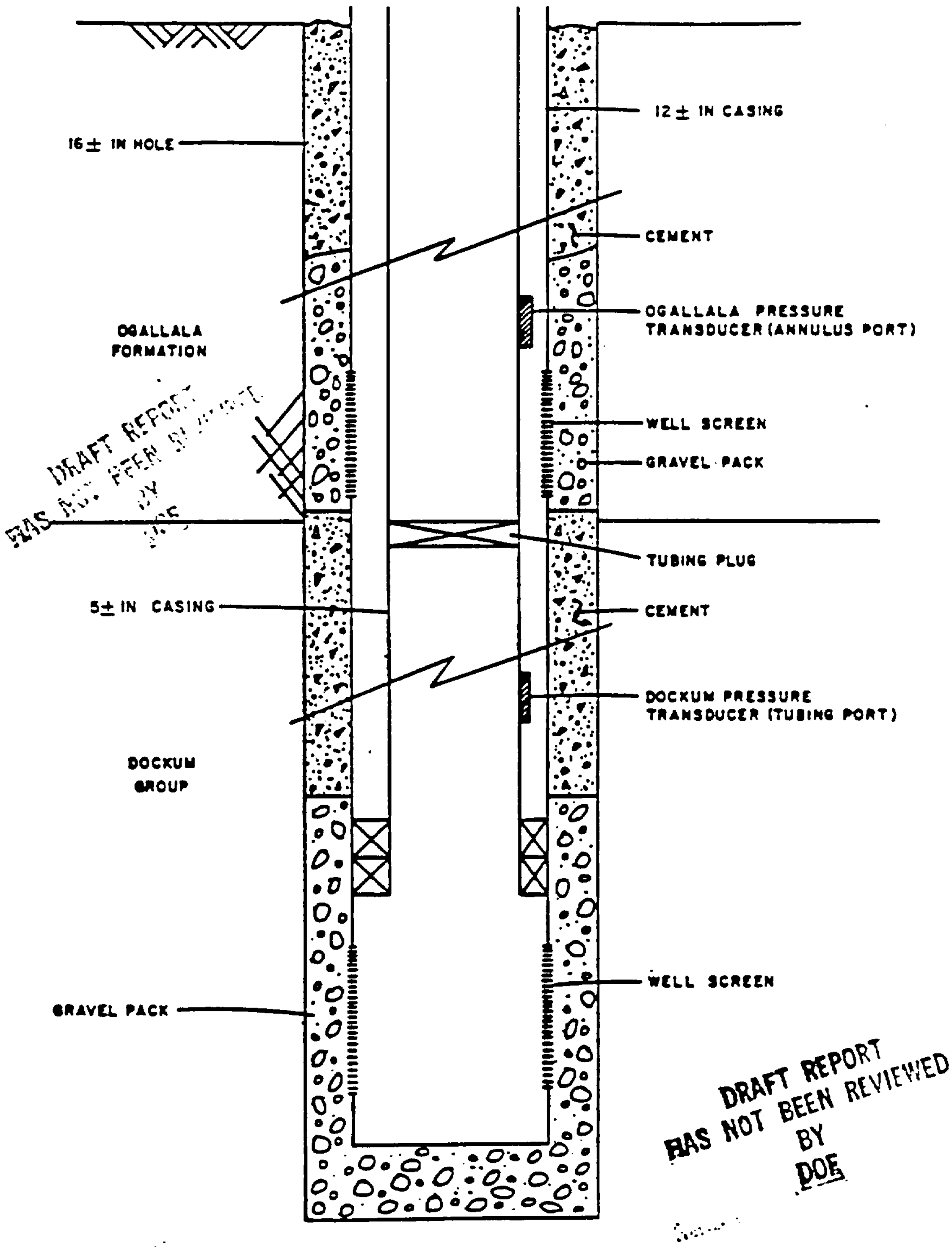
LEGEND

● Exploratory Shaft Monitoring Wells

Modified from Stone & Webster Engineering Corporation, 1985f, PTP 13697-20-0, Attachment 3

Location of the Exploratory Shaft Monitoring Wells

Figure 1-3



Source :
Stone & Webster Engineering Corporation, 1985e, AP 13697-25-0, Attachment 2.

Schematic of Exploratory Shaft Monitoring Well

Figure 1-4

parameters of the Ogallala and the Dockum, which are needed for the design of the freeze wall and for site characterization, can be determined from tests in these wells. Given this dual function, these wells could be referred to as "Shaft Monitoring/Near Shaft Characterization Wells". However, to maintain uniformity with previous references to these wells (SWEC, 1985e; DOE, 1986), they will continue to be referred to in this report as "Exploratory Shaft Monitoring Wells".

This report presents a plan for the hydrogeologic testing of the exploratory shaft monitoring wells and discusses the evaluations conducted in designing the plan.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

1.2 OBJECTIVE AND SCOPE

The objective of this study is to develop a plan for conducting hydrogeologic tests in the exploratory shaft monitoring wells with the purpose of determining the hydraulic properties of the saturated part of the Ogallala Formation and of the principal water-bearing zone of the Dockum Group in the vicinity of the exploratory shaft facilities.

The scope of the work performed to accomplish the above-stated objective included the following tasks:

1. Review of available data to determine hydrogeologic conditions associated with the zones to be tested and the potential range of the hydraulic properties of these zones;

2. Evaluation of the applicable testing procedures and of the expected aquifer responses under the hydrogeologic conditions and for the range of hydraulic properties determined in (1);

3. Review of the monitoring well locations and design, and development of the testing plan; and

4. Formulation of the test data analysis procedures.

The primary purpose of the data review carried out in this study (item 1 above) was to provide guidelines for the design of hydrogeologic tests. Documentation of the available data is beyond the scope of the study and, therefore, is not presented in this report.

2.0 REVIEW OF DATA ON KEY PARAMETERS

The hydraulic parameters of a hydrogeologic system may fall within a relatively wide range of potential values for these parameters. To provide a certain degree of assurance that a hydrogeologic test will yield data amenable to analysis, the expected response during the test must be evaluated for a reasonable range of these potential values. The determination of the type of response that would be expected during the test and estimates of the range of the parameters are based on an understanding of the hydrogeologic setting of the system and on a review of available data.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

The DOE/SRPO (1986) prepared estimates of hydrologic design values for the exploratory shaft construction including estimates of most of the hydraulic parameters of the water-bearing zones within the Ogallala Formation and the Dockum Group. These estimates were generally accepted as the baseline values of the parameters in the vicinity of the shaft locations. To identify a reasonable range of the parameters around these baseline values and to develop an understanding of the hydrogeologic setting of the Ogallala Formation and the Dockum Group, reports and documents prepared by federal and state agencies and by other contractors to the DOE were reviewed. Section 6.0, Bibliography, presents a list of the reviewed documents, including those not specifically referenced in the report.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

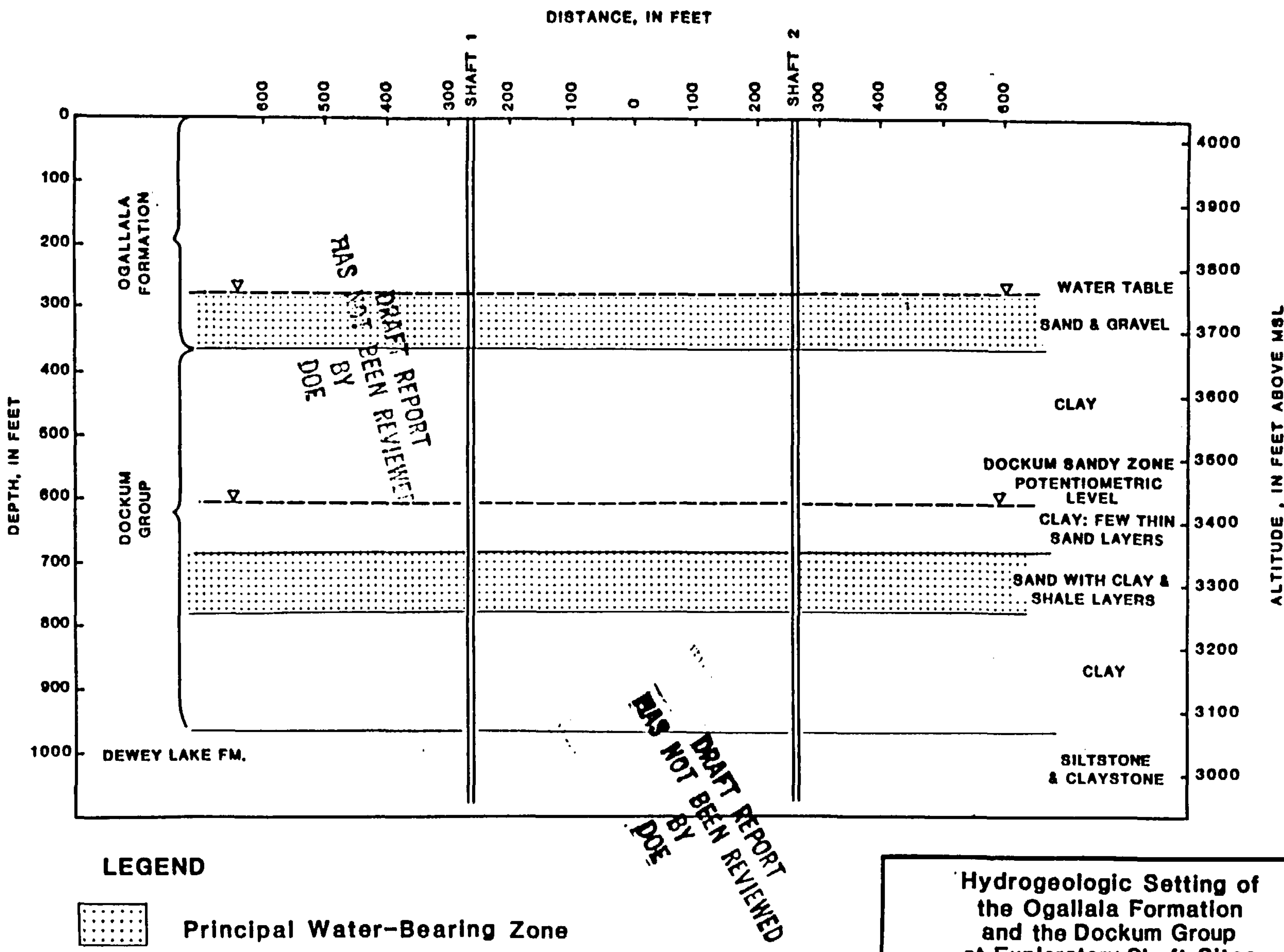
2.1 HYDROGEOLOGIC SETTING

The hydrogeologic setting of the Ogallala Formation and of the Dockum Group near the exploratory shaft sites is shown on Figure 2-1. A brief discussion is presented below.

2.1.1 Ogallala Formation

The Ogallala Formation of Tertiary age was deposited by overloaded streams (Fenneman, 1931, pp. 11-30) carrying materials eroded from the Rocky Mountains. The alluvial beds of sand and gravel, interbedded with silt and clay, were deposited on the eroded surface of the Dockum Group. The streams carrying runoff from the high mountains laid down beds of materials coarser than those in the finer grained Dockum Group which was deposited in a drier environment. The Ogallala Formation extended to the mountains and covered part of the Rolling Plains in Texas and Oklahoma. Headward erosion by the Pecos River has removed the Ogallala Formation in the Pecos Valley of New Mexico. Also, erosion by streams has cut the eastern edge of the Ogallala Formation back to a bluff overlooking the Rolling Plains. The bluff is maintained by caliche beds near the surface of the Ogallala. The caliche beds form the "caprock" and are generally overlain by windblown silt and sand that forms the present land surface. The pre-Ogallala land surface had a greater relief than the present surface; thus, the greatest thicknesses of the Ogallala sediments occur over valleys in the pre-Ogallala surface (Wyatt, Bell and Morrison, 1977; and Seni, 1980). The total thickness of the Ogallala Formation at the site ranges from about 375 feet in the southeast to 275 feet in the northwest [Stone & Webster Engineering Corporation (SWEC), 1984, Figure 23].

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE



DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

Hydrogeologic Setting of the Ogallala Formation and the Dockum Group at Exploratory Shaft Sites

Figure 2-1

Ground water within the Ogallala Formation occurs under unconfined (water table) conditions. Water-level measurements made during 1979-1981 (SWEC, 1984) indicate that the direction of ground-water flow at the site is to the southeast with the water-table elevation ranging from about 3,800 feet above mean sea level near the northwest corner of the site to about 3,770 feet near the southeast corner. The saturated thickness ranges from about 100 feet in the southeast to 50 feet in the northwest. Within a mile beyond the northwest corner of the site, the saturated thickness is only 25 feet. This reduction in the saturated thickness is mainly the result of thinning of the Ogallala Formation over a high on the buried pre-Ogallala surface, rather than the lowering of the water table by pumping.

At the exploratory shaft locations, the Ogallala Formation is estimated to extend to a depth of 340 feet below land surface and to have a saturated thickness of 100 feet (DOE/SRPO, 1986). Based on a land surface elevation of 4,033 feet, the elevation of the water table is estimated to be 3,793 feet.

The available data (Wyatt, Bell and Morrison, 1977; SWEC, 1984) support the above estimate of the saturated thickness of the Ogallala near the shaft locations and indicate that differences from this estimate, if any, would be minor (i.e., less than 10 feet). Differences of this magnitude would not have a significant effect on the evaluations presented in this report. Therefore, a range of saturated thickness values were not considered in the evaluations.

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

2.1.2 Dockum Group

Depositional conditions of the Triassic Dockum Group in the Southern High Plains area have been summarized by Fink (1963). The terrestrial sediments of

the Dockum are generally fine grained and have a lower permeability than the Ogallala. They were deposited in a basin-like area on the older Permian strata and include both coarse-grained alluvial material and fine-grained flood-plain deposits. The resulting strata consist of poorly sorted, heterogeneous, cross-bedded, lenticular, interfingering beds of silt, sand, clay, and gravel with a total thickness of about 600 to 700 feet in the vicinity of the site.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

The driller's log of well 07-52-902 (Duffin, 1984, p. 40), 4 to 5 miles northwest of the site (see Figure 1-1), indicates that the upper part of the Dockum Group consists mostly of clay and shale with some thin sandy layers. Most of the water produced by this well is apparently yielded from a sandy zone in the lower part of the Dockum. Core samples from the J. Friemel No. 1 well (SWEC, 1983b), about 5 miles southeast of the site (see Figure 1-1), indicate that here, too, the upper part of the Dockum consists mostly of fine-grained sediments, siltstone and claystone with some thin sandstone layers. The lower part of the Dockum Group in this well is mostly sandy alluvial strata; they consist of heterogeneous deposits of fine-grained sandstone interbedded with some medium-to-coarse-grained sandstone, siltstone, and claystone. The sandstone is variably indurated and is described as having a "moderately good" to "good" porosity. An approximately 100-foot thick sandstone in the lower part of the Dockum appears to correlate reasonably well with the thickness and elevation of the main sandy zone in well 07-52-902. At least one other well near the northwest corner of the site (well 07-52-903 on Figure 1-1) is also completed in a sandy zone of the Dockum (Duffin, 1984, p. 41) which appears to be correlative with that yielding water

to well 07-52-902. This sandy zone, also referred to as the Santa-Rosa, is the principal water-bearing zone of the Dockum.

Ground water within the principal water-bearing zone of the Dockum occurs under confined conditions. Although the potentiometric surface for the zone is not very well defined in the vicinity of the site, it appears to be at an elevation of about 3,400 feet above mean sea level (Bair, 1985) and decreases in an easterly direction. This potentiometric surface is about 350 to 400 feet below the water-table elevation in the Ogallala indicating downward flow from the Ogallala. The potentiometric level in zones in the upper part of the Dockum is not known, but it is presumed to be higher than that in the principal water-bearing zone of the Dockum and lower than the water table in the Ogallala.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

At the exploratory shaft locations, the Dockum Group is estimated to extend from a depth of 340 feet to 961 feet (DOE/SRPO, 1986) with the principal water-bearing zone being 93 feet thick and lying between a depth of 682 feet to 775 feet. The potentiometric level of the zone is estimated to be at an elevation of 3,420 feet above mean sea level. Based on a land surface elevation of 4,033 feet and the above mentioned depths, the top of the water-bearing zone is at an elevation of 3,351 feet; thus, the water level in wells open to this zone would rise about 70 feet above the top of the zone.

2.2 HORIZONTAL HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

2.2.1 Ogallala Formation

The hydraulic conductivity of the Ogallala in Deaf Smith County is reported to range from 34 to 619 gallons per day per square foot (gpd/ft^2) and

average 224 gpd/ft^2 (DOE, 1986, Table 3-25). These values are based on estimates of transmissivity compiled by Myers (1969) for 43 wells in Deaf Smith County. Myers (1969) developed these estimates from one drawdown measurement in each well using the method of Ogden (1965) and assuming a specific yield of 0.15.

Myers (1969, p. 417-421) also presents the results of two long-term injection tests in Randall County which borders Deaf Smith County to the east. Although the injection-test locations are about 30 miles east of the site, the test data are useful because they provide information on the behavior of the Ogallala in response to long-term injection (or pumping) and because the transmissivity values obtained from these tests are reliable and reflect conditions within a large volume of the aquifer. The transmissivities reported for these tests range from about 5,800 to 7,300 gallons per day per foot (gpd/ft) and the corresponding hydraulic conductivities range from about 60 to 75 gpd/ft^2.

To obtain an estimate of the range of the hydraulic conductivity in areas closer to the site and, therefore, more representative of conditions at the site, transmissivity data from 19 of the 43 Deaf Smith County wells, compiled by Myers (1969), were selected based on the proximity of the wells to the site and the apparent validity of the reported transmissivity. Values for horizontal hydraulic conductivity were computed from these data using the saturated thicknesses given by SWEC (1984, p. 59). The resulting values ranged from 60 to 410 gpd/ft^2 and averaged about 200 gpd/ft^2.

Based on these calculations, a range of 50 to 400 gpd/ft^2 for the hydraulic conductivity of the Ogallala near the proposed site was considered in this report. Using the baseline saturated thickness of 100 feet, the corresponding range of transmissivities is 5,000 to 40,000 gpd/ft. The hydrologic design values for hydraulic conductivity and transmissivity at the shaft locations are 224 gpd/ft^2 and 22,400 gpd/ft, respectively (DOE/SRPO, 1986).

