# AQUIFER TESTS IN THE STRATIFIED DRIFT, CHIPUXET RIVER BASIN, RHODE ISLAND

By David C. Dickerman

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## CONVERSION FACTORS

In this report, measurements are given in inch-pound units only. The following table contains factors for converting to International System of Units (SI).

| Multiply inch-pound unit | by | to obtain SI Unit |
|---|---|---|
| | **Length** | |
| foot (ft) | 0.3048 | meter (m) |
| inch (in) | 25.40 | millimeter (mm) |
| | **Volume** | |
| gallon (gal) | 0.003785 | cubic meter ($m^3$) |
| | **Flow** | |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| square foot per day ($ft^2/d$) | 0.0929 | square meter per day ($m^2/d$) |
| gallon per minute (gal/min) | 0.000063 | cubic meter per second ($m^3/s$) |
| gallon per minute per foot [(gal/min)/ft] | 0.000207 | cubic meter per second per meter [($m^3$/s)/m] |
| million gallons per day (Mgal/d) | 0.04381 | cubic meters per second ($m^3/s$) |

## LIST OF SYMBOLS

| Symbol | Dimensions | Description |
|---|---|---|
| $H(u, \beta)$ | ---------- | $H$ function of $u$, $\beta$ |
| $K$ | $L\ T^{-1}$ | Hydraulic conductivity of main aquifer |
| $K'$, $K''$ | $L\ T^{-1}$ | Vertical hydraulic conductivity of semipervious confining layers |
| $K_r$ | $L\ T^{-1}$ | Horizontal hydraulic conductivity |
| $L(u, \nu)$ | ---------- | $L$ (leakance) function of $u$, $\nu$ |
| $Q$ | $L^3 T^{-1}$ | Pumping rate |
| $S$ | ---------- | Storage coefficient |
| $S_s$ | ---------- | Specific storage of main aquifer |
| $S_s'$, $S_s''$ | ---------- | Specific storage of the confining layers |
| $T$ | $L^2\ T^{-1}$ | Transmissivity |
| $W(u)$ | ---------- | $W$ (well) function of $u$ |
| $b$ | L | Thickness of aquifer |
| $b'$ | L | Thickness of confining layer |
| $r$ | L | Radial distance from pumping well |
| $s$ | L | Drawdown |
| $t$ | T | Time since pumping began or stopped |
| $u$ | ---------- | $r^2\ S/4Tt$ |
| $\nu$ | ---------- | $r/2\ \frac{K'}{b'\ T}$ |
| $\beta$ | ---------- | $r/4b\ \frac{K'\ S_s'}{K\ S_s} + \frac{K''\ S_s''}{K\ S_s}$ |
| $\pi$ | ---------- | 3.1416 |
| $\psi$ | ---------- | $r/b$ |

## DEFINITION OF TERMS

The terms used in this report are defined as follows:

ANISOTROPY: Anisotropy is that condition in which all significant properties vary with direction.

AQUIFER: A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells or springs.

AQUIFER TEST: A controlled field experiment wherein the effect of pumping a well is measured in the pumped well and in observation wells for the purpose of determining hydraulic properties of an aquifer.

BEDROCK: The solid rock, commonly called "ledge", that forms the earth's crust.

CONFINED AQUIFER (ARTESIAN AQUIFER): An aquifer in which ground water is under pressure that is significantly greater than atmospheric. The water level in a well in a confined aquifer usually rises above the top of the aquifer.

DRAWDOWN: The decline of the water level in a well after pumping starts. It is the difference between the water level in a well after pumping starts and the water level as it would have been if pumping had not started.

GRAVEL PACK: A lining, or envelope of gravel placed around the outside of a well screen to increase well efficiency and yield.

GROUND-WATER RESERVOIR: Parts of the stratified-drift aquifer where water accumulates under conditions that make it suitable for development and use.

HETEROGENEITY: Heterogeneity is synonymous with nonuniformity. A material is heterogeneous if its hydrologic properties vary with position within it.

HYDRAULIC CONDUCTIVITY: The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Expressed herein in feet per day.

ISOTROPY: Isotropy is that condition in which all significant properties are independent of direction.

LITHOLOGIC LOG: Description of geologic material collected during sampling of test wells.

NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

NONSTEADY FLOW: Nonsteady flow occurs when at any point the magnitude or direction of the specific discharge changes with time.

RECOVERY: The rise of the water level in a well after pumping has stopped. It is the difference between the water level in a well after pumping stops and the water level as it would have been if pumping had continued at the same rate.

REFUSAL: A drilling term indicating the depth of a drill hole at which further penetration is impossible or impractical with the equipment being used.

SATURATED THICKNESS: The thickness of an aquifer below the water table. As measured for the stratified-drift aquifer in this report, it is the vertical distance between the water table and the bedrock surface. In places it may include till present between the stratified drift and the bedrock surface.

SPECIFIC CAPACITY: The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level within the well.

SPECIFIC DISCHARGE: The specific discharge for ground water is the rate of discharge of ground water per unit area measured at right angles to the direction of flow.

SPECIFIC YIELD: Ratio of the volume of water a fully saturated rock or unconsolidated material will yield by gravity drainage, given sufficient time, to the total volume of rock or unconsolidated material.

STEADY FLOW: Steady flow occurs if at every point the specific discharge has the same magnitude and direction.

STEP-DRAWDOWN TEST: A test of a pumped well in which drawdown is measured at different pumping rates for the purpose of determining head loss in the well caused by the turbulent flow of water through the well screen and inside the casing to the pump intake. Also commonly referred to as a well-efficiency test.

STORAGE COEFFICIENT: Volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer the storage coefficient is virtually equal to the specific yield.

STRATIFIED DRIFT: Unconsolidated sediment that has been sorted by glacial meltwater and deposited in layers, or strata.

TILL: A geologic term for a glacial deposit of predominantly unsorted, unstratified material ranging in size from boulders to clay. It is commonly so compact that it is difficult to penetrate with light drilling equipment.

TRANSMISSIVITY: Rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. It is equal to the product of hydraulic conductivity and saturated thickness. Expressed herein in square feet per day.

UNCONFINED AQUIFER (WATER-TABLE AQUIFER): An aquifer in which the upper surface of the saturated zone, the water table, is at atmospheric pressure and is free to rise and fall.

WATER TABLE: The upper surface of the saturated zone.

# AQUIFER TESTS IN THE STRATIFIED DRIFT, CHIPUXET RIVER BASIN, RHODE ISLAND

By David C. Dickerman


## ABSTRACT

*Analyses of 18 aquifer tests in the Chipuxet River basin in southern Rhode Island indicate that the stratified-drift aquifer is generally highly transmissive and would yield large quantities of water to properly constructed wells. The aquifer consists of complexly interbedded lenses of sand and gravel and subordinate amounts of silt and silty sand deposited by glacial streams in the Pleistocene Epoch. Ground water in the aquifer is under unconfined or water-table conditions. The tests were made in the thick, permeable parts of the stratified drift, which forms a major ground-water reservoir in the lower reaches of the Chipuxet River basin.*

*The hydraulic properties of the aquifer were determined by analyzing drawdown and recovery data by a combination of analytical methods. The analytical method most often used and whose inherent assumptions closely approximate actual field conditions was a method by R. W. Stallman intended for evaluating vertical movement in an unconfined, anisotropic aquifer. The transmissivity of the stratified-drift aquifer determined from the tests ranges from 5,000 to 39,100 $ft^2/d$ (square feet per day). The horizontal hydraulic conductivity ranges from 90 to 595 ft/d (feet per day) and the vertical hydraulic conductivity ranges from 3 to 52 ft/d. The ratio of vertical to horizontal hydraulic conductivity of the stratified-drift aquifer ranges from 1:5 to 1:80, and averages 1:10. The highest transmissivities were determined at the Wolf Rocks Trail site, at test well Exeter 402, where values computed by different analytical methods range from 37,400 to 39,100 $ft^2/d$ and horizontal hydraulic conductivity ranges from 435 to 455 ft/d.*

*Storage coefficients determined from 4 of 18 aquifer tests were comparative to specific yields typical of water-table aquifers. Direct measurement of specific yield probably will require a method other than aquifer-test analysis.*

*Transmissivities also were estimated from lithologic logs, and from specific-capacity data adjusted for well loss, effects of partial penetration, and (or) dewatering. Estimates of transmissivity from lithologic logs ranged from 4,800 to 37,600 $ft^2/d$ and estimates from specific-capacity data ranged from 4,700 to 28,600 $ft^2/d$. Estimates were used as an additional means of checking the reasonableness of values obtained by analysis of aquifer-test data. The hydraulic properties determined by analytical methods are judged to be the most reliable.*


## INTRODUCTION

### Background

In 1970, the Rhode Island Water Resources Board began a program of test drilling and aquifer testing designed to identify the most favorable sites for developing water from the principal ground-water reservoirs of the Pawcatuck River basin in southern Rhode Island. The U.S. Geological Survey, as part of its cooperative program with the Rhode Island Water Resources Board, is assisting in collecting geologic and hydrologic data and is responsible for preparing geohydrologic data reports and interpretive reports for each of five principal ground-water reservoirs.

Eighteen aquifer tests were made at 16 locations (fig. 1) in the stratified-drift aquifer. An aquifer test is a controlled field experiment made to determine the hydraulic properties of water-bearing rocks (Stallman, 1968, p. 1). The tests were made in the thick, permeable parts of the stratified drift, which forms a major ground-water reservoir in the lower reaches of the Chipuxet River basin and adjacent parts of the Chickasheen Brook basin. In this report, a ground-water reservoir is defined as that part of the stratified-drift aquifer where water accumulates under conditions that make it suitable for development and use. To best evaluate the stream-aquifer system, a mathematical model is indicated. In order to make a realistic model, reliable values of hydraulic properties are necessary.

## Purpose and Scope

The purpose of this study was to evaluate aquifer-test data to determine hydraulic properties of transmissivity, horizontal and vertical hydraulic conductivity, and storage coefficient for stratified drift in the Chipuxet River basin. Data evaluated in this report are from tests made between 1948 and 1976 in the stratified-drift aquifer in the Chipuxet River basin.

This report describes the methods and procedures used to determine aquifer hydraulic properties. The report presents the results of estimates and analytical determinations in tabular form, with detailed explanations of each aquifer-test site given in an appendix.

## Previous Studies

Most of the data on which this report is based are contained in geohydrologic data reports by Allen and others (1963), and Dickerman (1976). Results of earlier analyses of aquifer-test data from pumping wells EXW (Exeter well) 402, SNW (South Kingstown well) 888, 905, 907, and 1040 were published in an interpretive report on the upper Pawcatuck River basin (Allen and others, 1966, p. 13). Values shown in the present report are in reasonable agreement with earlier published results.

# DESCRIPTION OF STUDY AREA

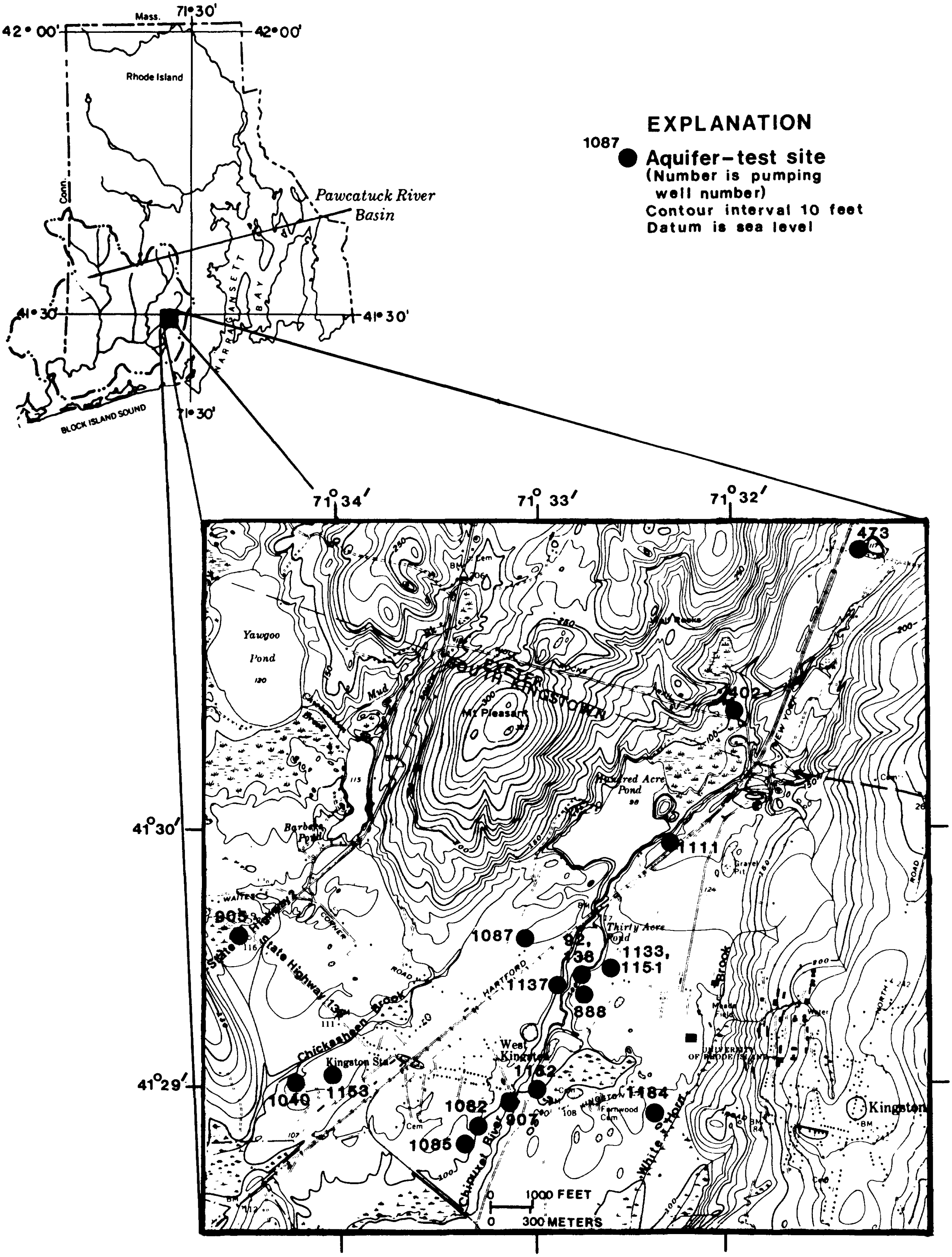
## Location

The study area is in Washington County in southern Rhode Island and includes test sites in parts of the towns of Exeter and South Kingstown. Figure 1 shows the location of the study area within the Pawcatuck River basin and the location of aquifer-test sites within the Chipuxet River ground-water reservoir. The Chipuxet River ground-water reservoir occupies an area of approximately 3 $mi^2$ in the valleys drained by the Chipuxet River and Chickasheen Brook. Most aquifer-test sites were located 200 to 500 feet from a stream within the valley floor, a low flat area between the upland ridges of till and the stream channel.