2.2.2 Dockum Group

As discussed earlier, the Dockum Group can be subdivided hydrologically into an upper section of low hydraulic conductivity, about 400 feet thick, composed mostly of claystone and siltstone; and a lower section which includes a relatively highly conductive zone, about 100 feet thick, composed of sand or sandstone with thin layers of shale and claystone. This sandy zone is underlain stratigraphically by siltstone and claystone of the Dockum Group that probably are indistinguishable hydrologically from the siltstone and claystone of the underlying Dewey Lake Formation of Permian Age, from which they were derived.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

Based on descriptions of cores from the J. Friemel No. 1 well (SWEC, 1983b), it is estimated that the horizontal hydraulic conductivity of the upper part of the Dockum is in the range of 0.001 to 0.1 gpd/ft^2.

Dutton and Simpkins (1985, Table 2) estimated the transmissivity of the lower Dockum in the previously mentioned well 07-52-902 northwest of the site from data reported by Duffin (1984, Table 2, p. 25). They estimated the transmissivity of the Dockum (Santa Rosa) to be 24,000 gpd/ft from a reported

8-hour pumping rate of 900 gallons per minute (gpm) and a reported drawdown of 79 feet, or a specific capacity of 11.4 gpm per foot of drawdown. Similar values for the lower part of the Dockum were obtained from a 96-hour pumping test in southeastern Deaf Smith County, about 17 or 18 miles southeast of the proposed site. An average transmissivity value of 22,000 gpd/ft and an average storage coefficient of 0.0001 for the sandy zone in the lower part of the Dockum were calculated from this test (Fink, 1963, p. 24). However, in a study of ground-water conditions in the Triassic aquifer in Deaf Smith and Swisher Counties, Duffin (1984) stated that these values are most nearly representative of the aquifer's hydraulic properties in the immediate vicinity of the test well, and that they should not be applied to the Triassic aquifer everywhere in the study area. The driller's log indicates that the aquifer tested (Fink, 1963) is composed of coarse gravel rather than fine sand and sandstone interbedded with the clay and shale found in the J. Friemel No. 1 well, which may be more typical of the Dockum at the shaft locations. Duffin (1984, Figure 10) shows many locations in the northern half of Deaf Smith County where test holes to the lower Dockum were abandoned and the drillers' logs indicate that most did not find much sand and gravel in the Dockum.

The hydrologic design values for hydraulic conductivity and transmissivity for the principal water-bearing zone in the Dockum at the shaft locations are 94 gpd/ft^2 and 8,740 gpd/ft, respectively (DOE/SRPO, 1986). Based on the core descriptions of the J. Fremiel No. 1 well and on the number of unsuccessful Dockum wells drilled in the vicinity of the site, these design values are considered to be upper limits for the horizontal hydraulic conductivity and transmissivity of the sandy zone of the Dockum at the shaft

locations with the lower limits being possibly as small as about 1 gpd/ft^2 and 100 gpd/ft, respectively.

2.3 STORAGE PROPERTIES

2.3.1 Ogallala Formation

Estimates of the storage properties of the Ogallala have been published by Myers (1969); Wyatt, Bell, and Morrison (1977); and Gutentag and others (1984). Based on an evaluation of information in these publications, it is estimated that the specific yield of the Ogallala ranges from 0.05 to 0.20. Observation well data from the two long-term injection tests in Randall County (Myers, 1969, pp. 417-421) gave specific yield values ranging from 0.10 to 0.16. Based on these results, a specific yield of 0.12 was estimated as the baseline value at the shaft locations.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

2.3.2 Dockum Group

Based on the results of the 96-hour pumping test analyzed by Fink (1963, p. 24) and the hydrologic and lithologic characteristics of the principal sandy zone in the lower part of the Dockum, the baseline storage coefficient for this zone was estimated to be 0.0001 with a potential range from 0.00001 to 0.001.

2.4 CONFINING LAYER PROPERTIES

HAS NOT BEEN BY DOE

The 300- to 350-foot thick section of siltstones and claystones with thin sandy interbeds in the upper part of the Dockum comprises the lower confining layer for the Ogallala aquifer and the upper confining layer for the main sandy zone in the lower part of the Dockum. Based on descriptions of cores

from the J. Friemel No. 1 well, the vertical hydraulic conductivity of this confining layer is estimated to range from 0.00001 to 0.001 gpd/ft^2 and its specific storage is estimated to be in the order of 0.000001 to 0.00001 per foot. Similar properties are also estimated for the siltstones and claystones underlying the main sandy zone of the Dockum.

3.0 DEVELOPMENT OF TESTING PLAN

3.1 EVALUATION OF POTENTIAL TESTING PROCEDURES

The most frequently used method of hydrogeologic testing is the pumping test. It involves the pumping of a well at a constant rate and the measurement of the drawdowns (water-level declines) caused by this pumping at different times after the beginning of the test. It can be conducted as a single-well test, where drawdown measurements are made only in the pumped well, or as a multi-well test where drawdown measurements are made in the pumped well and in one or more observation wells at different distances and directions from the pumped well. Although the volume of aquifer sampled by a pumping test depends on the duration of the test and the hydraulic parameters of the aquifer, it is usually large. Thus, the hydraulic parameters determined from the analysis of test data usually represent average values over a large volume of the aquifer.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

If the transmissivity of the hydrogeologic system to be tested and the available drawdown are too small to sustain even a reasonably low constant pumping rate, then other methods of testing must be used. Most of the methods available for use under these conditions are single-well tests, such as the slug test, also known as the falling-head or rising-head test, or the constant-head injection test. These methods usually sample a small volume of the hydrogeologic system and the hydraulic parameters estimated from the analysis of test data are usually representative of the immediate vicinity of the well. These methods are often the only means for testing formations of low hydraulic conductivity. They are also useful in some ground-water

contamination studies where determining the variability of the hydraulic parameters through single-well tests in a large number of wells may be more important than the average values determined by one multi-well test. However, when the primary interest is in the average characteristics of a hydrogeologic system over a distance of more than a few feet from the test well, multi-well, constant-rate pumping tests are preferable, if feasible.

Given the range of its expected transmissivities, the Ogallala Formation can be tested using the constant-rate pumping test method. Calculations based on the available drawdown and the minimum expected transmissivity of 100 gpd/ft for the principal water-bearing zone of the Dockum Group indicate that this zone can be pump tested also, albeit at a discharge rate of only a few gallons per minute. Consequently, in considering a testing plan for the exploratory shaft monitoring wells, evaluations were limited to constant-rate pumping tests.

3.1.1 <u>Ogallala Tests</u>

3.1.1.1 Type of Expected Response

Ground water in the Ogallala occurs under unconfined conditions. The response of an unconfined aquifer during a pumping test and theoretical models for simulating this response have been discussed by Boulton (1954, 1963, 1970), Boulton and Pontin (1971), and Neuman (1972, 1973, 1974). The behavior of drawdown data from a pumping test in an unconfined aquifer and the cause of this behavior is explained by Neuman (1975) as follows:

> "When these drawdowns are plotted versus time on logarithmic paper, they usually delineate an S-shaped curve consisting of a

> steep segment at early times, a flat segment at intermediate times, and a somewhat steeper segment at later times. The physical phenomenon that causes this behavior is known as delayed yield, delayed drainage, or delayed gravity response."

The steep segment at early times, referred to above, represents an early response governed by a storage coefficient associated with the elastic compressibility of the aquifer. The response follows the pattern of a "Theis type curve" (Theis, 1935) for a confined aquifer evaluated using the value of this storage coefficent. The somewhat steeper segment at later times represents the long-term response of the aquifer governed by its specific yield. After adjustment for dewatering effects, it also follows the Theis type curve evaluated using the value of the specific yield. The flat segment at intermediate times and adjacent curved segments that depart from or merge into the Theis type curves represent a transition period between the conditions represented by the two other segments. The length of this transition period depends on the contrast between the storage coefficient and the specific yield and the vertical-to-horizontal anisotropy of the aquifer. A larger contrast in the storage properties and/or a large anisotropy will produce a longer transition period.

During a pumping test, if the transition period begins very early (within a few minutes after the beginning of the test) and the test is not continued beyond the end of the transition period, the test data are not amenable to analysis. Data from such a test are difficult, if not impossible, to analyze reliably.

Data from the two long-term injection tests in Randall County (Myers, 1969, pp. 417-421), referred to earlier, confirm this type of response in the

Ogallala Formation. During these tests, the transition period occurred very early and continued for more than a week in the nearest observation well which was at a distance of about 120 feet from the pumping well. However, these tests were of a very long duration (about 100 days) and the data permitted the determination of the transmissivity and the specific yield.

The vertical hydraulic conductivity of the confining layer of the Upper Dockum, which underlies the Ogallala and separates it from the principal water-bearing zone of the Dockum, is small and leakage from this layer is not expected to affect data during a reasonable testing period. Data from the afore-mentioned long-term injection tests do not indicate any significant leakage effects even near the end of the test period of about 100 days. Therefore, the response of the Ogallala during pumping tests to be conducted in the exploratory shaft monitoring wells is expected to be that of an unconfined-aquifer as described above.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

3.1.1.2 Available Drawdown and Discharge Rate

In an unconfined aquifer, as the water level declines in response to pumping, the saturated thickness and consequently the transmissivity of the aquifer decreases. To approximate the conditions posed by this dewatering effect, Jacob (1944) suggests the following adjustment to the observed drawdowns:

$$s^* = s - s^2/2b$$

where s^* is the adjusted drawdown, s is the observed drawdown and b is the initial saturated thickness of the aquifer. The hydraulic parameters are determined from analyses of the adjusted drawdown data. Neuman (1975)

indicates that this adjustment should be made only to data from the period that follows the transition period of the test. The adjustment provides a good approximation to the effects of dewatering for drawdowns that do not exceed 25 percent of the initial thickness and, excluding well losses, drawdowns of as much as 50 percent of the initial thickness can be tolerated in the pumped well without causing significant errors.

Based on the above, and given the initial 100-foot saturated thickness of the Ogallala at the shaft locations, the available drawdown in the pumped well during an Ogallala test was assumed to be 50 feet, excluding well losses (see Section 3.1.3). The corresponding adjusted drawdown is 37.5 feet. The discharge rate that would result in a drawdown of 50 feet in the pumped well at the end of the pumping period was calculated for different transmissivities and for pumping periods of 1, 2, 5 and 10 days. Neuman's (1973) equation for an unconfined aquifer was used for these calculations. The discharge rate of a well is not significantly affected by the value of the storage properties; therefore, the calculations were made only for the baseline value of 0.12 for the specific yield (S_y). Calculations with Neuman's (1973) equation also require an estimate of the storage coefficient (S) associated with the elastic compressibility of the aquifer and of the vertical-to-horizontal anisotropy, that is, the ratio of the vertical to horizontal hydraulic conductivity (K_z/K_h). Data on these parameters for the Ogallala sediments are not available. Therefore, the calculations were made for assumed values for these parameters. The storage coefficient (S) was assumed to be 0.0001 and the vertical-to-horizontal anisotropy was assumed to be 0.2. For most of the values of transmissivity that were considered, the end of the pumping period

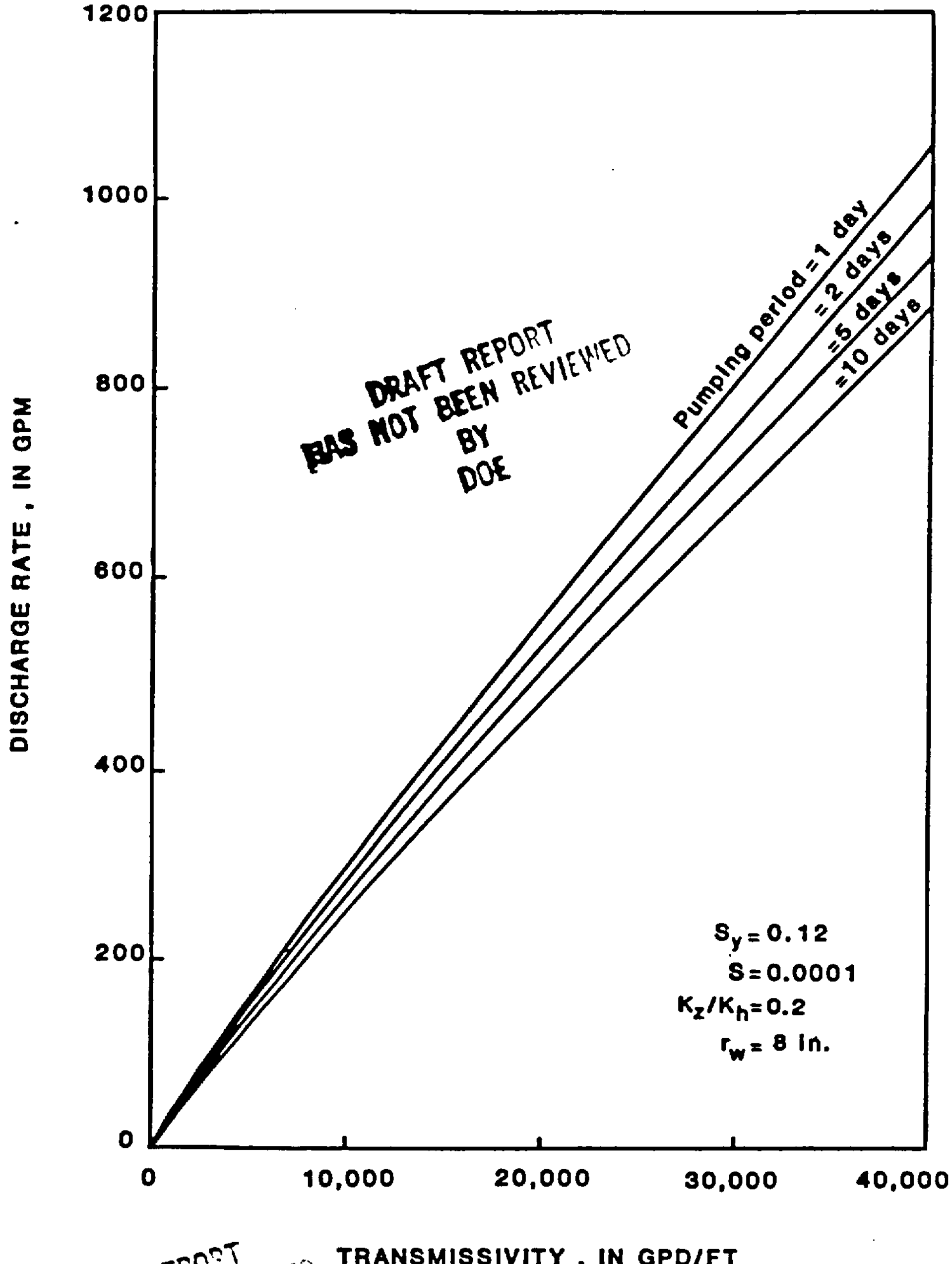
was beyond the transition period and thus the response was governed only by the specific yield. Finally, the effective radius (r_w) of the monitoring wells was assumed to be 8 inches, equal to the planned radius of the drilled hole (see Figure 1-4). The results of the calculations are shown in Figure 3-1.

3.1.1.3 Range of Test Response

For the preliminary layout of the monitoring wells each monitoring well has one or two nearest neighbors at a radial distance (r) of 424 feet (see Figure 1-3). Computations were made to evaluate the response in the pumped monitoring well and in the nearest neighboring well(s) during a pumping test. Neuman's (1973) equation for fully penetrating pumping and observation wells in an unconfined aquifer was used in these computations.

DRAFT REPORT HAS NOT BEEN RE... BY DOE

Computations were made for three cases. For Case 1, the transmissivity (T) and the specific yield of the Ogallala were assumed to be equal to the baseline values of 22,400 gpd/ft and 0.12, respectively. Based on the results presented in Figure 3-1, a pumping rate (Q) of 550 gpm was assumed for the test. For Case 2, a transmissivity of 40,000 gpd/ft, (the high end of the estimated range), a specific yield of 0.05 (the low end of the range), and a discharge rate of 900 gpm were assumed. For Case 3, a transmissivity of 5,000 gpd/ft (the low end of the range), a specific yield of 0.20 (the high end of the range), and a discharge rate of 130 gpm were assumed. Cases 2 and 3 envelop potential responses for all combinations of transmissivity and specific yield within the specified range of these parameters. As in the discharge calculations, the storage coefficient was assumed to be 0.0001 and the vertical-to-horizontal anisotropy equal to 0.2, for all three cases. The



NOTE : Drawdown does not include well losses

Ogallala Test
Discharge Rate
Resulting in 50 Feet of Drawdown

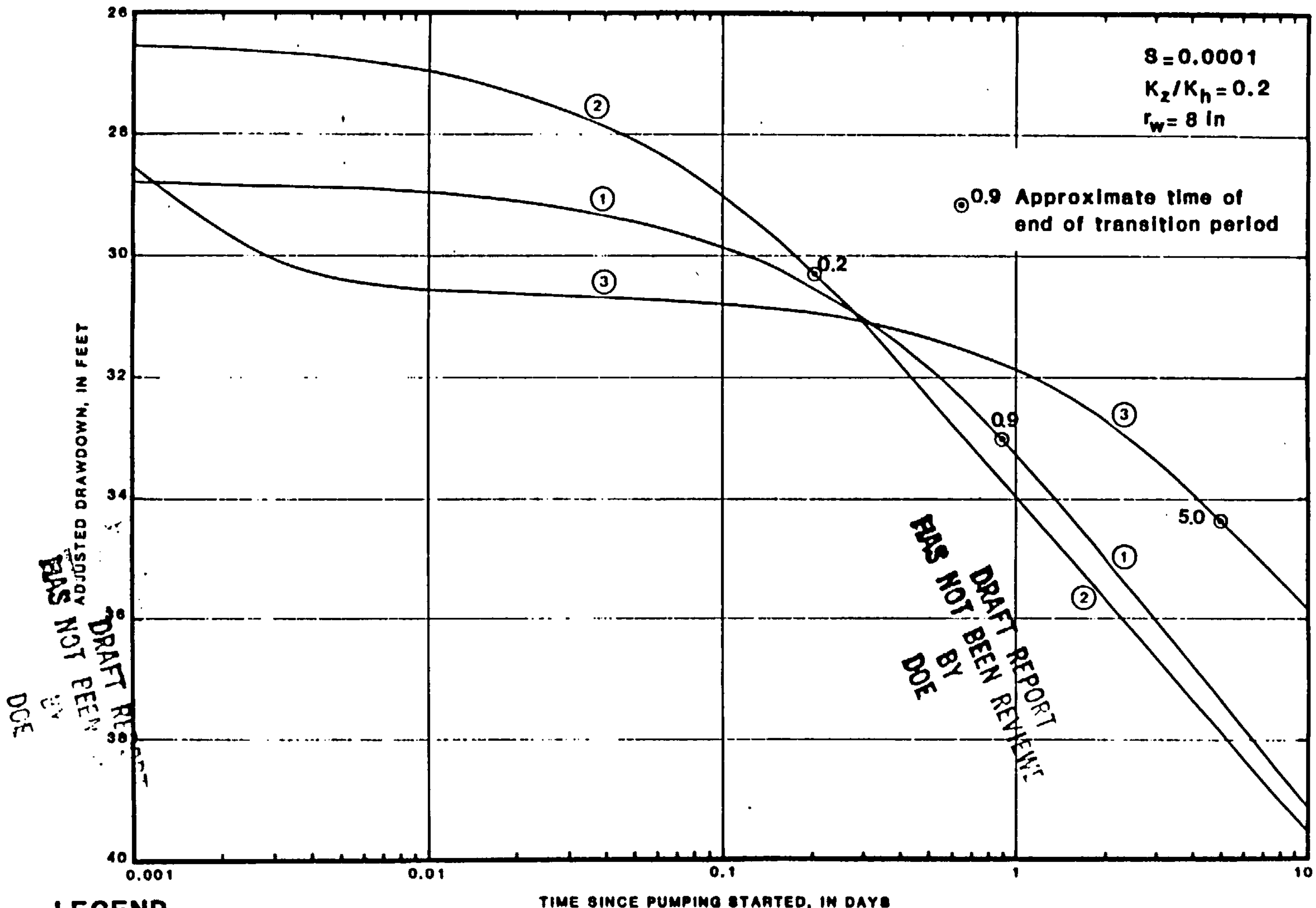
Figure 3-1

effect of other potential values for these two parameters on the expected response of the Ogallala during a pumping test is discussed in Section 3.4.