## General hydrogeology

The Chipuxet River ground-water reservoir (Allen and others, 1966, p. 50) is an irregularly shaped body of aquifer material consisting of complexly interbedded lenses of sand and gravel and subordinate amounts of silt and silty sand deposited by glacial streams in the Pleistocene Epoch. Locations of generalized geologic sections of the Chipuxet River valley are shown in figure 2. The longitudinal geologic section A-A' (fig. 3) illustrates the lithologic heterogeneity of this aquifer system. The aquifer is hydraulically anisotropic because the vertical hydraulic conductivity differs from the horizontal hydraulic conductivity. The anisotropy is due in part to the interbedding of coarser and finer materials and in part to the orientation of the plate-shaped grains. This causes the hydraulic conductivity of the aquifer to be lower in the vertical direction.

Depth to the water table at test sites ranged from 1 foot to as much as 28 feet below land surface. The saturated thickness of the stratified-drift aquifer ranges from a few feet near the bounding till ridges to about 210 feet at the Liberty Lane site.




**Based from U.S. Geological Survey**
**1:24,000 Kingston, 1957; and Slocum, 1955**

Figure 1.--Location of aquifer-test sites in the Chipuxet River ground-water reservoir, Washington County, Rhode Island.

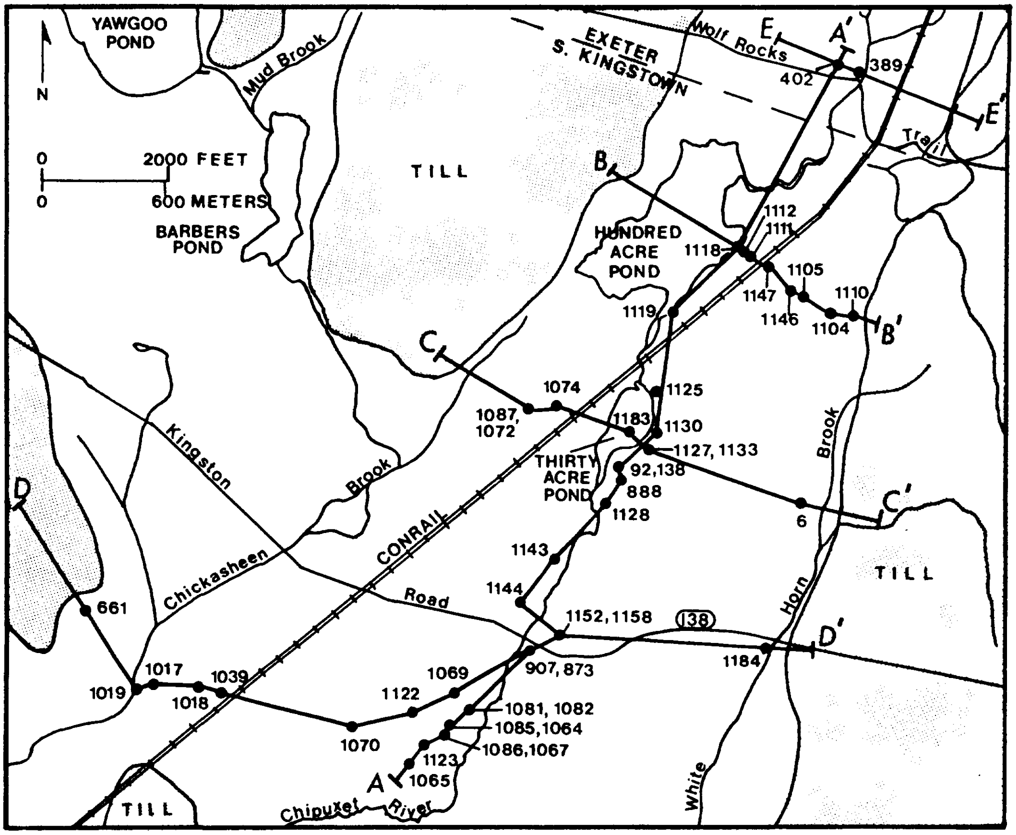



Figure 2.--Locations of five generalized geologic sections of the Chipuxet River valley (See figures 3, 4, 8, 11, and 15 for geologic sections).

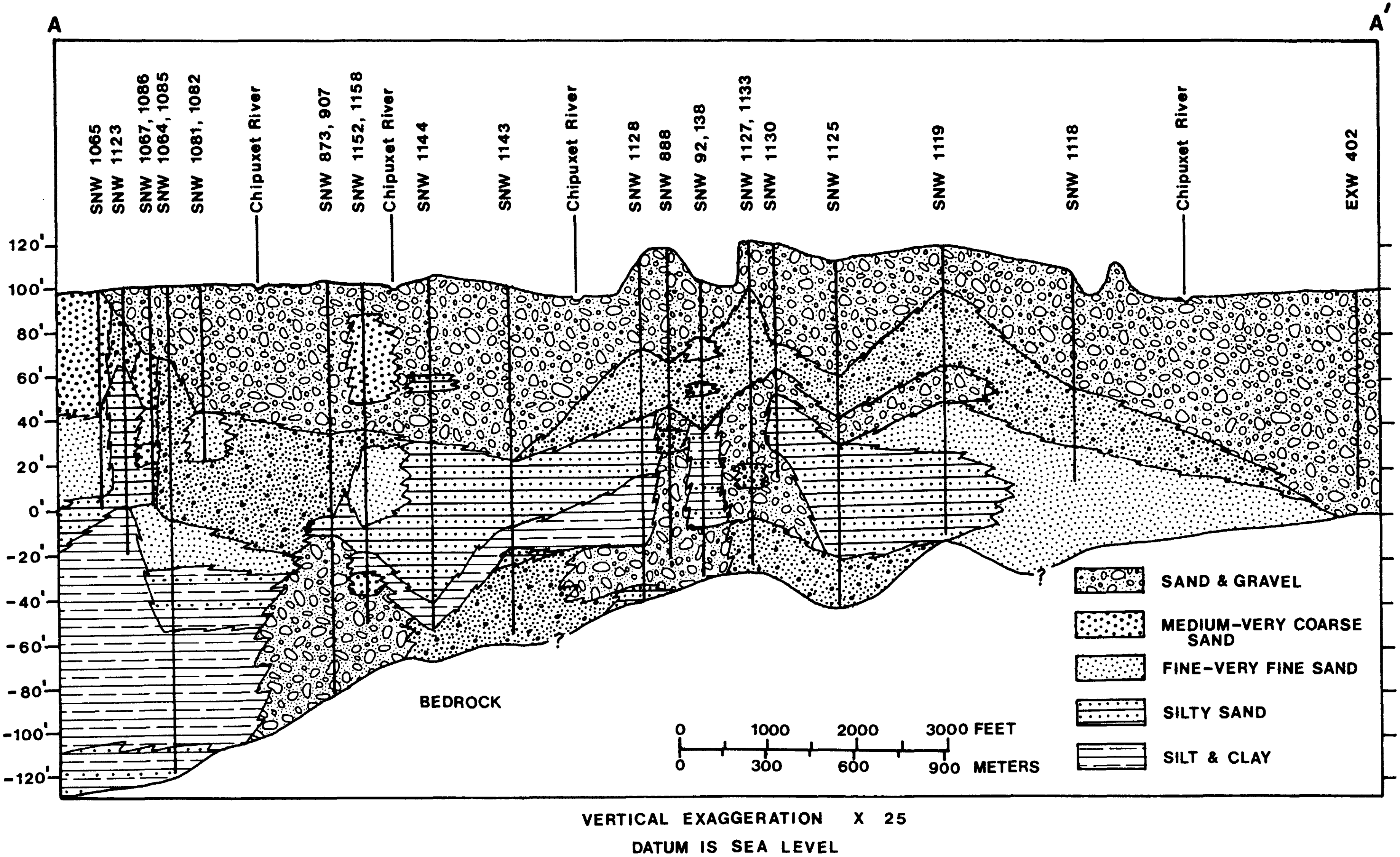



Figure 3.--Longitudinal geologic section (A - A') of the Chipuxet River valley showing the lithologic heterogeneity of the complexly interbedded aquifer system. (See figure 2 for line of section.)