Figure 3-2 shows plots of the drawdown in the pumped well, adjusted for dewatering effects, against the logarithm of time since pumping started. Figure 3-3 shows logarithmic plots of the adjusted drawdown in the nearest monitoring well against time. For all three cases, the transition period starts almost immediately after the beginning of the test, both in the pumped well and in the nearest monitoring well. The approximate time at which the transition period ends (i.e., drawdowns begin to follow the Theis (1935) equation governed by specific yield) is shown on the figures.

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

The drawdown in the pumped well (Figure 3-2) does not include well losses, that is additional drawdown due to frictional losses which occur as water enters the well and moves up the well casing into the pump intake. Because of these well losses and, also, because the effective radius of a pumped well is often different than the actual radius of the well screen or of the drilled hole, data from the pumped well cannot be analyzed reliably for the storage properties or for the vertical-to-horizontal anisotropy of the aquifer. However, the transmissivity can be determined from a semi-logarithmic plot, such as that shown on Figure 3-2, by applying the straight-line method of analysis (Cooper and Jacob, 1946) if the testing period extends beyond the transition period and the data fall on a straight line. [Well losses also affect the shape of logarithmic plots of time-drawdown data; thus, the type-curve approach of analysis (Theis, 1935) should not be applied to pumped-well data.]



LEGEND

① T = 22,400 gpd/ft ; S_y = 0.12 ; Q = 550 gpm

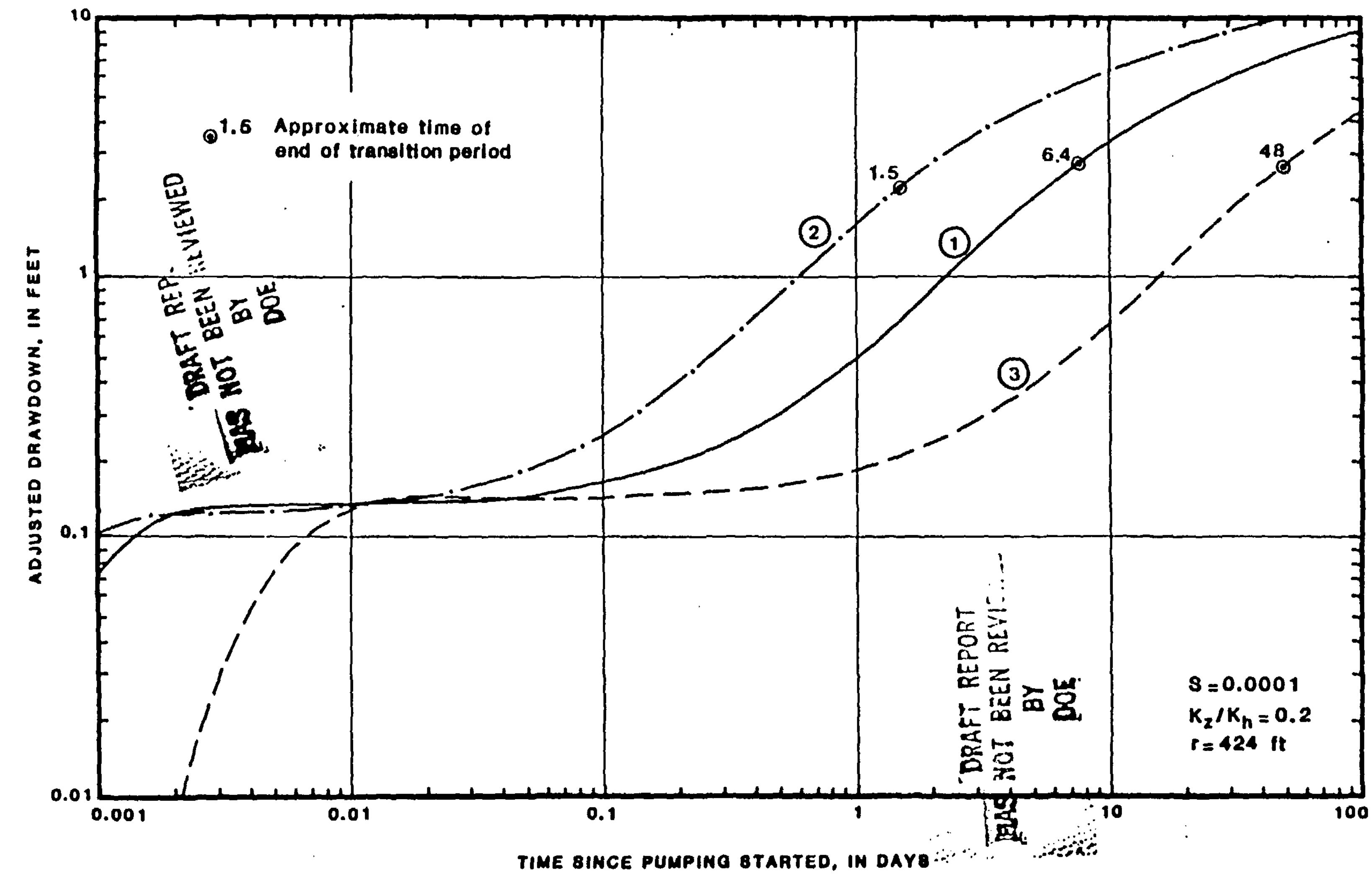
② T = 40,000 gpd/ft ; S_y = 0.05 ; Q = 900 gpm

③ T = 5,000 gpd/ft ; S_y = 0.20 ; Q = 130 gpm

NOTE : WELL LOSSES NOT INCLUDED

Ogallala Test
Time-Drawdown in Pumped Well

Figure 3-2



LEGEND

① T = 22,400 gpd/ft ; S_y = 0.12 ; Q = 550 gpm

② T = 40,000 gpd/ft ; S_y = 0.05 ; Q = 900 gpm

③ T = 5,000 gpd/ft ; S_y = 0.20 ; Q = 130 gpm

Ogallala Test
Time-Drawdown in Nearest
Ogallala Monitoring Well

Figure 3-3

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

As shown on Figure 3-2, for Cases 1 and 2, the transition period in the pumped well would end in less than one day. A test of two to three days would provide sufficient data for determining the transmissivity under the conditions stipulated by these two cases. For Case 3, the low transmissivity case, the transition period would last for approximately five days; nevertheless, the slope of the response curve for a few days prior to the end of the transition period is not significantly different from that after its end. A six to seven day test may permit the determination of the transmissivity for this case without significant error.

Although the transmissivity of the aquifer can be determined from pumped-well data, the determination of its storage and anisotropic properties requires data from a well other than the pumped well. The response curves for the nearest monitoring well (Figure 3-3) indicate that at this distance the transition period would be much longer than that in the pumped well. To obtain a clear definition of the shape of the curve, that would permit a complete analysis, data for about one logarithmic time cycle beyond the end of the transition period may be required. Therefore, with monitoring wells located in accordance with the preliminary layout plan (Figure 1-3), a testing period of about 50 or more days may be required for the baseline case (Case 1). For parameter values that are different than those for the baseline case, the required testing periods may range from 10 to over several hundred days.

3.1.2 <u>Dockum Tests</u>

3.1.2.1 Type of Expected Response

Ground water within the principal water-bearing zone of the Dockum Group occurs under confined conditions. The vertical hydraulic conductivities of the sediments overlying and underlying this zone are estimated to be in the range of 0.00001 to 0.001 gpd/ft^2. Even for a vertical hydraulic conductivity at the high end of this range, the amount of leakage that would occur during a reasonable testing period is very small and the test data are not expected to deviate significantly from those from a confined aquifer without leakage. Therefore, the response of the principal water-bearing zone of the Dockum during pumping tests is expected to be of the Theis (1935) confined-aquifer type.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

3.1.2.2 Available Drawdown and Discharge Rate

As discussed earlier, the potentiometric surface of the principal water-bearing zone of the Dockum at the shaft locations is estimated to be about 70 feet above the top of the zone. If, during pumping, the potentiometric surface declines below the top of the zone in the vicinity of the pumped well, unconfined flow conditions could occur in the area around the well. Although methods of analyzing pumping tests under these conditions are available (Moench and Prickett, 1972), the analysis of test data becomes more complicated. Therefore, it is preferable to avoid the occurrence of these conditions. For this purpose, the available drawdown during the testing of the principal zone of the Dockum was assumed to be also 50 feet, excluding well losses.

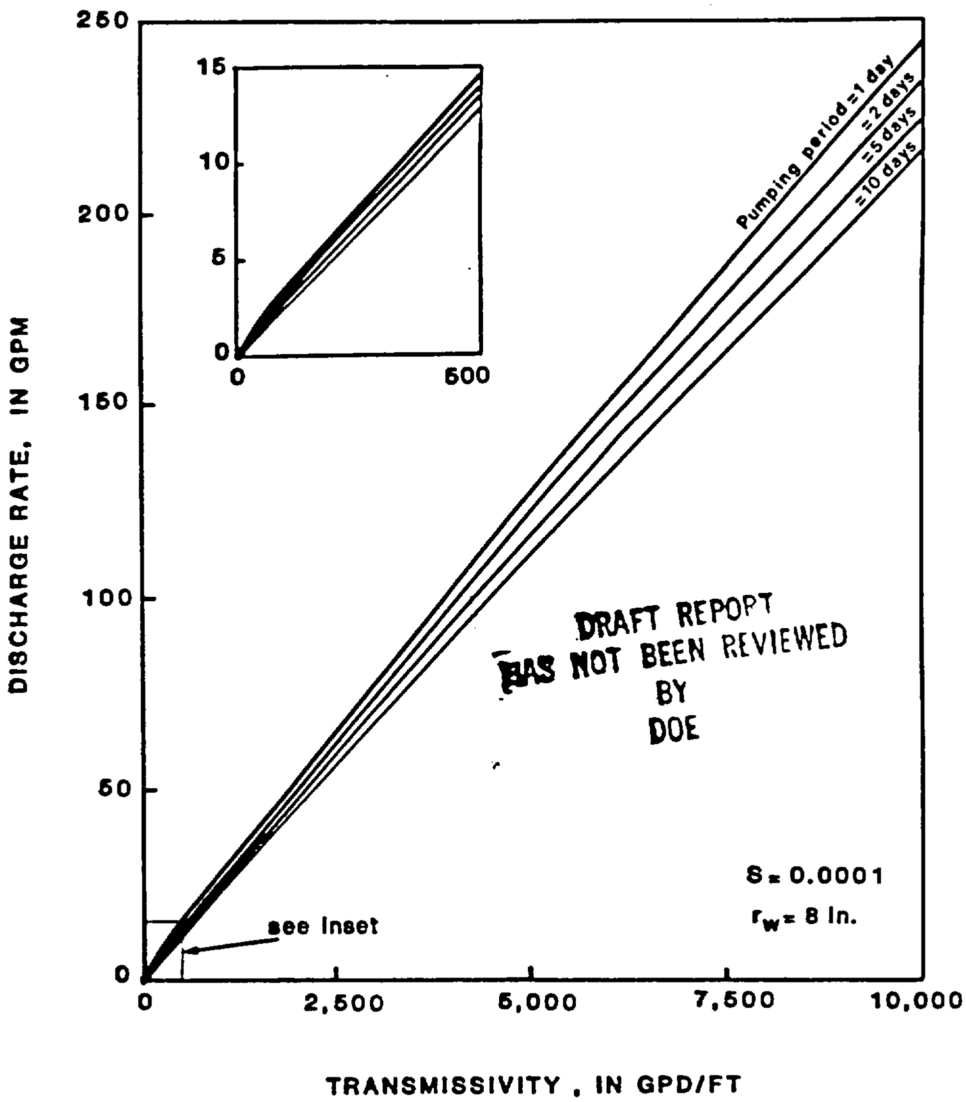
Calculations were made to determine the discharge rate that would result in a drawdown of 50 feet at the end of the pumping period, for different transmissivities and different pumping periods. The results of these calculations are shown on Figure 3-4.

3.1.2.3 Range of Test Response

Computations were made using the Theis (1935) equation to evaluate the response of a pumped monitoring well and of its nearest neighbor(s) during the testing of the principal water-bearing zone of the Dockum. As in the evaluations of Ogallala tests, the computations were made for three cases. For Case 1, the transmissivity and the storage coefficient were assumed to be equal to the baseline values of 8,740 gpd/ft and 0.0001, respectively. Based on the results presented on Figure 3-4, the pumping rate for this case was assumed to be 180 gpm. Since the baseline hydraulic conductivity of 94 gpd/ft^2 was estimated to be also an upper limit, Case 2 considered a transmissivity of 4,650 gpd/ft corresponding to a hydraulic conductivity of 50 gpd/ft^2, at the middle of the estimated range for hydraulic conductivity. A storage coefficient of 0.00001 and a discharge rate of 100 gpm were assumed for this case. For Case 3, a transmissivity of 100 gpd/ft (the low end of the estimated range), a storage coefficient of 0.001 (the high end of the range) and a discharge rate of 3 gpm were assumed.

DRAFT HAS NOT BEEN BY DOE

During the initial period of pumping, part of the discharge is derived from water stored in the pumped well. During this period, the net discharge from the aquifer is somewhat smaller than the pumping rate. In aquifers of relatively low transmissivity, these wellbore storage effects cause drawdowns during the early period of pumping to deviate significantly from the Theis



DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

NOTE : Drawdown does not include well losses

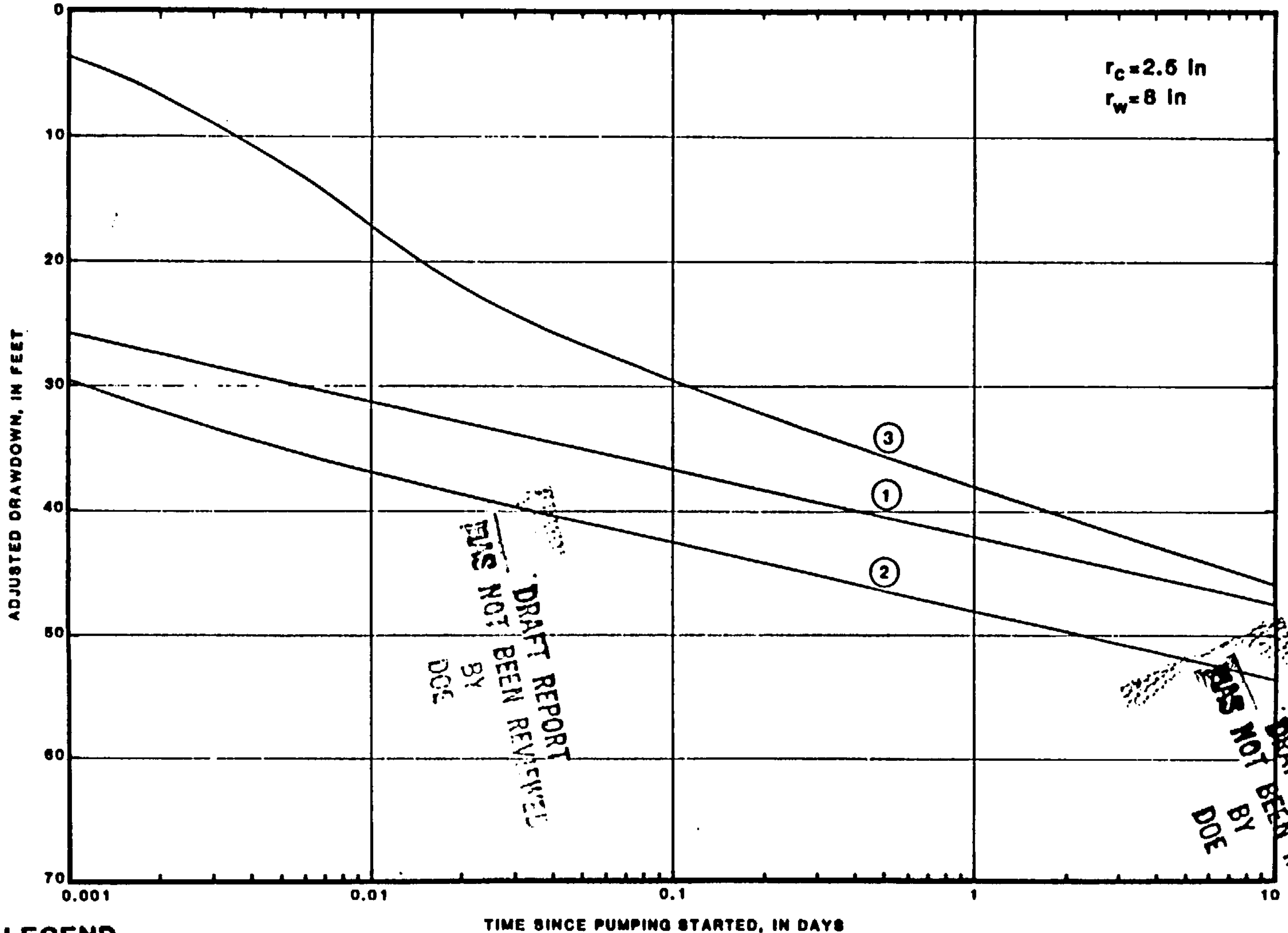
Dockum Test
Discharge Rate
Resulting in 50 Feet of Drawdown

Figure 3-4

type curve (Papadopulos & Cooper, 1967). Since the cases to be evaluated included relatively low transmissivities, borehole storage effects for a well casing radius (r_c) of 2.5 inches (see Figure 1-4) were taken into consideration in computing the response of the principal zone of the Dockum during pumping tests.

Figure 3-5 shows plots of the drawdown in the pumped well against the logarithm of time since the beginning of pumping. Note that for Case 3, borehole storage affects the data for about 0.1 day (about 150 minutes); for Case 2, these effects disappear within less than 0.01 day (about 15 minutes) and for the baseline case, Case 1, they are insignificant. For all three cases, a straight line is well established within less than a day and the transmissivity can be determined from a test of one-day duration.

Figure 3-6 shows logarithmic plots of the drawdown against time in the nearest monitoring well. At this distance (424 feet) from the pumped well, borehole storage effects are insignificant even for Case 3 and the response for all three cases follows the Theis type curve for a confined aquifer. For Cases 1 and 2, the shape of the curve is clearly defined in less than one day; therefore, a test of one-day duration would permit the determination of the transmissivity and of the storage coefficient, either by the type-curve method (Theis, 1935) or by the straight-line method (Cooper & Jacob, 1946) using plots of drawdown against the logarithm of time (semi-logarithmic plots). For Case 3, a test of at least three to four day duration would be required to obtain sufficient data for analysis.



LEGEND

① T = 8,740 gpd/ft ; S = 0.0001 ; Q = 180 gpm

② T = 4,650 gpd/ft ; S = 0.00001 : Q = 100 gpm

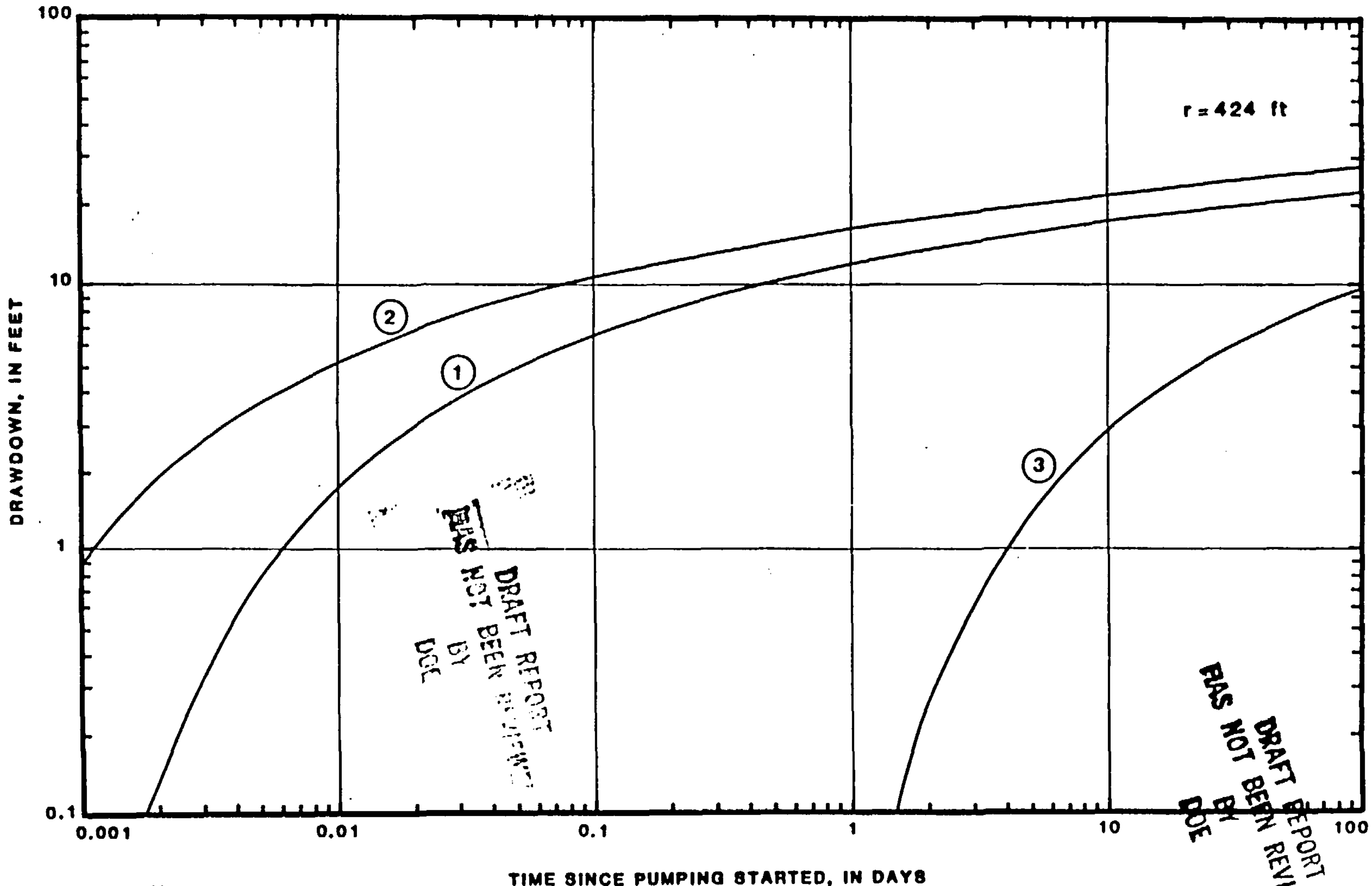
③ T = 100 gpd/ft ; S = 0.001 ; Q = 3 gpm

NOTE : WELL LOSSES NOT INCLUDED.

Dockum Test

Time-Drawdown in Pumped Well

Figure 3-5



LEGEND

1. T = 8,740 gpd/ft ; S = 0.0001 ; Q = 180 gpm
2. T = 4,650 gpd/ft ; S = 0.00001 : Q = 100 gpm
3. T = 100 gpd/ft ; S = 0.001 ; Q = 3 gpm

Dockum Test
Time-Drawdown in Nearest Dockum Monitoring Well

Figure 3-6

3.1.3 Well Losses

In the evaluations presented above, well losses were not included in determining the available drawdown in the pumped well or in calculating the expected drawdown in the pumped well. Well losses represent an additional drawdown due to head losses which occur as water enters and moves up the well toward the pump intake. They are controlled by the construction characteristics of the well and the velocities at which water enters and moves inside the well.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

To minimize well losses, Driscoll (1986, p. 417 and p. 450) recommends an uphole velocity of 5 ft/sec or less and an entrance velocity of 0.1 ft/sec or less. The proposed diameter of the screened interval of the monitoring wells is 16 inches (see Figure 1-4), and the maximum expected discharge rates were calculated to be 900 gpm and 180 gpm for the Ogallala and the Dockum, respectively. About 45 feet of 20-slot (0.020-inch slot opening) screen in the Ogallala and about 9 feet of 20-slot screen in the Dockum would result in an entrance velocity of less than 0.1 ft/sec. For both monitoring and pumping test purposes, the wells should be screened across the entire thickness of the aquifer. Also, the actual screen slot size may be larger than that of a 20-slot screen. Thus, entrance velocities would be expected to be much less than the recommended 0.1 ft/sec.

The proposed casing diameter is 16 inches for the Ogallala and 5 inches for the Dockum (see Figure 1-4). For the maximum expected discharge rates, the uphole velocity would be less than 1.5 ft/sec during the Ogallala test and less than 3 ft/sec during the Dockum test.

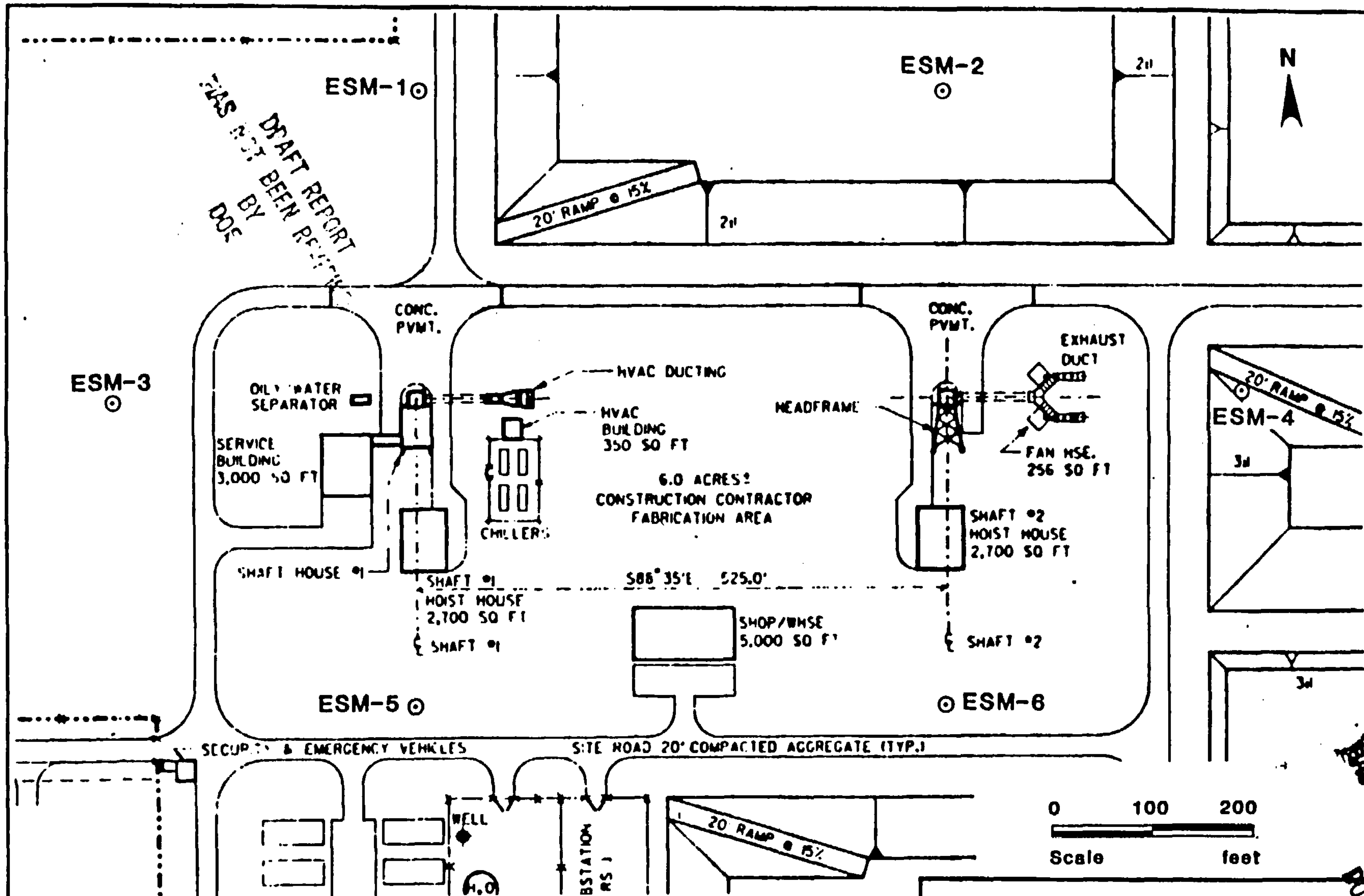
Based on the above, well losses are expected to be negligible during the Ogallala and Dockum tests even for screen and casing diameters smaller than those proposed.

3.2 REVIEW OF MONITORING-WELL SYSTEM

The evaluation of testing procedures presented in the previous section indicates that the preliminary layout of the exploratory shaft monitoring wells would permit the determination of the hydraulic parameters of the principal water-bearing zone of the Dockum through the conduct of pumping tests that are of reasonable duration. However, to determine all of the hydraulic parameters of the Ogallala without having to conduct tests of a very long duration, observation wells which are located closer to the pumped well would also be required.

It should be re-emphasized that the monitoring well locations shown on Figure 1-3 are preliminary. To avoid conflicts with other structures associated with the exploratory facility, the actual location of the monitoring wells cannot be determined until final design of the exploratory shaft facilities have been completed. For example, comparison of the preliminary locations of monitoring wells with the preliminary design of the exploratory shaft facility (Figure 3-7) indicates that the preliminary locations of wells ESM-2 and ESM-4 are in areas that may be assigned to storage structures. Also note that well ESM-5 is very close to a planned production well.

In determining the final locations and design of the monitoring wells, consideration should be first given to the primary purpose of these wells,



DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

LEGEND

⊙ **Dual Completion Monitoring Well**

NOTE : Modified from Preliminary Design, Exploratory Shaft Facility, Parsons Brinckerhoff/ PB-KBB, Drawing No. 2-C-300.

Location of Monitoring Wells Relative to Exploratory Shaft Facilities

Figure 3-7

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

that is: to monitor water-level fluctuations and changes in water quality resulting from the construction of the exploratory shafts. However, changes in location and design that would maximize the hydrogeologic information that can be obtained from these wells, without violating their primary purpose, should also be considered.

At a given distance from the exploratory shafts, water-level changes would be detected much earlier than water-quality changes caused by shaft construction. For example, for the baseline values of the hydraulic parameters and a shaft radius of 6 feet, a sudden change of ten feet in the water level of the Ogallala or of the principal water-bearing zone of the Dockum at a shaft location would cause a change of 0.5 feet at a distance of 300 feet after 1.2 days in the Ogallala and after 3.5 minutes in the Dockum. By contrast, based on the design values estimated by DOE/SRPO (1986) for seepage velocities (204 feet per year for the Ogallala and 46 feet per year for the Dockum), a water-quality change in the Ogallala would not be detected at a distance of 300 feet downgradient from the shaft until about 1.5 years after it occurs; in the Dockum about 6.5 years would elapse before detection.

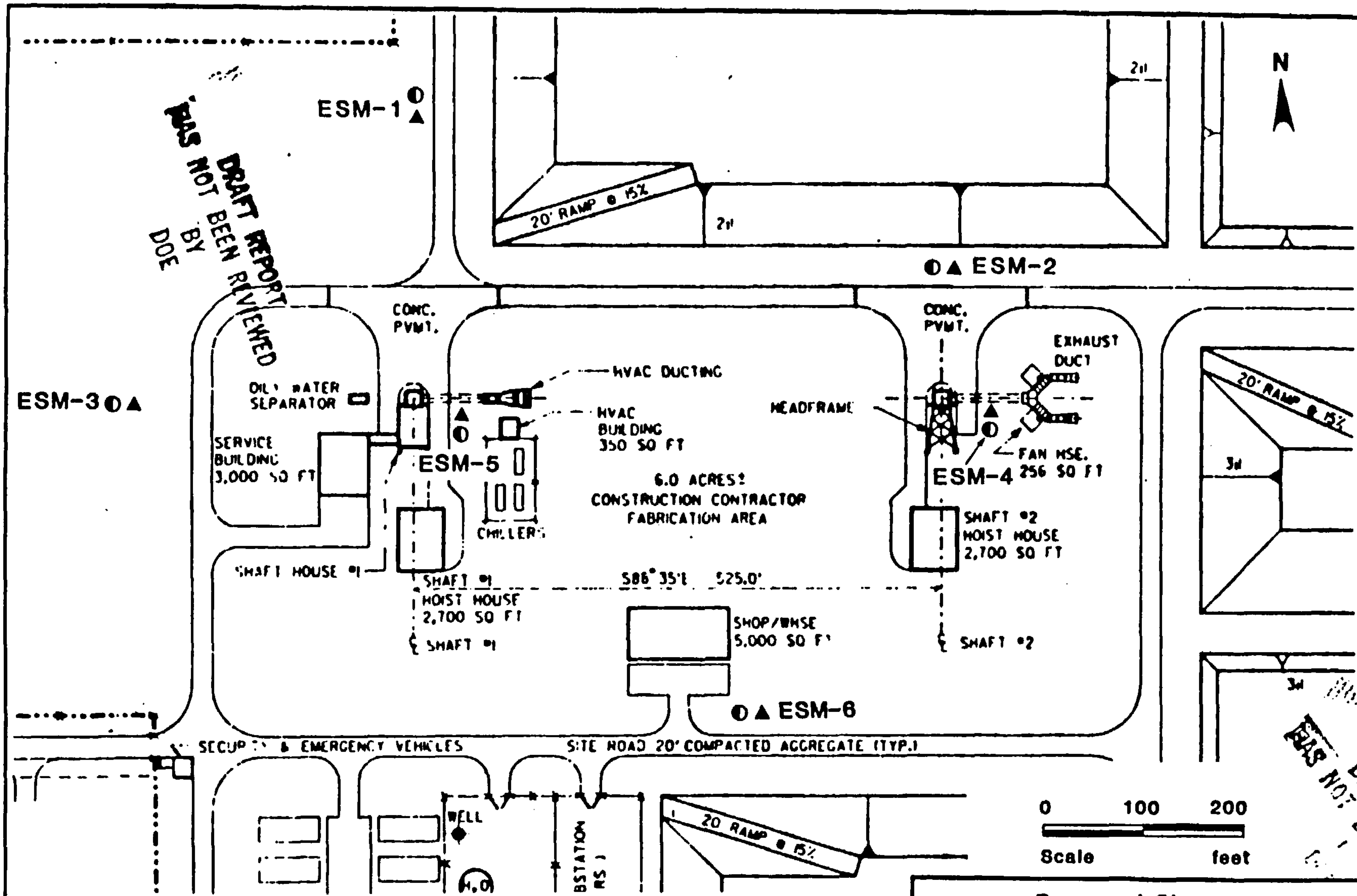
These calculations indicate that while the location of the monitoring wells may not be critical for the detection of water-level changes, the timely detection of water-quality changes requires monitoring wells downgradient of the shaft to be located as close to the shaft locations as possible. Furthermore, since the direction of ground-water flow is to the southeast in the Ogallala and to the east in the Dockum, separate Ogallala and Dockum wells, rather that dual-completion wells, would be more suitable for detecting water-quality changes downgradient of the shafts.