## DESCRIPTION OF TEST SITES

Table 1 summarizes well construction and pump-test data for 18 pumping wells tested in the Chipuxet River stratified-drift aquifer. General locations for each test site are shown in figure 1. For more detailed information, see individual site explanations in the appendix at the back of this report. Detailed information consists of individual location maps showing pumping wells and observation wells, generalized geologic sections, descriptions of site lithology, well development procedures, methods of analysis, and results of analysis.

Table 1.—Well construction and pump-test data for pumping wells tested in the Chipuxet River stratified-drift aquifer

| Pumping well[1] | Diameter[2] (inches) | Screened interval[3,4] (feet) | Static water level[4] (feet) | Date of aquifer test | Length of test (hours) | Pumping rate (gallons per minute) | Draw-down (feet) | Specific capacity (gallons per minute per foot) |
|---|---|---|---|---|---|---|---|---|
| | | | | TOWN OF EXETER | | | | |
| 402 | 8 | 17-87 | 1.04 | 01-06-60 | 24 | 610 | 7.36 | 83 |
| 473 | 24X18 | 74-84 | 15.00 | 03-06-67 | 24 | 460 | 43.96 | 10 |
| | | | | TOWN OF SOUTH KINGSTOWN | | | | |
| 92 | 18X12 | 111-131 | 8.88 | 03- -49 | 20 | 800 | 9.00 | 89 |
| 138 | 18X12 | 50-70 | 9.80 | 05- -48 | 4 | 235 | 39.54 | 6 |
| 888 | 18X12 | 113-138 | 21.30 | 05- -58 | 72 | 800 | 6.00 | 133 |
| 905 | 8 | 13-37 | 4.08 | 12-07-59 | 24 | 290 | 13.26 | 22 |
| | 8 | 55-76 | | | | | | |
| 907 | 8 | 10-62 | 6.76 | 01-27-60 | 24 | 395 | 11.74 | 34 |
| | 8 | 124-176 | | | | | | |
| 1040 | 24X18 | 45-65 | 5.00 | 10-26-60 | 45.5 | 725 | 26.00 | 28 |
| 1082 | 8 | 40-70 | 5.50 | 01-25-71 | 124 | 550 | 26.50 | 21 |
| 1085 | 8 | 65-90 | 3.38 | 10-08-70 | 24 | 610 | 35.00 | 17 |
| 1087 | 8 | 60-85 | 21.83 | 11-30-70 | 100 | 290 | 26.00 | 11 |
| 1111 | 8 | 53-60 | 28.00 | 12-11-73 | 40 | 360 | — | — |
| 1133 | 8 | 80-95 | 24.26 | 05-20-74 | 96 | 650 | 26.94 | 24 |
| 1137 | 8 | 42-55 | 4.75 | 06-10-74 | 48 | 100 | 21.90 | 5 |
| 1151 | 24X18 | 75-95 | 25.10 | 10-21-74 | 48 | 910 | 7.45 | 122 |
| 1152 | 18X12 | 48-63 | 10.00 | 03-18-65 | 66 | 515 | 33.00 | 16 |
| 1153 | 8 | 52-62 | 8.50 | 05-07-74 | 24 | 300 | 32.50 | 9 |
| 1184 | 12X8 | 48-58 | 11.50 | 11-09-76 | 9 | 205 | 20.67 | 10 |

[1] Local well number based on the town in which it is located.
[2] The smaller number or single number is the diameter of the well casing and screen, and the larger number is the diameter of the drilled hole. The space between the drilled hole and screen is filled with a highly permeable material, the gravel pack.
[3] Bottom of screened interval is well depth.
[4] Feet below land-surface datum.

## METHODS OF STUDY

### Analysis of Drawdown and Recovery Data

Hydraulic properties of transmissivity, hydraulic conductivity, and storage coefficient were determined by analyses of unadjusted drawdown and recovery data by one or more of the following methods: (1) Stallman (1963, 1965) method for vertical movement in an unconfined, anisotropic aquifer, (2) Boulton (1954) method for vertical movement in an unconfined, isotropic aquifer, (3) Hantush (1960) modified method for a leaky confined aquifer, (4) Cooper (1963) method for nonsteady radial flow in a leaky confined aquifer, (5) Jacob (1946b) method for steady state leaky confined aquifer conditions, (6) Cooper and Jacob (1946) method for graphical solution to the modified nonleaky confined formula, and (7) the Theis (1935) nonequilibrium formula for a nonleaky confined aquifer. Methods 1-4 are described in Lohman (1979, p. 31-40), and methods 5-7 are described in Walton (1962, p. 5-6, 9). The flow equations are presented in the first individual site section in which they appear. Symbols used in equations are explained in the "List of Symbols."

A short discussion on curve-matching is necessary to aid the reader in understanding figures showing match points and results of analytical solutions to flow equations. The log-log curve-matching technique requires selecting a match point by matching field data to a type curve. A type curve is a dimensionless theoretical response curve determined from a plot of a well function versus $1/u$ on log-log paper. Field values of $s$ (drawdown) versus $t$ (time) or $t/r^2$ (time/distance from observation well to pumping well squared) are plotted on log-log paper of the same size and scale as the type curve. The field curve is superimposed on the type curve with the axes of the papers held parallel, and the curves are adjusted to a best fit of the data to the type curve. An example of the curve-matching technique is shown in figure 6 in the Wolf Rocks Trail section of this report. The best fit is determined when most of the field data points fall on the type curve. For ease of calculation, the match point is commonly taken where the well function is equal to 1.0. For further information on curve-matching, the reader is referred to Lohman (1979, p. 15-18).

### Estimation of Transmissivity

#### Use of Lithologic Logs

The product of the hydraulic conductivity and saturated thickness of a layer of aquifer material is a measure of its transmissivity. By assigning values of hydraulic conductivity to layers of known thickness described in lithologic logs (Dickerman, 1976, table 2), transmissivities of individual layers can be summed to estimate aquifer transmissivity at well sites.

In the adjacent Potowomut-Wickford area, Rosenshein and others (1968) determined hydraulic conductivity for materials by multiple-regression analysis. Transmissivity was determined at a well site from aquifer-test data and related to lithology. Values of hydraulic conductivity for materials shown in table 2 were modified after Rosenshein and others (1968) and used to estimate transmissivity from lithologic logs at each pumping well shown in table 6. An example of the method of estimating transmissivity from a lithologic log of a well is shown in table 3. Assignment of hydraulic conductivity involves considerable judgment; but, with experience, hydraulic conductivity and transmissivity can be estimated with fair to good accuracy.

Transmissivity estimated from lithologic logs of pumping wells, shown in table 6, was based on the aquifer thickness between the water table and the bottom of the well screen. Most transmissivities estimated from lithologic logs in this manner are in reasonable agreement with those determined by analytical methods. At 7 of 14 sites, where transmissivity was determined from both lithologic logs and analysis of aquifer-test data, values determined from logs were smaller than those determined from aquifer tests (table 6). Where transmissivity determined by aquifer test analysis is considerably higher than that estimated from the lithology at the pumping well, the thickness of stratified drift between the bottom of the well screen and the bedrock surface is generally substantial. At these sites, the lower part of the stratified drift was not penetrated by the pumping well because earlier 2-1/2-inch exploratory test wells showed either fine grained material or poor water quality at depth.

Table 2.—Values of hydraulic conductivity used to estimate transmissivity from lithologic logs in the Chipuxet River ground-water reservoir

(Modified from Rosenshein and others, 1968)

| Material | Hydraulic conductivity (feet per day) |
|---|---|
| Gravel | 470 |
| Sand and gravel | 200 |
| Very coarse sand | 160 |
| Coarse sand | 135 |
| Medium sand | 105 |
| Fine sand | 55 |
| Very fine sand | 20 |
| Silt | [1]4 |
| Clay, till (hardpan) | [1]0.1 |

[1] Hydraulic conductivity used for silt and clay, till, or hardpan is based on values published in Allen and others (1963, p. 8-10). Values were determined by laboratory analysis of samples at the U.S. Geological Survey Hydrologic Laboratory.

Table 3.—Log of pumping well South Kingstown 1040 showing an example of the method for estimating transmissivity from lithology

| Material | Saturated thickness (feet) | x | Hydraulic conductivity (feet per day) | = | Estimated transmissivity (square feet per day) |
|---|---|---|---|---|---|
| Sand, medium | 5 | | 105 | | 525 |
| Sand and gravel | 25 | | 200 | | 5,000 |
| Sand, medium | 5 | | 105 | | 525 |
| Sand, coarse | 20 | | 135 | | 2,700 |
| Sand, fine | 5 | | 55 | | 275 |
| | 60 | | | | 9,025 |

Transmissivity (rounded) = 9,000 $ft^2/d$

$$\text{Average hydraulic conductivity} = \frac{\text{transmissivity}}{\text{saturated thickness}} = \frac{9{,}000\ ft^2/d}{60\ feet} = 150\ ft/d$$

The three wells shown below all tap coarse sand to boulder gravel material at the same site (figs. 10a and 10b). Wells SNW 1127 and SNW 1133 are test wells, and SNW 1151 is a gravel-packed supply well. Transmissivities estimated from lithologic logs are shown in table 4 to illustrate the range in values determined for various well diameters by different sampling methods. Hydraulic conductivities used in estimating transmissivities for each sampling method were assigned by the same person. The purpose of this comparison is to show that estimates of transmissivity, based entirely on lithologic logs of 2-1/2-inch wells, may be several times too low. Estimated transmissivities in table 4 show an apparent increase as well diameter increases, because, as well diameter increases, the size of the sample increases, allowing the coarser gravel material to be sampled. Agreement between estimated transmissivities determined from test wells having different diameters will probably be much closer in granule gravel or finer materials.

Table 4.—Comparison of variation of transmissivities estimated from lithologic logs of wells located at the same site

| Well No. | Well diameter[1] (inches) | Sampling method | Transmissivity (square feet per day) |
|---|---|---|---|
| SNW 1127 | 2-1/2 | Drive-wash | 5,900 |
| SNW 1133 | 8 | Bailer | 11,600 |
| SNW 1151 | 24X18 | Bailer | 16,900 |

[1]The smaller number or single number is the diameter of the well casing and screen; the larger number is the diameter of the drilled hole. The space between the drilled hole and screen is filled with a highly permeable material, the gravel pack.

## Use of Specific-Capacity Data

The productivity of a well is commonly expressed in terms of specific capacity, $C_s$, which is defined as $C_s = Q/\Delta h_w$, where $Q$ is the rate of discharge of water from the well and $\Delta h_w$ is the drawdown of water level within the well. Specific-capacity tests are made primarily to determine the yield per foot of drawdown of a well, but the data may also be used to estimate transmissivity roughly. Specific capacity is commonly affected by well loss, partial penetration, dewatering, and hydrogeologic boundaries. Generally these factors adversely affect specific capacity, and the true transmissivity is greater than that estimated from specific-capacity data (Walton, 1970, p. 314). Nevertheless, specific-capacity data were used to estimate transmissivity at aquifer-test sites as an additional means of checking the reasonableness of values obtained by analysis of aquifer-test data (table 6). Transmissivities were computed from specific capacities by the Theis (1935) nonequilibrium equation. Most transmissivities estimated from specific capacity were computed by drawdown adjusted for one or more of the following: well loss (Jacob, 1946a), partial penetration (Butler, 1957), and dewatering (Jacob, 1944). These adjustments are described in Walton (1962, p. 7-8, 27). Drawdowns were not adjusted for hydrogeologic boundaries. A vertical to horizontal hydraulic conductivity ratio of 1:1 was used to make a minimum adjustment when correcting drawdown for partial penetration. Transmissivities at three sites were computed from unadjusted drawdown. Test data and transmissivities estimated from specific capacity at 16 screened wells are given in table 6, and well locations are shown in figure 1. Transmissivities estimated from adjusted specific capacity were lower in 11 of 13 sites than transmissivities determined by analytical method. Estimates of transmissivity would have been higher if drawdowns in more pumping wells could have been adjusted for well loss.

## Pumping-Test Procedures

In each of the tests, large-diameter (8- to 24-inch) wells were pumped at constant rates that ranged from 100 to 910 gal/min for 4 to 124 hours. Step-drawdown tests were made at several sites to determine the efficiency of the pumped well. Several of these tests indicated that some pumped wells were only partly developed. The fact that a well is partially developed does not affect the analysis or results of hydraulic properties determined from drawdown or recovery data in observation wells. The assumptions inherent in each analytical solution used to determine transmissivity, hydraulic conductivity, and storage coefficient are summarized in table 5. Despite the restrictive assumptions on which the equations for each analytical method are based, the equations have been applied successfully to many problems of ground-water flow. For detailed pumping-test procedures at individual sites, see the appendix at the back of this report.

Table 5.—Assumptions on which equations used to analyze aquifer-test data in the Chipuxet River area are based (x, condition treated in this report)

| Assumption | Stallman (1963, 1965) | Boulton (1954) | Hantush (1960) | Cooper (1963) | Jacob (1946b) | Cooper and Jacob (1946) | Theis (1935) |
|---|---|---|---|---|---|---|---|
| A. Control-well characteristics: | | | | | | | |
| Full penetration | x | x | x | x | x | x | x |
| Partial penetration | x | — | — | — | — | — | — |
| Diameter infinitesimal | — | x | x | x | x | x | x |
| Diameter finite | x | — | — | — | — | — | — |
| B. Conductivity and flow conditions: | | | | | | | |
| Homogeneous, isotropic | x | x | x | x | x | x | x |
| Homogeneous, anisotropic | x | — | — | — | — | — | — |
| Areally infinite | x | x | x | x | x | x | x |
| Dewatering negligible | x | x | x | x | x | x | x |
| Flow radial | — | x | x | x | x | x | x |
| Flow radial and vertical | x | — | — | — | — | — | — |
| Nonsteady flow | x | x | x | x | — | x | x |
| Steady flow | — | — | — | — | x | — | — |
| Horizontal flow in aquifer | x | x | x | x | x | x | x |
| Vertical flow through confining bed | — | — | x | x | x | — | — |
| C. Storage relation: | | | | | | | |
| Water released from storage instantaneously | x | x | x | x | x | x | x |
| Storage in confining bed neglected | — | — | — | x | x | — | — |
| Storage in confining bed significant | — | — | x | — | — | — | — |
| Confined (artesian) | — | — | x | x | x | x | x |
| Leaky confined | — | — | x | x | x | — | — |
| Unconfined (water table) | x | x | — | — | — | — | — |

## RESULTS OF STUDY

Results of the aquifer-test analysis summarizing hydraulic properties of the Chipuxet River stratified-drift aquifer are given in table 6. Transmissivity ranges from 5,000 to 39,100 $ft^2/d$, horizontal conductivity ranges from 90 to 595 ft/d, and vertical hydraulic conductivity ranges from 3 to 52 ft/d. Estimates of aquifer transmissivity also were made from lithologic logs and specific-capacity data. The hydraulic properties determined by analytical methods are judged to be the most reliable. The average values of transmissivity and hydraulic conductivity shown in table 6 are probably higher than those for much of the stratified drift in the Chipuxet River basin. This is because many of the existing municipal and industrial well fields and most aquifer-test sites were located in choice areas selected in many cases after extensive 2-1/2-inch exploratory test drilling. Therefore, the test results and reported well yields in this report are indicative of what may be expected from properly constructed wells tapping the stratified drift in the more productive parts of the Chipuxet River ground-water reservoir.