Dual-completion monitoring wells with a good seal between the two water-bearing zones most probably would be satisfactory upgradient of the shaft where only water-level changes would be expected to occur. However, given the large head difference between the Ogallala and the Dockum, there may often be the need to investigate whether a certain water-level change is due the shaft construction or to leakage through the seal in the monitoring well. The additional cost of installing separate Ogallala and Dockum wells, not only downgradient of the shaft where they are needed for technically sound water-quality monitoring, but on all locations, may not be so high. In addition to providing more reliable water-quality and water-level data, separate wells at each location would permit the testing of the Ogallala with a nearby observation well.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

Based on the above, it is proposed that separate Ogallala and Dockum monitoring wells be installed at six locations as shown on Figure 3-8. At locations ESM-4 and ESM-5, it is proposed that the wells be placed as close to the shafts as possible without interfering with other shaft facilities. The Dockum well at these two locations should be placed to the east of the shafts and the Ogallala well to the southeast of the shafts.

Assuming that separate monitoring wells at each location are cost-effective, Ogallala tests can be conducted at each location by first completing both wells in the Ogallala. After the Ogallala test has been conducted, one of the wells can be deepened and completed as a Dockum monitoring well. The two wells at each location may be placed as close as 10 feet from each other, except for locations ESM-4 and ESM-5 where the need to place the wells downgradient may require a larger spacing.



LEGEND

◐ Ogallala Monitoring Well

▲ Dockum Monitoring Well

NOTE : Modified from Preliminary Design, Exploratory Shaft Facility, Parsons Brinckerhoff/PB-KBB, Drawing No. 2-C-300.

Proposed Changes in Monitoring Well Completion and Location

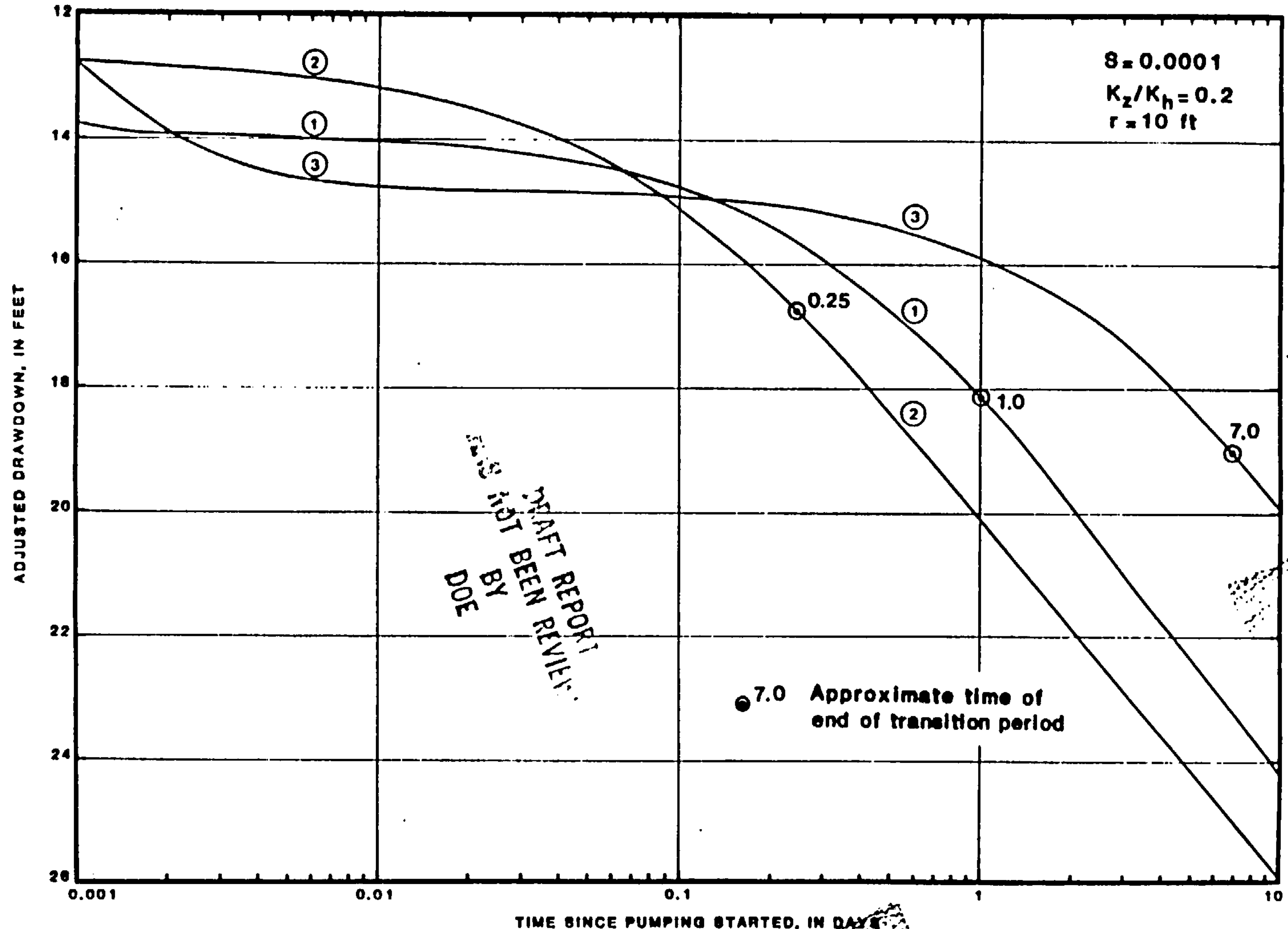
Figure 3-8

Figure 3-9 shows the response in an Ogallala observation well at a distance of 10 feet from the pumped well for the three cases considered earlier. Note that at this distance the transition period for Cases 1 and 2 would end within a day after the beginning of the test and a testing period of about 5 days would be sufficient to determine both the transmissivity, the specific yield and the vertical-to-horizontal anisotropy. For Case 3, the transition period would last for about seven days; however, it is apparent that a test of about a 15-day duration would yield sufficient data for analysis.

3.3 PROPOSED TESTING PLAN

On the basis of the evaluation of the potential responses during testing and the review of the monitoring-well system presented in the preceding sections, a plan was developed for the hydrogeologic testing of the exploratory shaft monitoring wells. In developing the plan it was assumed that the proposed changes in the monitoring system - at least with respect to installing separate wells at each monitoring location - are feasible. It was further assumed that the schedule of activities at the exploratory shaft facility would not be in conflict with the proposed plan.

A two-phase testing plan is proposed. During Phase I, two Ogallala wells are installed at each monitoring location and pump tested consecutively. During Phase II, one of the Ogallala wells at each location is deepened and completed in the principal water-bearing zone of the Dockum; consecutive Dockum tests are then conducted. The details of the proposed testing plan are presented below.



LEGEND

① T = 22,400 gpd/ft ; S_y = 0.12 ; Q = 550 gpm
② T = 40,000 gpd/ft ; S_y = 0.05 ; Q = 900 gpm
③ T = 5,000 gpd/ft ; S_y = 0.20 ; Q = 130 gpm

Ogallala Test
Time–Drawdown
in Proposed Observation Well

Figure 3-9

3.3.1 Phase I - Ogallala Tests

1. At each monitoring location install two Ogallala wells. Except for locations ESM-4 and ESM-5, where well spacing may be governed by other shaft facilities, place wells about 10 feet apart. Drill one of the wells as an 8-inch diameter hole and complete as a 4-inch diameter permanent Ogallala monitoring well with a screened interval extending throughout the saturated thickness of the Ogallala. Drill the second well as a 16-inch diameter hole and complete as a 12-inch diameter temporary Ogallala well, also screened throughout the saturated thickness of the Ogallala. Develop both wells.

2. Upon completion of the larger diameter well at each location, conduct a step-drawdown test in this well using three steps of 2-hour duration. Evaluate the step-test data to estimate the discharge rate for the pumping tests at this location. Install a water-level recording device in one of the wells and begin to collect pre-test water-level data.

3. Complete the well installation and step-testing at all monitoring locations. Continue to collect pre-test water-level data for at least two weeks after the installation of the last well.

4. Evaluate pre-test data to establish water-level trends and correlations with climatic and other factors that might affect water levels.

5. Conduct a six-day pumping test followed by a six-day recovery period at one of the monitoring locations. Collect water-level data from the pumped well, the nearby monitoring well and at least one well at each of the other five monitoring locations. Also collect data on factors that have been determined to affect water levels in step 4.

6. Move to the next monitoring location and repeat step 5. Repeat this step until tests have been conducted at all six locations.

7. During each test, maintain field plots of the data. Evaluate these plots at least daily to assess the adequacy of the pumping period; extend or reduce the pumping and recovery periods, if necessary.

This plan of testing the Ogallala would require about three months to complete after all the wells have been installed and step-tested. Assuming that the proposed monitoring locations are acceptable, tests should first be conducted at locations ESM-4 and ESM-5 (see Figure 3-8) to provide early information for the freeze-wall design. The testing then may sequentially proceed to locations ESM-6, ESM-1, ESM-3 and ESM-2. This sequence of testing provides a large areal coverage with the first three or four tests. Thus, if for some reason or other, the need arises to eliminate one or two of the later tests, the reduction in the areal coverage would be minimum.

3.3.2 Phase II - Dockum Tests

1. At each monitoring location, deepen the larger-diameter Ogallala well by drilling an 11 7/8-inch hole, through the 12-inch casing and screen, to the bottom of the principal water-bearing zone of the Dockum and complete the hole as a 6-inch diameter Dockum monitoring

well screened throughout the principal water-bearing zone. Develop the well and conduct a step-drawdown test in the completed well using 3 steps of 1-hour duration. Evaluate the step-test data to estimate the discharge rate for the pumping test at this location. Install a water-level recording device in the well and begin to collect pre-test water-level data. Also begin to record barometric pressure changes.

2. Complete the installation and step-testing of the Dockum wells at each location as specified in step 1. Continue to collect water-level and barometric pressure data for at least one week after the completion of the last well.

3. Evaluate pre-test data to establish trends, barometric efficiency and correlations with other factors that might affect water levels.

4. Conduct a two-day pumping test followed by a two-day recovery period at the first monitoring location. Collect water-level data from the pumped well, from the five other Dockum wells, from the Ogallala well at the pumped well location, and another nearby Ogallala well. (Occasional measurements could also be made in the remaining Ogallala wells.) Continue to record barometric pressure changes during the testing period.

5. Move to next monitoring location and repeat step 4. Repeat this step until tests have been conducted at all six locations.

6. During each test, maintain field plots of the data. Evaluate these plots at least twice daily to assess adequacy of testing period; extend or reduce the pumping and recovery periods, if necessary.

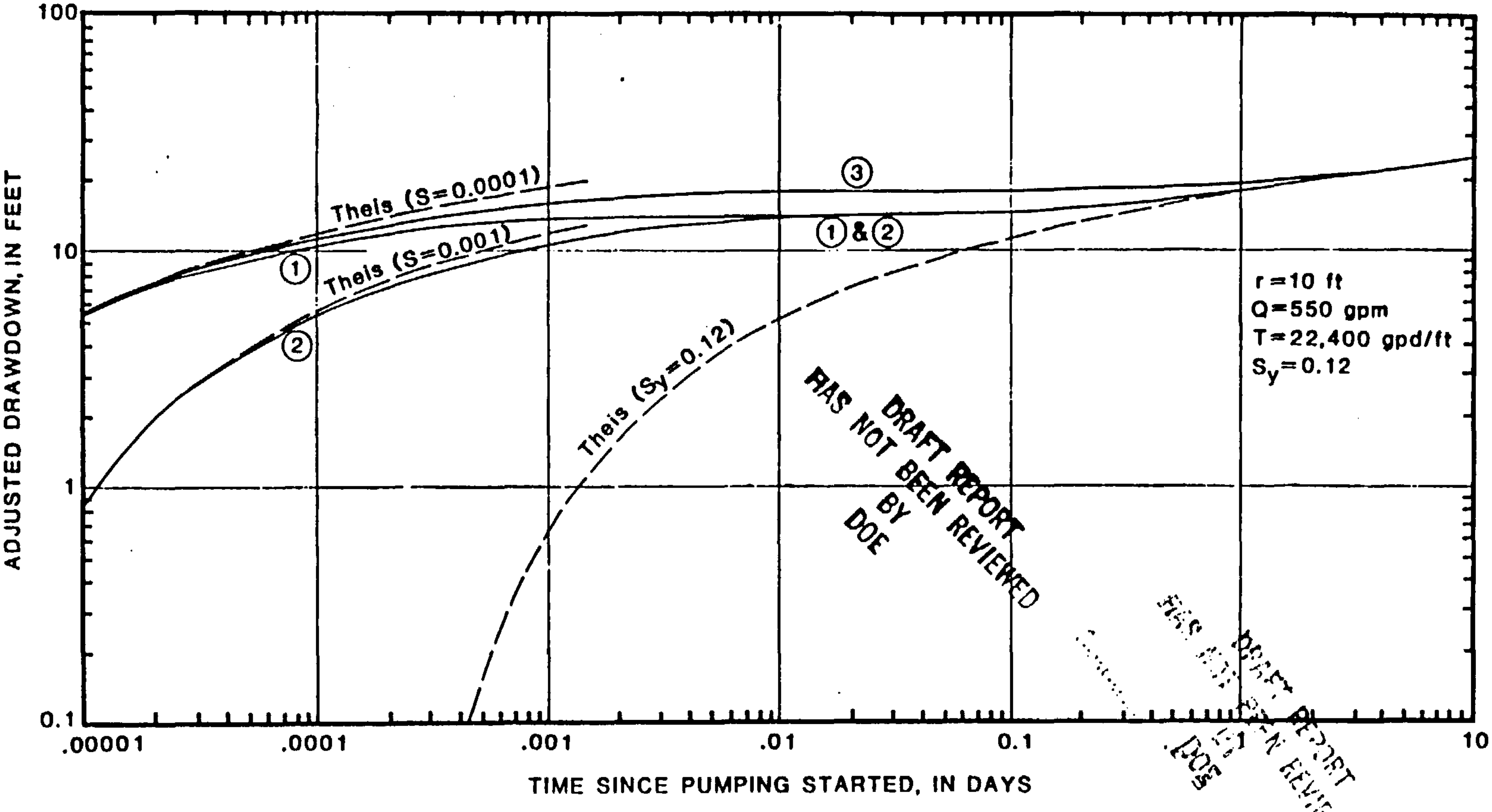
The overall testing period for this phase would last for about one-month after the completion and step-testing of the wells. The proposed sequence of testing is the same as that for the Ogallala, and would provide the same flexibility with respect to a potential need for eliminating one or two of the later tests.

3.4 EFFECT OF STORAGE COEFFICIENT AND ANISOTROPY

As stated earlier, data on the storage coefficient associated with elastic compressibility and on the vertical-to-horizontal anisotropy of the Ogallala are not available. The design of the Ogallala tests proposed above was based on evaluations made using assumed values of 0.0001 for the storage coefficient and of 0.2 for the vertical-to-horizontal anisotropy. To determine the effect of using assumed values for these parameters on the proposed test design, the sensitivity of the expected test response to these parameters was evaluated.

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

Figure 3-10 shows plots of three response curves for the proposed Ogallala observation well. The response curves are labeled 1, 2 and 3. For all three curves the transmissivity and the specific yield have the baseline values of 22,400 gpd/ft and 0.12, respectively. Curve 1 represents the expected response for the assumed values of 0.0001 for storage coefficient and 0.2 for vertical-to-horizontal anisotropy. In curve 2, the storage coefficient is increased to 0.001 while all the other parameters retain their



LEGEND

① S=0.0001 : K_z/K_h=0.2
② S=0.001 : K_z/K_h=0.2
③ S=0.0001 : K_z/K_h=0.05

Ogallala Test
Effect of Storage Coefficient and of Anisotropy on Expected Response in an Observation Well

Figure 3-10

original values. In curve 3, the the vertical-to-horizontal anisotropy is decreased to 0.05; the other parameters have the same values as those for curve 1. Also shown on the figure are traces of the "early" and "late" Theis (1935) curves governed by the values of the storage coefficient and specific yield, respectively. To examine the very early behaviour of the responses, the time scale for the plots begins at 0.00001 day, or about 1 second, after the start of the test.

Comparison of the early part of curves 1 and 2 indicates that departure from the corresponding Theis curve, that is the start of the transition period, occurs at a later time for a larger storage coefficient. For a storage coefficient of 0.0001 (curve 1), the transition period has already started before 0.00001 day (1 second), whereas for a storage coefficient of 0.001 (curve 2), it does not start until about 0.00003 day (3 seconds). As time progresses, the two curves converge and the response becomes independent of the storage coefficient.

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

Comparison of curves 1 and 3 indicates that a smaller vertical-to-horizontal anisotropy also delays the start of the transition period. During the transition period, the drawdown is larger for the smaller value of anisotropy and the duration of the transition period is longer. The transitiion period ends at about 1 day for an anisotropy o 0.2 (Curve 1) whereas it continues for about 3.5 days for an anisotropy of 0.05 (Curve 3).