The storage coefficient in an unconfined water-table aquifer is virtually equal to the specific yield (Lohman and others, 1972, p. 13). In water-table aquifers, the storage coefficient or specific yield may range from about 0.05 to 0.30 (Ferris and others, 1962, p. 78). There are no known areally extensive layers of relatively impervious sediment in the stratified-drift aquifer to suggest confined conditions at any of the sites tested. The specific yield of the stratified-drift aquifer has been determined by laboratory analysis of sediment samples and by aquifer-test analysis. Results of specific yield determined by laboratory analyses of sediment samples from the stratified-drift aquifer in the upper Pawcatuck River basin (Allen and others, 1963, tables 1 and 12) are given in table 7. Because laboratory determinations of specific yield from disturbed samples are likely to be larger than those obtained by field methods (Lohman, 1979, p. 54), values given in table 7 may be somewhat high. However, it is probably reasonable to assume that the average specific yield of the stratified-drift aquifer, which consists chiefly of sand and gravel, is about 0.2.

Results of storage coefficients determined by aquifer tests are shown in table 6. Storage coefficients shown in table 6 smaller than 0.11 were determined from early time-drawdown data and are not indicative of the true storage coefficient. Storage coefficients in table 6 greater than 0.11 probably approach specific yields typical of the stratified-drift aquifer. Storage coefficients determined from 4 of 18 aquifer tests, SNW 1082 and 1085 at the Liberty Lane site, SNW 1087 at the Fairgrounds site, and SNW 1111 at the Hundred Acre Pond site, were comparative to specific yields typical of water-table aquifers. An average specific yield of 0.09 was determined from SNW 1085 after pumping 24 hours. However, the average specific yield increased to 0.14 after pumping 124 hours from nearby SNW 1082. As indicated, aquifer tests of longer duration might give truer values of specific yield, but the additional cost may not be justified. Williams and Lohman (1949, p. 213, 220) state that the true value of specific yield is obtained only after the saturated material has been drained for a long time. They conclude that, even for sand-size materials, 2 months to more than 1 year would be required for the drainage to reach equilibrium and, thus, give the maximum specific yield. To obtain direct measurements of specific yield would probably require a longer period of observation than the relatively short time period of most aquifer tests. One such possibility would be to observe the difference between the moisture content of saturated material and the moisture content of the same material after it has been drained, by use of a neutron-moisture probe (Meyer, 1962, p. E174).

Table 6. Summary of hydraulic properties determined from aquifer tests for the stratified-drift aquifer in the Chipuxet River basin

| Pumping well[1] | Transmissivity estimated from: Lithologic log (square feet per day) | Transmissivity estimated from: Adjusted specific capacity[2] (square feet per day) | Observation well: Number[1,3] | Observation well: Screened interval (feet) | Hydraulic properties determined by analytical methods: Method[4] | Transmissivity (square feet per day) | Hydraulic conductivity: Horizontal[5] (feet per day) | Hydraulic conductivity: Vertical (feet per day) | Storage coefficient[6] |
|---|---|---|---|---|---|---|---|---|---|
| | | | | TOWN OF EXETER | | | | | |
| 402 | 37,600 | 19,600 | 397 | 10-13 | a | 37,400 | 435 | -- | -- |
| | | | 397 | 10-13 | b | 39,100 | 455 | -- | -- |
| | | | | | Site average----- | 38,200 | 445 | -- | -- |
| 473 | 6,800 | 5,400 | 474 | (7) | c | 7,700 | 110 | -- | -- |
| | | | | TOWN OF SOUTH KINGSTOWN | | | | | |
| 92 | 20,000 | 17,000 | -- | -- | -- | -- | 150 | -- | -- |
| 138 | 9,400 | -- | -- | -- | -- | -- | -- | -- | -- |
| 888 | 27,000 | 28,600 | -- | -- | -- | -- | -- | -- | -- |
| 905 | 8,300 | 6,800 | 900 | [8]10 | b | 6,600 | 90 | -- | -- |
| 907 | 33,700 | 10,700 | -- | -- | c | 28,700 | 170 | -- | -- |
| 1040 | 9,000 | 13,800 | 1026, 1037 | 42-60, 54-64 | d | 14,000 | 235 | -- | 0.02 |
| 1082 | 12,600 | 9,000 | 1064, 1067 | 83-95, 67-77 | c | | | | |
| | | | 1068, 1069 | 74-84, 21-31 | | 9,000 | 140 | -- | .11 |
| | | | 1068 | 74-84 | a | 7,700 | 120 | -- | .13 |
| | | | 1068 | 74-84 | b | 8,100 | 125 | 8 | .16 |
| | | | 1069 | 21-31 | b | 9,500 | 145 | 27 | .17 |
| | | | | | Site average----- | 8,800 | 135 | 18 | 0.14 |
| 1085 | 15,500 | 10,900 | 1064 | 83-95 | b | 13,700 | 160 | -- | -- |
| | | | 1067 | 67-77 | b | 17,000 | 200 | 24 | .08 |
| | | | 1068 | 74-84 | b | 14,700 | 170 | 13 | .11 |
| | | | 1069 | 21-31 | b | 13,800 | 160 | 11 | .07 |
| | | | | | Site average----- | 14,800 | 170 | 16 | 0.09 |
| 1087 | 12,000 | 8,400 | 1072, 1074 | 80-92, 73-85 | c | 8,900 | 140 | -- | .13 |
| 1111 | 8,100 | 20,000 | 1114, 1116 | 45-50, 55-61 | c | 19,000 | 595 | -- | .27 |
| 1133 | 11,600 | -- | 92, 1131 | 111-131, 120-125, | f | | | | |
| | | | 1128, 1130 | 144-157, 100-104 | | 27,000 | 387 | -- | -- |
| | | | 1130 | 100-104 | e | 19,200 | 240 | 3 | -- |
| | | | 92, 1128 | 111-131, 144-157, | e | | | | |
| | | | 1130, 1131 | 100-104, 120-125 | | 24,900 | 355 | 6 | -- |
| | | | 92, 1128 | 111-131, 144-157 | c | | | | |
| | | | 1130, 1131 | 100-104, 120-125 | | 27,000 | 385 | -- | .06 |
| | | | | | Site average----- | 26,300 | 375 | 6 | 0.06 |
| 1137 | 10,000 | 6,200 | 1138 | 47-53 | g | 5,000 | 100 | -- | .004 |
| | | | 1139 | 43-48 | g | 7,700 | 150 | -- | .005 |
| | | | | | Site average----- | 6,400 | 125 | -- | 0.004 |
| 1151 | 16,900 | 26,700 | 92, 888 | 111-131, 113-138 | c | | | | |
| | | | 1128 | 114-157 | | 28,600 | 410 | -- | .03 |
| | | | 92, 888 | 111-131, 113-138 | f | | | | |
| | | | 1128 | 114-157 | | 25,800 | 370 | -- | -- |
| | | | | | Site average----- | 27,200 | 390 | -- | 0.03 |
| 1152 | 6,200 | 6,600 | 1161 | [8]60 | b | 21,000 | 400 | 48 | .03 |
| | | | 1162 | [8]60 | b | 21,000 | 400 | 52 | .10 |
| | | | 1162 | [8]60 | c | 21,600 | 400 | -- | .04 |
| | | | | | Site average----- | 21,200 | 400 | 50 | 0.06 |
| 1153 | 13,400 | 6,000 | -- | -- | -- | -- | 250 | -- | -- |
| 1184 | 4,800 | 4,700 | 1188 | (7) | c | 6,900 | 145 | -- | .009 |