As these results indicate, the storage coefficient controls only the very early response of the test and, therefore, the use of an assumed values does not affect the test design. However, the vertical-to-horizontal anisotropy significantly affects the duration of the transition period and, therefore,

the duration of the test. Although the proposed 6-day duration of the test may be sufficient for a vertical-to-horizontal anisotropy value of 0.05 or larger, a longer test duration would be required if it is smaller. Therefore, it is imperative that field plots of the data be maintained, as proposed in step 7 of the Ogallala test, to prevent the untimely termination of the test.

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

4.0 DATA ANALYSIS PROCEDURES

The drawdown data collected from pumping tests must be analyzed to determine the hydraulic parameters of the Ogallala and of the principal water-bearing zone of the Dockum. The basic concept that underlies the analysis of pumping test data is relatively simple: to determine a set of hydrologic conditions and hydraulic parameters that best explain the observed response of the aquifer to pumping. The hydraulic parameters of the aquifer are determined either by type-curve methods based on the comparison of the shape of the observed response to that of a theoretical response, or by straight-line methods based on features common to both the observed and the theoretical response, such as slope, intercept, etc.

The methods that will most likely be applicable to the analysis of data from the proposed Ogallala and Dockum tests are discussed in the sections that follow.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

4.1 ANALYSIS OF OGALLALA TEST DATA

As discussed earlier, theoretical models applicable to the analysis of data from an unconfined aquifer have been developed by Boulton, (1954, 1963, 1970), Boulton and Pontin (1971) and Neuman (1972, 1973, 1974). Boulton's (1954) model and its extensions by Boulton (1970) and Boulton and Pontin (1971) are based on a semiempirical quantity, referred to as the delay index, which was introduced to simulate the S-shaped behavior of the unconfined aquifer response. Methods of analyzing test data on the basis of this model are discussed by Boulton (1963, 1970) and Prickett (1965). Neuman's (1972)

model explains the S-shaped behavior on the basis of a physical parameter, the vertical-to-horizontal anisotropy of the aquifer. The methods of analysis based on this later model (Neuman, 1975) will be used to discuss the analysis of data from Ogallala tests.

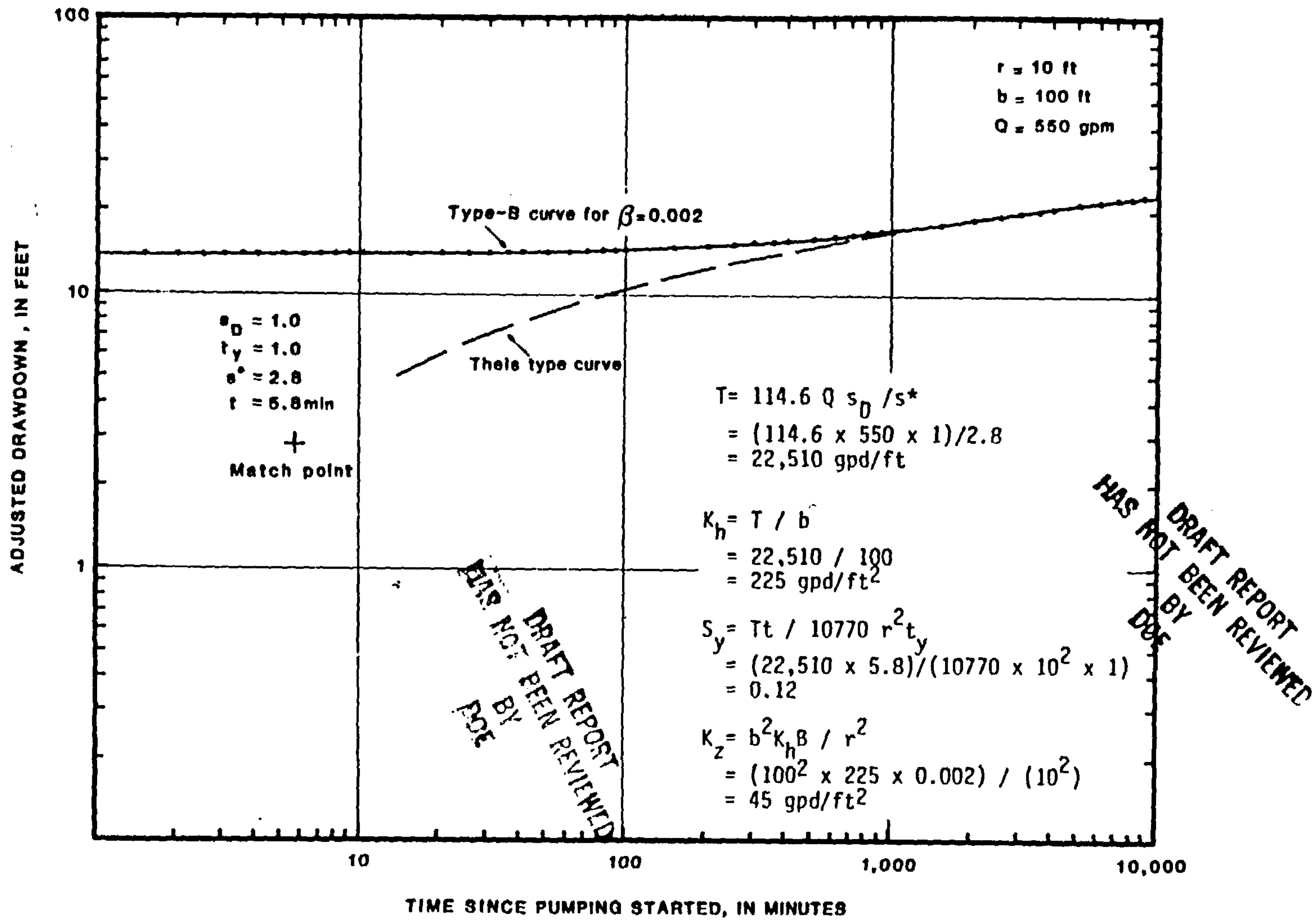
Both the type-curve and the straight-line methods can be used to analyze data by Neuman's model. The approach to analysis by both methods is discussed in detail by Neuman (1975). Their application to data from an Ogallala test is demonstrated below using the expected response in observation wells for the baseline values of the hydraulic parameters.

Figure 4-1 shows a logarithmic plot of the adjusted drawdown s^* in the proposed nearby observation well against the time t since pumping started. [As Neuman (1975) suggests, the dewatering adjustment is applied only to drawdown data from the later part of the test.] The plot indicates that the transition period starts soon after the beginning of the test and that early data fall on the flat segment of the S-shaped, unconfined-aquifer response curve. Therefore, Neuman's type-B curves, which are logarithmic plots of the dimensionless drawdown s_D against the dimensionless time t_y for different values of the parameter β, are applicable to the analysis of the data. The dimensionless parameters s_D, t_y and β are defined as follows:

$$s_D = 4\pi T s^*/Q \quad ;$$
$$t_y = Tt/r^2 S_y \quad ;$$
$$\beta = r^2 K_z / b^2 K_h \quad ;$$

where

T = Transmissivity;



Ogallala Test Type-Curve Analysis of Expected Response in Nearby Observation Well

Figure 4-1

s^* = Adjusted drawdown;

Q = Discharge rate;

t = Time since pumping started;

r = Radial distance to observation well;

S_y = Specific yield;

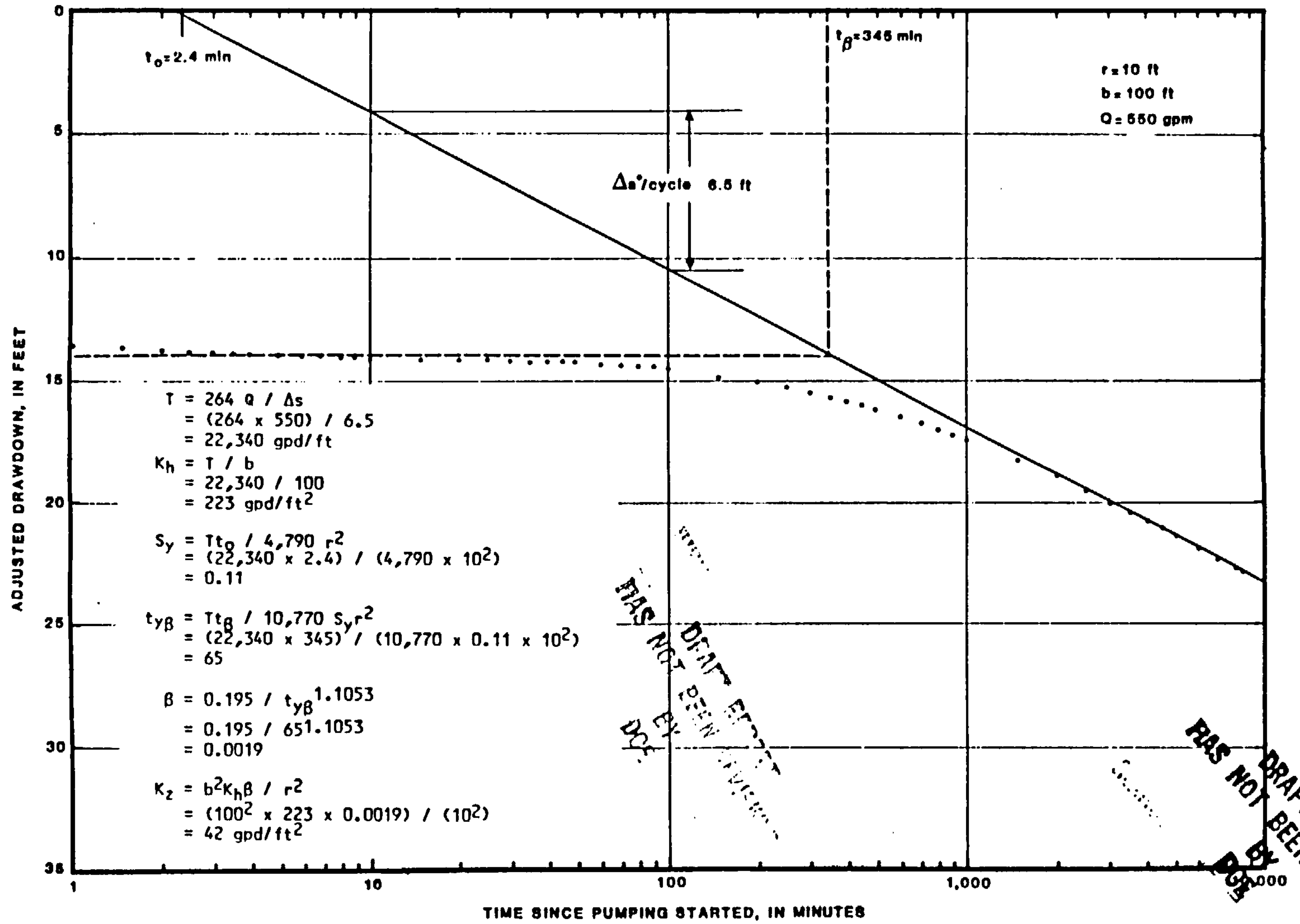
K_z = Vertical hydraulic conductivity;

K_h = Horizontal hydraulic conductivity; and

b = Initial saturated thickness,

all expressed in consistent measurement units. The data plot is matched to the plots of the type-B curves and a match point common to both plots is selected as shown on Figure 4-1. The transmissivity and the specific yield are determined from the coordinates of the match point and the above definition of s_D and t_y. The vertical hydraulic conductivity is determined from the value of β for the type curve that matches the data. The calculations involved in this type-curve method of analysis and the results are shown on Figure 4-1.

Figure 4-2 shows a semilogarithmic plot of the same data. The plot indicates that data after about 2,000 minutes fall on a straight line. A line is drawn through these data and the slope of the line (the change in the adjusted drawdown Δs^* per log-cycle) and the intercept t_0 of the line is recorded. A second, horizontal line is drawn through the flat segment of the plot and the time t_β corresponding to the intersection of this line with the sloping line is recorded. The transmissivity and the specific yield are determined using the values of the slope Δs^* and of the intercept t_0 in a manner identical to that presented by Cooper and Jacob (1946). The



Ogallala Test Straight-Line Analysis of Expected Response in Nearby Observation Well

Figure 4-2

determination of the vertical hydraulic conductivity involves three steps. First, the value of t_β is used to calculate the parameter

$$t_{y\beta} = Tt_\beta / r^2 S_y$$

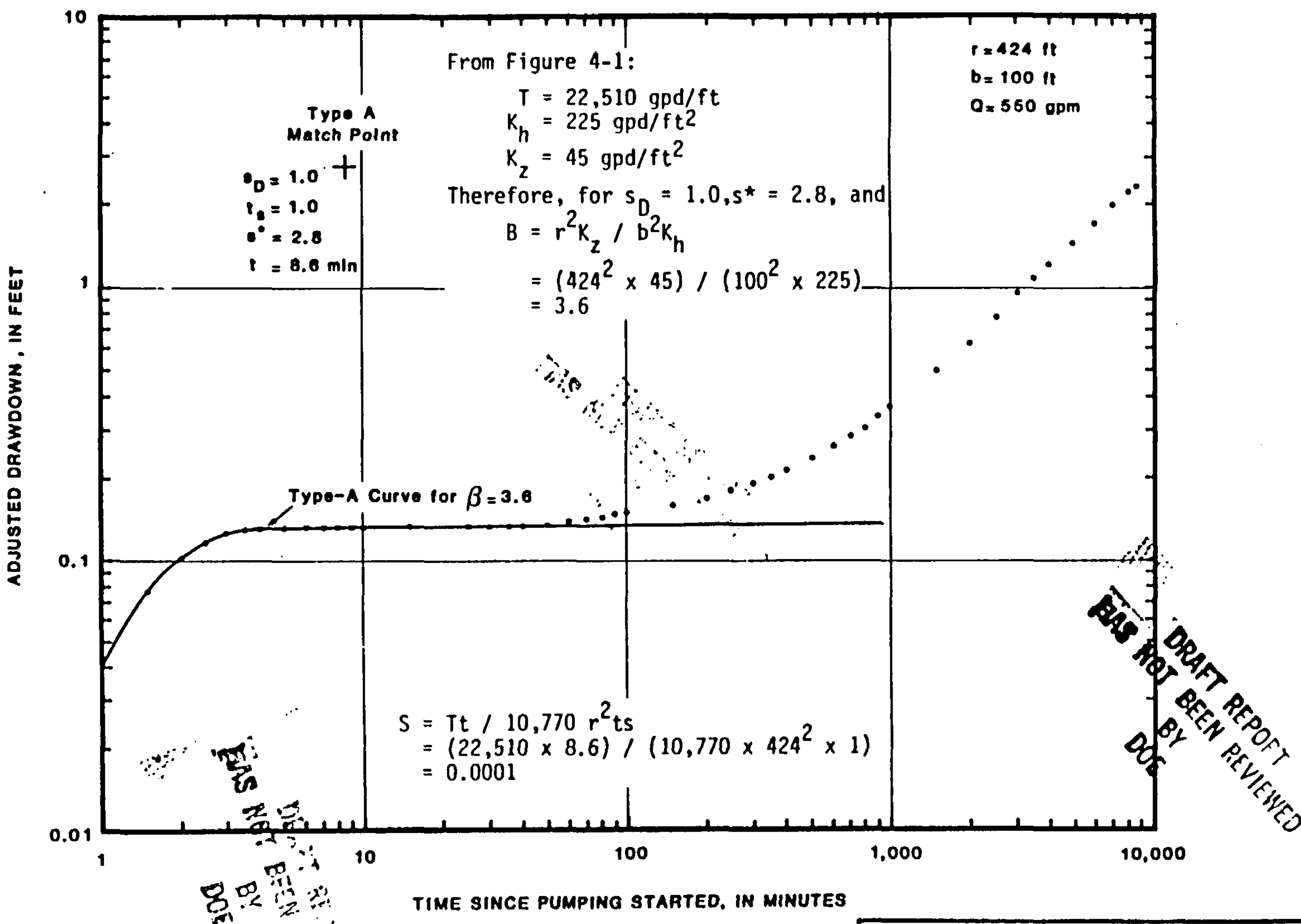
where all parameters are as previously defined and expressed in consistent units. Second, if $4 \leq t_{y\beta} \leq 100$, the value of β is calculated using the following relationship (Neuman, 1975)

$$\beta = 0.195/t_{y\beta}^{\,1.1053} \quad ;$$

Outside this range, β is determined from a graph given by Neuman (1975, Figure 3). Finally, the vertical hydraulic conductivity is determined from the definition of β. The calculations involved in this straight-line method of analysis and the results are shown on Figure 4-2.

Note that the storage coefficient S cannot be determined using data from the nearby observation well because the early data fall on the flat segment of the response curve. If the early data showed some curvature, the storage coefficient could have been determined by matching these data with Neuman's type-A curves, which are plots of the dimensionless drawdown s_D against the dimensionless time t_s for different values of β. (The definition of dimensionless time t_s is the same as that of t_y except that S_y is replaced by S.) The determination of the storage coefficient may be possible using data from other, more distant observation wells.

Figure 4-3 shows a plot of drawdown data from an observation well 424 feet from the pumped well (the distance between monitoring locations ESM-1 and ESM-3 on Figure 3-8). The early data from this well shows sufficient



Ogallala Test
Type-Curve Analysis of Expected Response in Distant Observation

Figure 4-3

curvature to match with the type-A curves. Theoretically, if the transmissivity and the vertical hydraulic conductivity of the aquifer are uniform, the ratio of s_D to s^* at the match point for these data should be the same as that at the match point for the data from the nearby observation well (Figure 4-1). Also, the value of β for the type-A curve to which the data from the well should be matched can be calculated. This information can then be used to match the early data from the distant observation well to the type-A curve for the calculated β, and to determine the storage coefficient, as shown on Figure 4-3.

4.2 ANALYSIS OF DOCKUM TEST DATA

As also discussed earlier, the theoretical response model applicable to the analysis of data from pumping tests conducted on wells open to the principal water-bearing zone of the Dockum is the confined-aquifer model of Theis (1935). Either the type-curve method or the straight-line method can also be used to analyze observation well data by this model.