1 Local well number based on town in which it is located.

2 Drawdown in Exeter well 473 and South Kingstown wells 905, 907, 1082, 1085, 1087, 1152, 1153, and 1184 was adjusted for the effects of partial penetration and dewatering. Drawdown in Exeter well 402 was adjusted only for dewatering; drawdown in South Kingstown wells 1040, 1111, and 1137 was adjusted for well loss, partial penetration and dewatering; and drawdown in South Kingstown wells 92, 888, and 1151 were unadjusted.

3 Well or wells used in analysis.

4 (a) Delayed yield (Boulton, 1954), described in Lohman (1979, p. 34-40); (b) vertical movement (Stallman, 1963, 1965), described in Lohman (1979, p. 34-40); (c) modified nonleaky confined (Cooper and Jacob, 1946), described in Walton (1962, p. 9); (d) nonsteady flow leaky confined (Hantush, 1960), described in Lohman (1979, p. 32-34); (e) nonsteady radial flow leaky confined (Cooper, 1963), described in Lohman (1979, p. 31-32); (f) steady state leaky confined (Jacob, 1946b), described in Walton (1962, p. 5-6); (g) non-equilibrium formula (Theis, 1935), described in Walton (1962, p. 6).

5 Determined by dividing transmissivity by distance from static water level to bottom of screen in pumped well.

6 Values smaller than 0.11 were determined from drawdown data within the first few minutes of the start of pumping. They are not indicative of the true storage coefficient of the aquifer. Values greater than 0.11 are believed to approach the true storage coefficient (specific yield) of the stratified-drift aquifer in the Chipuxet River basin.

7 Screened interval unknown.

8 Well finish, open end.

Table 7.—Laboratory determinations of specific yield of sediment samples from the upper Pawcatuck River basin (from Allen and others, 1963)

| Material | Number of samples | Specific yield | | |
|---|---|---|---|---|
| | | Low | Average | High |
| Stratified drift | | | | |
| Gravel | 1 | — | 0.279 | — |
| Sand and gravel | 3 | 0.204 | .227 | 0.251 |
| Sand, medium to coarse | 15 | .125 | .269 | .392 |
| Sand, fine to very fine | 10 | .163 | .292 | .413 |
| Sand, silty | 2 | .125 | — | .257 |
| Silt | 1 | — | .257 | — |
| Silt, organic (swamp deposit) | 1 | — | .393 | — |
| Till | 6 | .038 | .111 | .215 |

## SUMMARY AND CONCLUSIONS

Transmissivities, horizontal hydraulic conductivities and vertical hydraulic conductivities were determined by analyses of data from 18 tests in the Chipuxet River stratified-drift aquifer. Results of analysis indicate that the aquifer is generally highly transmissive and would yield large quantities of water to properly constructed wells. The hydraulic properties of the aquifer judged to the the most reliable were determined by analytical methods. A method by R. W. Stallman intended for evaluating vertical movement in an unconfined, anisotropic aquifer, described in Lohman (1979, p. 34-40), was the analytical method most commonly used, and whose inherent assumptions closely approximate actual field conditions. The range in values for hydraulic properties were obtained from the thickest and more highly transmissive parts of the stratified-drift aquifer, and are not necessarily representative of the range to be expected throughout the aquifer.

Large diameter (8- to 24-inch) wells were pumped at constant rates that ranged from 100 to 910 gal/min for 4 to 124 hours. Analyses of drawdown and recovery data indicate that the transmissivity of the thicker, more transmissive parts of the aquifer ranges from 5,000 to 39,100 $ft^2/d$. The horizontal hydraulic conductivity ranges from 90 to 595 ft/d and the vertical hydraulic conductivity ranges from 3 to 52 ft/d. The aquifer is anisotropic because the vertical and horizontal hydraulic conductivity differ. The vertical hydraulic conductivity of the aquifer indicates that water can move readily from streams to wells under pumping conditions. The ratio of vertical to horizontal hydraulic conductivity ranges from 1:5 to 1:80, and averages 1:10.

The highest transmissivities and horizontal hydraulic conductivities were determined at the Wolf Rocks Trail site. Here, transmissivities obtained range from 37,400 to 39,100 $ft^2/d$ and horizontal hydraulic conductivities obtained range from 435 to 455 ft/d. However, the southeast corner of Thirty Acre Pond constitutes the most favorable known withdrawal site in the Chipuxet River ground-water reservoir. Here, transmissivities obtained range from 19,200 to 28,000 $ft^2/d$. Horizontal hydraulic conductivities range from 240 to 410 ft/d. Transmissivities obtained by multiple well analyses range from 24,900 to 28,600 $ft^2/d$.

The range in transmissivities determined by composite analyses from multiple wells is small in comparison to single well analyses. Transmissivity determined by composite analysis is believed to represent the average transmissivity of the aquifer at the Thirty Acre Pond test site. It is a combination of aquifer thickness, high transmissivity, and recharge available from infiltration of pond water that make this site favorable for development.

Analysis of aquifer-test data from single observation wells can give wide ranges for hydraulic properties. These hydraulic properties are representative of those parts of the aquifer body between the observation well and the pumping well. On the other hand, hydraulic properties determined by composite analyses from multiple observation wells, at varying distances and directions from the pumping well, are more representative of a larger part of the aquifer body encompassing the area between all observation wells and the pumping well.

Analyses of drawdown data from 4 of 18 aquifer tests gave storage coefficients that approached specific yields typical of water-table aquifers. Aquifer tests of longer duration might give more accurate and slightly greater values of specific yields, but the additional cost may not be justified. Other studies indicate that the true value of specific yield is obtained only after the saturated material has been drained for a long time. These studies also concluded that, even for sand-size materials, 2 months to more than 1 year would be required for the drainage to reach equilibrium and, thus, give the maximum specific yield. To obtain direct measurements of specific yield would probably require a longer period of observation than the relatively short time period of most aquifer tests. One such possibility would be to observe the difference between the moisture content of saturated material and the moisture content of the same material after it has been drained, by use of a neutron-moisture probe. Based on laboratory analysis of sediment samples in the upper Pawcatuck River basin, it is probably reasonable to assume that the average specific yield of the stratified-drift aquifer in the Chipuxet River ground-water reservoir is about 0.20.

In addition to transmissivities determined by analytical methods, transmissivities were estimated from lithology and adjusted specific-capacity data. Transmissivities estimated from lithologic logs were lower than those determined by analytical methods in 7 of 14 estimates. Although lower, most were in reasonable agreement with those determined by aquifer-test solution. Estimates of transmissivity made from adjusted specific-capacity data were lower in 11 of 13 estimates than those determined by analytical method. Estimates of transmissivity from specific-capacity data are low, because the drawdown in most pumping wells could not be adjusted for well loss.