The type-curve method in this case involves a single type-curve which is a logarithmic plot of the dimensionless function W(u) - equivalent to the dimensionless drawdown s_D and often referred to as the "well function" - against the dimensionless parameter u, defined as

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

$$u = r^2S/4Tt$$

where S is the storage coefficient and all other parameters are as previously defined and expressed in consistent units. Data are matched to this type curve and the transmissivity and storage coefficient are determined from the

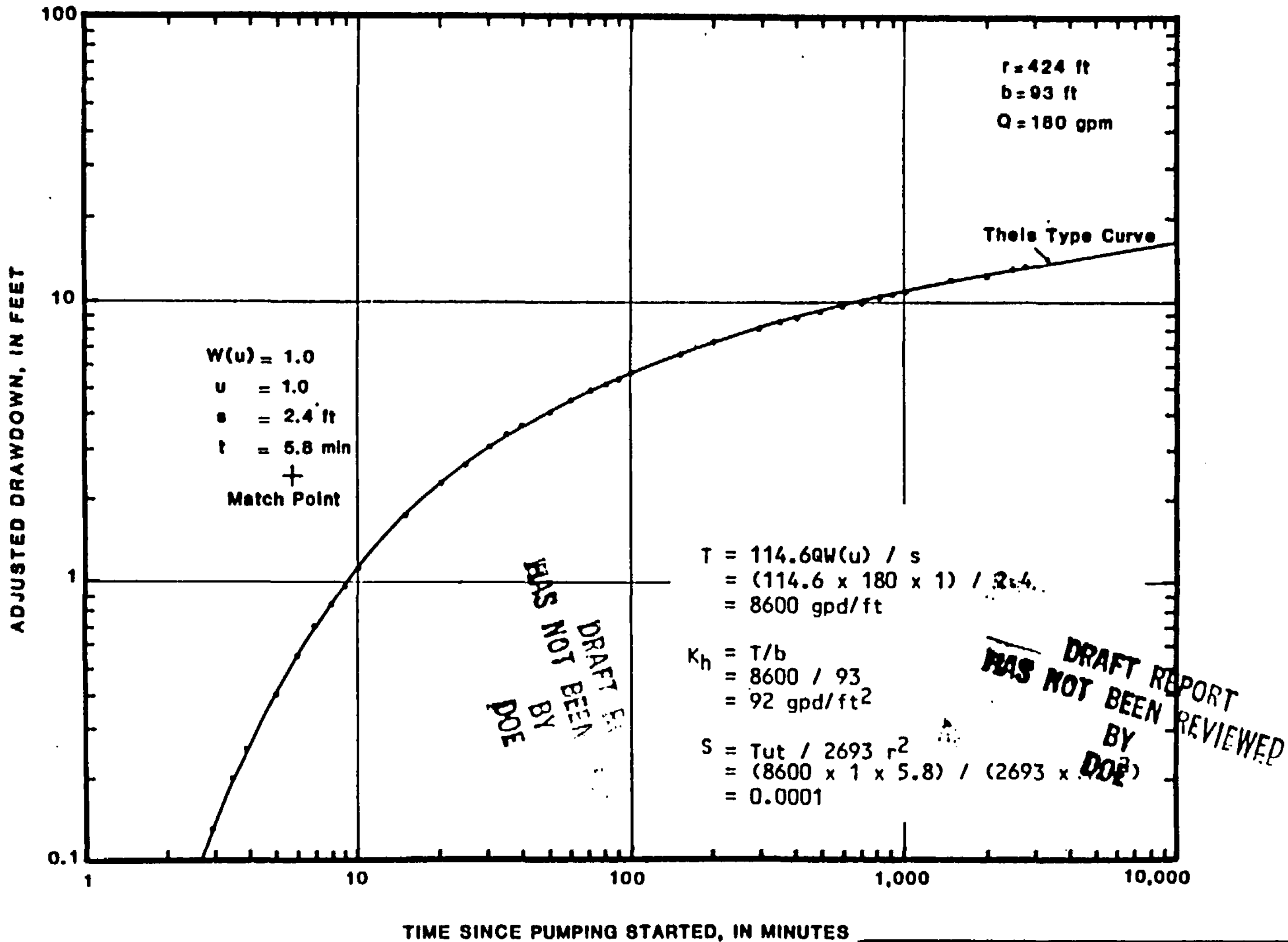
match-point coordinates. Figure 4-4 shows the type-curve analysis of the expected response in an observation well during a Dockum test.

The application of the straight-line method to the analysis of data from a confined aquifer is discussed in detail by Cooper and Jacob (1946), and was demonstrated in the analysis of data from Ogallala tests presented in the previous section. It should be noted that, both for confined and unconfined aquifers, the method is applicable only to data that fall in the range of $u < 0.01$ or $t > r^2S/0.04Tt$ ($t > r^2S_y/0.04Tt$ in the case of adjusted data from unconfined aquifers). Since semilogarithmic plots of data from pumping tests often display segments that appear to be nearly on a straight line, this criterion should be evaluated after determining T and S (or S_y) to check the applicability of the straight-line method and, hence, the correctness of the results.

4.3 ALTERNATE ANALYSIS PROCEDURES

4.3.1 Analysis of Recovery Data

The methods of analysis discussed earlier considered only data from the pumping cycle of the tests. Data from the recovery cycle can also be analyzed to determine the transmissivity of the tested aquifers. However, analyses of recovery data do not provide information on storage properties. The method of analysis consists of plotting the residual drawdown s', that is the drawdown during the recovery period, against the logarithm of the ratio t/t', where t is time since pumping started and t' is time since pumping stopped. Late recovery data, that is the data for values of t/t' near one, would fall on a



Dockum Test
Type-Curve Analysis
of Expected Response
in an Observation Well

Figure 4-4

straight line and the transmissivity can be determined from the slope of this line.

It should be noted, however, that two conditions must be met before this method is applicable. First, it should have been established from the pumping cycle that the aquifer response conforms with the Theis response curve; that is, either the aquifer is confined or, if it is unconfined, late data from the pumping cycle fall on the specific yield governed Theis response curve. Second, the time t' should satisfy the criterion presented earlier in discussing the applicability of the straight-line method of analysis.

Recovery data can be also used to extend the pumping cycle data beyond the end of the pumping period. This could be particularly useful if, after the end of the test, it is discovered that the pumping period was not sufficiently long to permit a complete analysis. The method of extending the pumping cycle data through use of recovery data is discussed below.

To simulate the residual drawdown during the recovery period, it is assumed that the pumped well continues pumping beyond the shut-down time t_e and that another hypothetical well at the same location begins injecting at the shut-down time at a rate equal to the discharge rate. Thus, equations describing the residual drawdown generally have the form

$$s'(t') = QF(t) - QF(t')$$

where $s'(t')$ is the residual drawdown at time t' since pumping stopped and the function F is the response function applicable to the hydrogeologic setting of the tested aquifer. Note that

$QF(t) = s(t)$ = the drawdown at time t since pumping started ($t > t_e$) that would have occurred if pumping continued beyond time t_e; and

$QF(t') = s''(t')$ = the build-up (water-level increase) caused by the hypothetical injection well at time t′ since pumping stopped.

Therefore, the residual drawdown can also be expressed as

$$s'(t') = s(t) - s''(t')$$

Figure 4-5 schematically shows the relationship of the terms of this equation.

If the drawdown $s(t_1)$ at time $t = t_1$ since pumping started and the residual drawdown $s'(t_1)$ at time $t' = t_1$ since pumping stopped are considered, then

$$s(t_1) = QF(t_1)$$

and

$$s'(t_1) = QF(t_e + t_1) - QF(t_1)$$

or

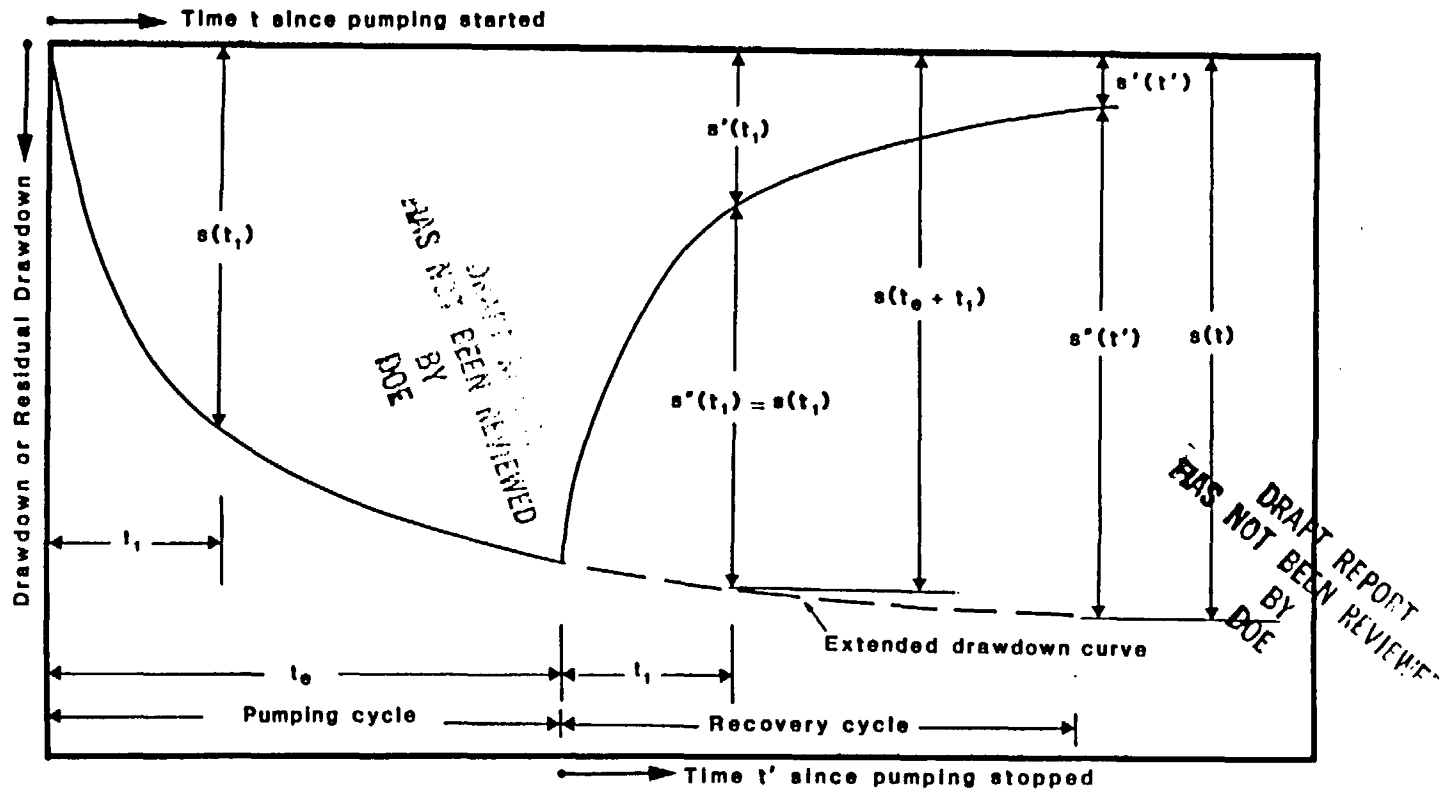
$$s'(t_1) = s(t_e + t_1) - s''(t_1)$$

Since both $s(t_1)$ and $s''(t_1)$ are equal to $QF(t_1)$, they are equal and

$$s'(t_1) = s(t_e + t_1) - s(t_1)$$

or

$$s(t_e + t_1) = s'(t_1) + s(t_1)$$



Relationship Between Pumping and Recovery Cycle Test Data

Figure 4-5

Thus, the drawdown that would have occurred at time $t = t_e + t_1$ if pumping had continued beyond the time t_e, can be calculated by adding the observed drawdown at time $t = t_1$ since pumping started to the observed residual drawdown at time $t' = t_1$ since pumping stopped. This relationship is also illustrated on Figure 4-5.

Using this approach, recovery data can be used to extend the pumping cycle data to the end of the recovery cycle. The combined observed and synthesized pumping cycle data can then be analyzed by the methods applicable to the analysis of pumping data.

4.3.2 Other Potential Responses

The methods of analysis considered so far assumed that the data to be obtained from the tests would conform with the expected response estimated from the review of the hydrogeologic conditions at the exploratory shaft site. For example, based on the estimated vertical hydraulic conductivity of the confining layers separating the Ogallala from the principal water-bearing zone of the Dockum and of those underlying this zone, leakage was determined not to be a significant factor during the tests.

DRAFT
HAS NOT BEEN REVIEWED
BY
DOE

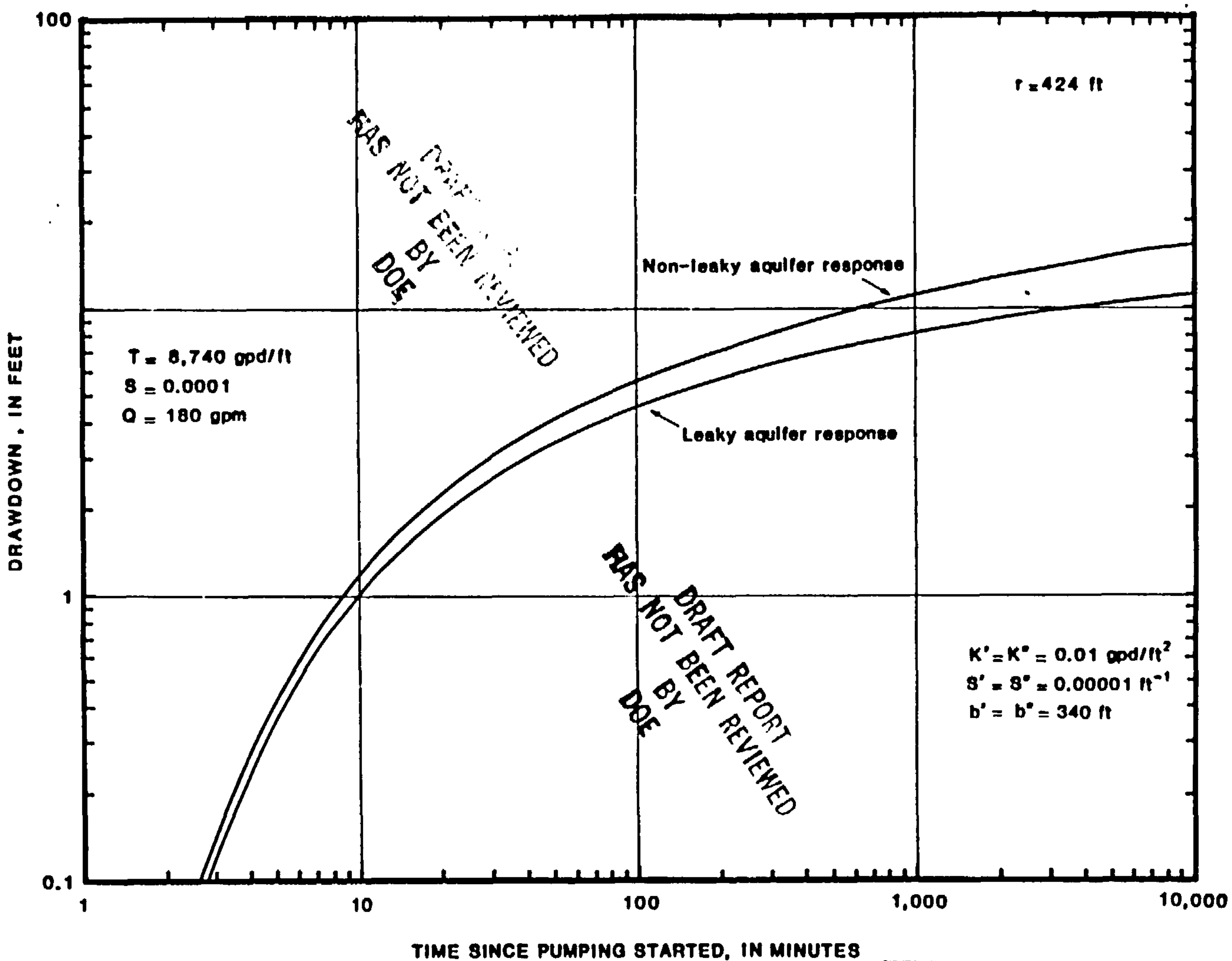
The highest value for the vertical hydraulic conductivity of these confining layers was estimated to be 0.001 gpd/ft^2. Calculations made using a confining layer vertical hydraulic conductivity of 0.01 gpd/ft^2 - one order of magnitude larger than the highest estimated value - indicate that, even for this higher value, leakage would not be a significant factor during the Ogallala test because of the large specific yield of the aquifer. The vertical hydraulic conductivity of the confining layers must be considerably

higher for leakage to begin affecting the Ogallala test data within the proposed testing period. If such is the case, the analysis of data from the tests would be complicated as analytical models that consider both the delayed gravity response and leakage are not available. Under these circumstances, the analysis of the test data will have to be made using numerical aquifer simulation models.

The principal water-bearing zone of the Dockum, however, has a small storage coefficient and confining layers lie both above and below this zone. Calculations indicate that if the vertical hydraulic conductivities K' and K'' of the upper and lower confining layer, respectively, are both equal to 0.01 gpd/ft^2, leakage would affect the test data. These calculations were made using Hantush's (1960) modified leaky aquifer theory; the specific storages S'_s and S''_s of the upper and lower confining layer, respectively, were assumed to be 0.00001 per foot and the corresponding confining layer thicknesses, b' and b'', 340 feet.

Figure 4-6 shows the leaky aquifer response in a Dockum observation well based on the above parameters. Also shown on the figure is the expected response under non-leaky conditions. Note that the two response curves are very similar in shape. Given that test data would undoubtedly have some noise, the leaky-aquifer response could be easily mistaken for a non-leaky response and an analysis could be made that led to erroneous results.

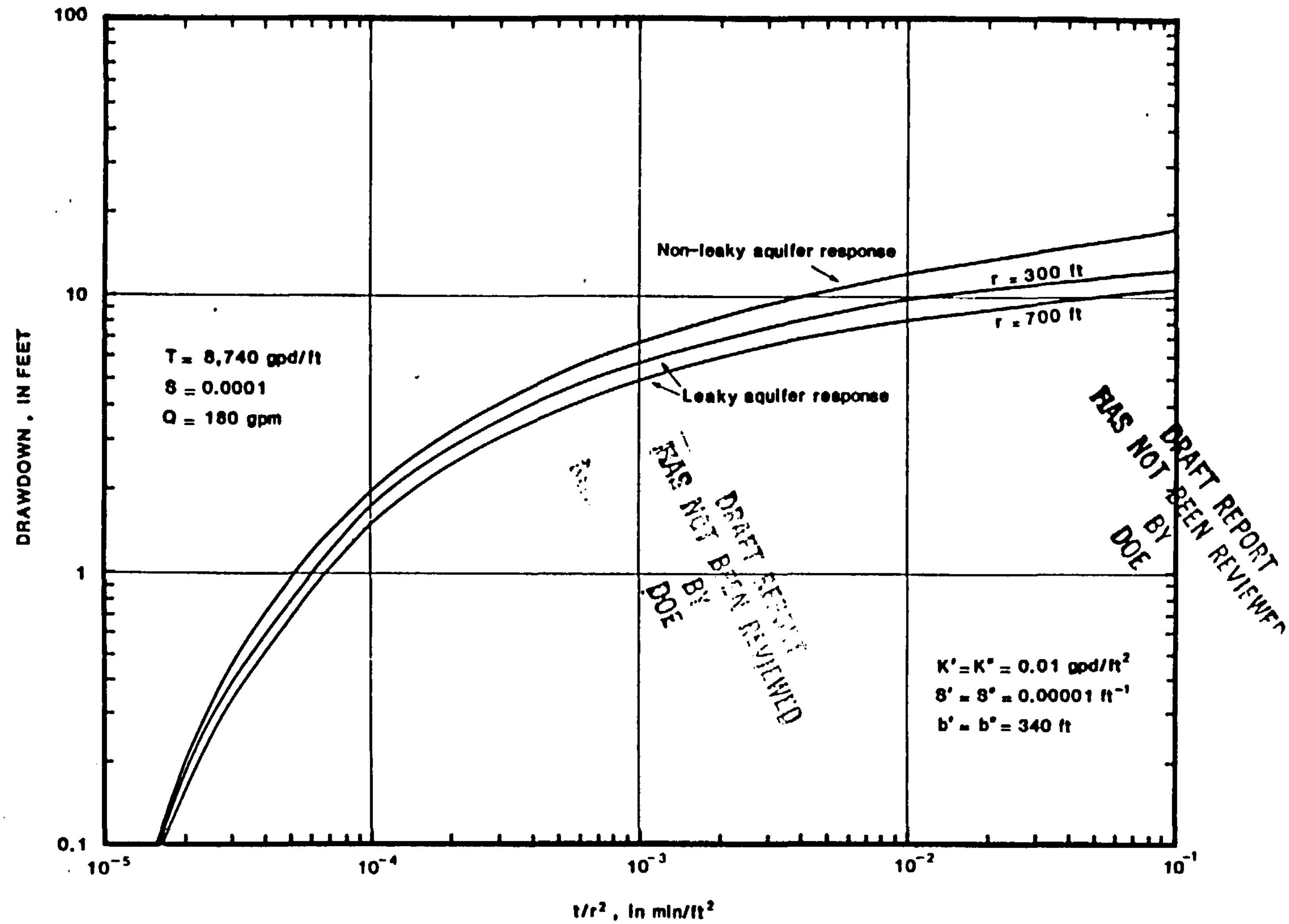
To avoid misinterpretation, data from several observation wells should be plotted on a single graph against the parameter t/r^2. Figure 4-7 shows the expected leaky-aquifer response from two Dockum observation wells, at distances of about 300 ft (ESM-1 to ESM-5) and 700 ft (ESM-1 to ESM-6),



Dockum Test

Effect of Leakage on Expected Response in an Observation Well

Figure 4-6



Dockum Test
Expected Leaky Aquifer Response in Two Observation Wells

Figure 4-7

plotted against the parameter t/r^2. Also shown on the figure is the expected non-leaky aquifer response. Note that, in this type of plot, under non-leaky conditions, the data from both observation wells would fall on the same response curve; whereas, under leaky conditions the data from each well plot as a separate response curve. Therefore, leaky-aquifer conditions can be distinguished from non-leaky conditions by using this type of plot and analyzed using appropriate methods. The methods of analysis that are applicable to pumping test data from leaky aquifers are discussed in detail by Hantush (1960, 1964).

Other potential responses that could deviate from the expected responses discussed earlier are those affected by nearby hydrologic boundaries. The review of the hydrogeologic conditions at the vicinity of the exploratory shaft facility does not indicate the presence of such boundaries. However, nearby areas of higher or lower transmissivity may create effects similar to those of recharge or impermeable boundaries and the analysis of test data may require the use of the method of images (Ferris and others, 1962).

All of the analysis procedures discussed above rely on available analytical models for analyzing test data. Analytical models have inherent assumptions regarding the hydrogeologic setting and the nature of the hydraulic parameters controlling the test response. If field conditions differ significantly from these assumptions, the data may not be amenable to analysis by available analytical models and numerical aquifer simulation models may have to be considered. Numerical aquifer models provide the flexibility of simulating complex aquifer boundaries, nonhomogeneities in the hydraulic parameters of the aquifer and many other hydrogeologic conditions

which cannot be considered by analytical models. Thus, they provide a powerful tool for the analysis of test data that are not amenable to analysis by analytical models.

5.0 SUMMARY AND CONCLUSIONS

To develop a hydrogeologic testing plan for the exploratory shaft monitoring wells, available reports and data were reviewed to obtain an understanding of the hydrogeologic setting of the Ogallala Formation and the Dockum Group and to estimate the range of the hydraulic parameters of water-bearing zones within these geologic units. This review led to the following conclusions:

- Ground water occurs under unconfined conditions in the Ogallala and under confined conditions in the principal water-bearing zone of the Dockum.

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE

- The transmissivity of the Ogallala may range from 5,000 gpd/ft to 40,000 gpd/ft and its specific yield from 0.05 to 0.20.

- The transmissivity of the principal water-bearing zone of the Dockum may range from 100 gpd/ft to 8,740 gpd/ft and its storage coefficent from 0.00001 to 0.001.

- Given the estimated range of the hydraulic parameters, a constant rate pumping test would be the preferable method for evaluating the hydraulic parameters of the water-bearing zones of the Ogallala and the Dockum.

- During Ogallala pumping tests, monitoring wells would be expected to respond to pumping in a manner typical of unconfined aquifers with delayed gravity response from the water table. During Dockum tests,

monitoring well response would be expected to be typical of confined aquifers.

Based on these conclusions, the potential response of monitoring wells during pumping tests was evaluated for the range of the hydraulic parameters. Also, the location and design of the monitoring wells were reviewed with respect to their primary monitoring function and with respect to their function as observation wells during tests. This evaluation and review led to the following conclusions and recommendations:

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

- To provide for a complete evaluation of hydraulic parameters of the Ogallala and of the principal water-bearing zone of the Dockum, pumping test data must be collected from the pumped monitoring well and from at least one additional monitoring well.

- The planned monitoring well locations would provide adequate data for evaluating the hydraulic parameters of the Dockum with pumping tests of reasonable duration. However, tests of very long duration may be required to determine the hydraulic parameters of the Ogallala.

- The dual-completion design and the planned location of monitoring wells downgradient from the shaft location is not suitable for monitoring potential water-quality impacts of the shaft construction.

- It is recommended that monitoring wells downgradient of the shafts be placed as close to the shafts as possible. Since the directions of flow are different in the Ogallala (southeast) and the Dockum (east), these wells should be completed as two separate wells with the

Ogallala well placed to the southeast and the Dockum well to the east of the shafts.

- It is further recommended that the separate well design be adopted also for the other monitoring locations and that both wells at each location first be completed in the Ogallala to provide a nearby observation well that would permit the evaluation of the hydraulic parameters of the Ogallala with tests of reasonable duration.

On the basis of these conclusions and assuming that the recommended changes in the monitoring well design and locations are feasible, a hydrogeologic testing plan was developed for the exploratory shaft monitoring wells. The following sequence of well completion and testing is recommended:

- At each monitoring location, drill two Ogallala wells. Complete one well as the Ogallala monitoring well and the other as a temporary Ogallala test well.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

- Conduct six-day Ogallala pumping tests followed by six-day recovery periods at each monitoring location.

- Deepen the temporary Ogallala wells and complete as Dockum monitoring wells.

- Conduct 2-day Dockum pumping tests followed by 2-day recovery periods at each monitoring location.

The data from the Ogallala tests would most likely be amenable to analysis by Neuman's (1975) model for unconfined aquifers with delayed gravity response from the water table. Those from the Dockum test would be expected

to be amenable to analysis by Theis' (1935) confined aquifer model. Although leakage from adjacent confining layers is not expected to have a significant effect on test data, precautions, such as preparing composite plots of data from several observation wells, must be taken to avoid misinterpretations of the data. If the response during the tests is considerably different than expected, numerical aquifer simulation models may be required to analyze the data.

6.0 BIBLIOGRAPHY

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

Bair, E. S., 1985. Hydrodynamic Investigations in the Texas Panhandle Area, Stone & Webster Engineering Corporation, Boston, Mass., ONWI/SUB/85/E512-05000-T42.

Bair, E. S., T. P. O'Donnell, and L. W. Picking, (Stone & Webster Engineering Corporation), 1985a. Hydrogeologic Investigations Based on Drill-Stem Test Data: Palo Duro Basin Area, Texas and New Mexico, prepared for Office of Nuclear Waste Isolation, BMI-ONWI/566, Battelle Memorial Institute, Columbus, OH.

Bair, E. S., T. P. O'Donnell, and L. W. Picking, 1985b. Potentiometric Mapping from Incomplete Drill-Stem Test Data: Palo Duro Basin Area, Texas and New Mexico: Ground Water, v. 23, no. 2, pp. 198-211.

Boulton, N. S., 1954. Unsteady Radial Flow to a Pumped Well Allowing for Delayed Yield from Storage: Int. Ass. Sci. Hydrol. Rome, 2, 474.

Boulton, N. S., 1963. Analysis of Data from Nonequilibrium Pumping Tests Allowing for Delayed Yield from Storage: Proc. Inst. Civil Eng., v. 26, 469-482.

Boulton, N. S., 1970. Analysis of Data from Pumping Tests in Unconfined Anisotropic Aquifers: J. Hydrol., 10, 369.

Boulton, N. S., 1973. The Influence of Delayed Drainage on Data from Pumping Tests in Unconfined Aquifers: J. Hydrol., 19, 157.

Boulton, N. S., and J. M. A. Pontin, 1971. An Extended Theory of Delayed Yield from Storage Applied to Pumping Tests in Unconfined Anisotropic Aquifers: J. Hydrol., 14(1), 53.

Cooper, H. H. Jr., and C. E. Jacob, 1946. A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History: Am. Geophys. Union Trans., v. 27, no. 4, pp. 526-534.

Cronin, J. G., 1961. A Summary of the Occurrence and Development of Groundwater in the Southern High Plains of Texas: Texas Board of Water Engineers, Bulletin 6107.

Driscoll, Fletcher G., 1986, Groundwater and Wells, Johnson Division, St. Paul, Minnesota.

Duffin, G. L., 1984. Ground-Water Conditions in the Triassic Aquifer in Deaf Smith and Swisher Counties (Texas), Texas Department of Water Resources, 95 p.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

Dutton, A. R., and W. W. Simpkins, 1985. Estimated Hydraulic Properties of the Triassic Dockum Group Aquifer: OF-WTWI-1985-31, Texas Bureau Of Economic Geology, prepared for the U.S. Department of Energy, Office of Nuclear Waste Isolation.

Fenneman, Nevin M., 1931, Physiography of Western Units States , McGraw-Hill Company, Inc., New York and London.

Ferris, J. G., D. B. Knowles, R. H. Brown, and R. W. Stallman, 1962. Theory of Aquifer Tests: U.S. Geol. Survey Water-Supply Paper 1536-E, pp. 69-174.

Fink, B. E., 1963. Ground-Water Geology of Triassic Deposits, Northern Part of the Southern High Plains of Texas, High Plains Underground Water Conservation District No. 1, Report 163.

Gustavson, T. C., and R. T. Budnick, 1985. Structural Influences on Geomorphic Processes and Physiographic Features, Texas Panhandle: Technical Issues in Siting a Nuclear-Waste Repository: Geology, v. 13, pp. 173-176.

Gutentag, E. D., F. J. Heimes, N. C. Krothe, R. R. Luckey, and J. B. Weeks, 1984. Geohydrology of the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, U.S. Geological Survey Professional Paper 1400-B, 63 p.

Hantush, M. S., 1960. Modification of the Theory of Leaky Aquifers, Jour. Geophys. Res., v. 65, no. 11, pp. 3713-3725.

Hantush, M. S., 1964. Hydraulics of Wells, in Advances in Hydroscience, v. 1: New York, Academic Press, Inc., pp. 281-442.

Jacob, C. E., 1944. Notes-on Determining Permeability by Pumping Tests under Water-Table Conditions: U.S. Geol. Survey, Mimeo. Rep.

Knowles, T., P. Nordstrom, and W. B. Klemt, 1982. Evaluating the Ground Water Resources of the High Plains of Texas, Final Report, Volume 1, Texas Department of Water Resources LP-173.

Kreitler, C. W., R. S. Fisher, R. K. Senger, S. D. Hovorka, and A. R. Dutton, 1985. "Hydrology of an Evaporite Aquitard: Permian Evaporite Strata, Palo Duro Basin, Texas," in International Association of Hydrogeologists, Hydrogeology of Rocks of Low Permeability: Proceedings, Tucson, AZ Congress Memoires, v. 17, part 1, pp. 150-168.

Moench, A. F., and T. A. Prickett, 1972. Radial Flow in an Infinite Aquifer Undergoing Conversion from Artesian to Water Table Conditions: Water Resour. Res., v. 8, No. 2, pp. 494-499.

McGowen, J. H., G. E. Granata, and S. J. Seni, 1979. Depositional Framework of the Lower Dockum Group (Triassic), Texas Panhandle, Texas Bureau of Economic Geology Report of Investigations No. 97.

DRAFT REPORT HAS NOT BEEN REVIEWED BY DOE

Myers, B. N., 1969. Compilations of Aquifer Tests in Texas, Texas Water Development Board Report No. 98.

Neuman, S. P., 1972. Theory of Flow in Unconfined Aquifers Considering Delayed Response of the Water Table: Water Resour. Res., 8(4), 1031.

Neuman, S. P., 1973. Supplementary Comments on Theory of Flow in Unconfined Aquifers Considering Delayed Response of the Water Table: Water Resour. Res., 9(4), 1102.

Neuman, S. P., 1974. Effect of Partial Penetration on Flow in Unconfined Aquifers Considering Delayed Gravity Response: Water Resour. Res., 10(2), 303.

Neuman, S. P. 1975. Analysis of Pumping Test Data from Anisotropic Unconfined Aquifers Considering Delayed Gravity Response: Water Resour. Res. v. 11, no. 2, pp. 329-342.

Nus Corporation, 1985. Water Supply and Use in Deaf Smith, Swisher, and Nearby Counties in the Texas Panhandle, BMI/ONWI-557, prepared for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Ogden, Lawrence, 1965, Estimating Transmissivity with One-Drawdown, Ground Water, v. 3, no. 3, pp. 51-54.

Papadopulos, I. S., and H. H. Cooper, Jr., 1967. Drawdown in a Well of Large Diameter: Water Resour. Res., v. 3, no, 1, pp. 241-244.

Prickett, T. A., 1965. Type-Curve Solutions to Aquifer Tests under Water Table Conditions: Ground Water, v. 3, no. 3, pp. 5-14.

Seni, S. J., 1980. Sand-Body Geometry and Depositional Systems, Ogallala Formation, Texas: Texas Bureau of Economic Geology, Report of Investigations No. 105.

Stallman, R. W., 1971. Aquifer-Test Design, Observation and Data Analysis: U.S. Geol. Survey Techniques of Water-Resources Invest., Book 3, Chapter B1, 26 p.

Stone & Webster Engineering Corporation, 1983a. Area Geological Characterization Report for the Palo Duro and Dalhart Basins, Texas, DOE/CH/10140-1, prepared for the U.S. Department of Energy.

Stone & Webster Engineering Corporation, 1983b. Well Completion Report, J. Friemel No.1 (PD-9), Palo Duro Basin (Deaf Smith County, Texas), prepared for the Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Stone & Webster Engineering Corporation, 1984. Ogallala Aquifer Mapping Program, BMI/ONWI-524, prepared for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Stone & Webster Engineering Corporation, 1985a. Permian Basin Study Field Activity Plan, Shallow Exploratory Borings for Exploratory Shafts and Surface Facilities, AP-13697-27-0, Boston, MA.

Stone & Webster Engineering Corporation, 1985b. Permian Basin Study Field Activity Plan, Engineering Design Boreholes, AP-13697-4, Boston, Mass.

Stone & Webster Engineering Corporation, 1985c. Permian Basin Project Activity Plan for Hydrostratigraphic Parameter Definition Studies, AP-13697-30, Boston, MA.

Stone & Webster Engineering Corporation, 1985d. Project Technical Procedure for Hydrologic Testing in Shallow Boreholes, Permian Basin Project, Texas Panhandle, PTP-13697-25-0, Boston, MA.

Stone & Webster Engineering Corporation, 1985e. Permian Basin Study Activity Plan, Monitoring and Pumping Wells for Exploratory Shafts and Surface Facilities, AP-13697-25-0, Boston, MA.

Stone & Webster Engineering Corporation, 1985f. Project Technical Procedure for Pumping Tests and Fluid Sampling in Ogallala and Dockum Test Wells, PTP-13697-20-0, Boston, MA.

Theis, C. V., 1935. The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage: Am. Geophys. Union Trans., v. 14, pt. 2, pp. 519-524.

U.S. Department of Energy, 1986. Environmental Assessment, Deaf Smith County Site, Texas, Volume 1 of 3, DOE/RW-0069, Washington, D.C.

U.S. Department of Energy, Salt Repository Project Office, 1986, Synthetic Geotechnical Design Reference Data for the Deaf Smith Site, Revision 1, SRP/B-11, Columbus, OH.

Wyatt, A. W., A. E. Bell, and S. Morrison, 1977. Analytical Study of the Ogallala Aquifer in Deaf Smith County, Texas, prepared for Texas Water Development Board Report 213.

DRAFT REPORT
HAS NOT BEEN REVIEWED
BY
DOE