A miscellaneous site near SNW 1184 produced 1,260 to 2,800 gal/min from a cluster of closely spaced wells during a 4-month dewatering operation. Individually, SNW 1184 only pumped 182 to 205 gal/min. The dewatering operation illustrates that, in those parts of the stratified-drift aquifer where a single well will not yield the amount of water needed, several wells might be used to obtain the desired yield.

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## -APPENDIX-

## SUPPLEMENTARY DATA--AQUIFER-TEST SITES

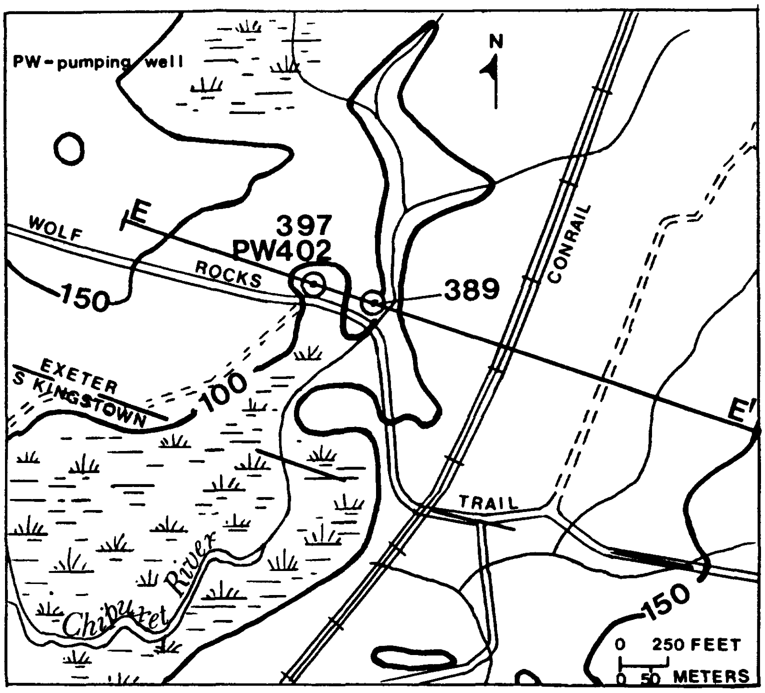
### Wolf Rocks Trail

The Wolf Rocks Trail aquifer-test site is in a valley flat 450 feet west of the Chipuxet River (fig. 4). The water table is about 1 foot below land surface, and the site is within 100 feet of a large swampy area. The lithologic log of test hole EXW 389 indicates that bedrock is 103 feet below land surface. The saturated thickness of the stratified-drift aquifer at the Wolf Rocks Trail site is between 86 and 100 feet. A generalized geologic section (E-E') of the Chipuxet River valley through the aquifer-test site is shown in figure 4.

One 2-inch diameter observation well, EXW 397, was available for measuring drawdown during the aquifer test. This well was 4 feet northeast of pumping well EXW 402 and was screened from 10 to 13 feet. The pumping well was 8 inches in diameter and screened from 17 to 87 feet. Most of the drilling material sampled from the 8-inch well was collected by bailer (commonly called a sand pump by drillers), except for four samples collected by split spoon. Samples were analyzed by the Materials Testing Laboratory of the Rhode Island Division of Roads and Bridges for grain size. Particle-size distribution of aquifer materials are shown in figure 5. The hydraulic conductivities shown in figure 5 were determined by the U.S. Geological Survey Hydrologic Laboratory, on repacked samples. Laboratory determinations for hydraulic conductivity do not generally give reliable values; however, they may be useful in indicating relative values (Lohman 1979, p. 53).

Well EXW 402 was developed by pumping at 300 gal/min for 20 minutes and at 600 gal/min for 3 minutes. Between pumping rate changes, during development, the pumping water level was allowed to recover to its static (nonpumping) water level. Although a 4-hour aquifer test preceded the 24-hour aquifer test, the time of well development was too short to develop the entire 70-foot length of screen fully. Additional drawdown in the pumping well caused by well loss could not be determined because no step-drawdown test was made. The aquifer was pumped for 24 hours at 610 gal/min, and well water was discharged into a swamp 360 feet east of the pumping well.

The hydraulic properties of the aquifer at the Wolf Rocks Trail site were determined by analyzing drawdown data using methods by Boulton (1954) and Stallman (1963, 1965). The Boulton and Stallman methods are described in Lohman (1979, p. 34-40). Figure 6 identifies the flow equations, curve match points, and calculations used to determine transmissivity by both methods. Boulton's solution is based on the concept of delayed water-table response, for an isotropic unconfined aquifer, in which the vertical and horizontal hydraulic conductivity are equal. Transmissivity determined by this method was 37,400 $ft^2d$, and the horizontal hydraulic conductivity was 435 ft/d (table 6). Stallman's solution is based on the concept of vertical movement, for an anisotropic unconfined aquifer, in which the vertical hydraulic conductivity differs from the horizontal hydraulic conductivity. This method accounts for partial penetration of the aquifer by taking into consideration the different depths of both pumping and observation wells. Transmissivity determined by this method was 39,100 $ft^2/d$, and the horizontal hydraulic conductivity was 455 ft/d (table 6).



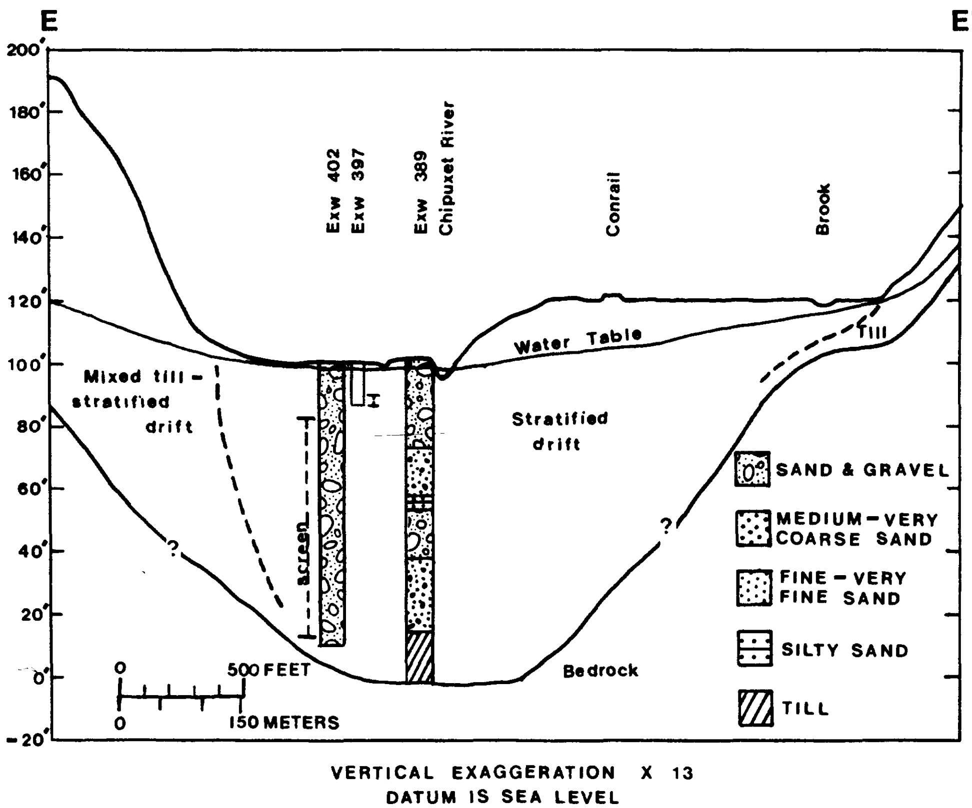




Figure 4.--Location map and generalized geologic section (E-E') of the Chipuxet River valley at the Wolf Rocks Trail site.

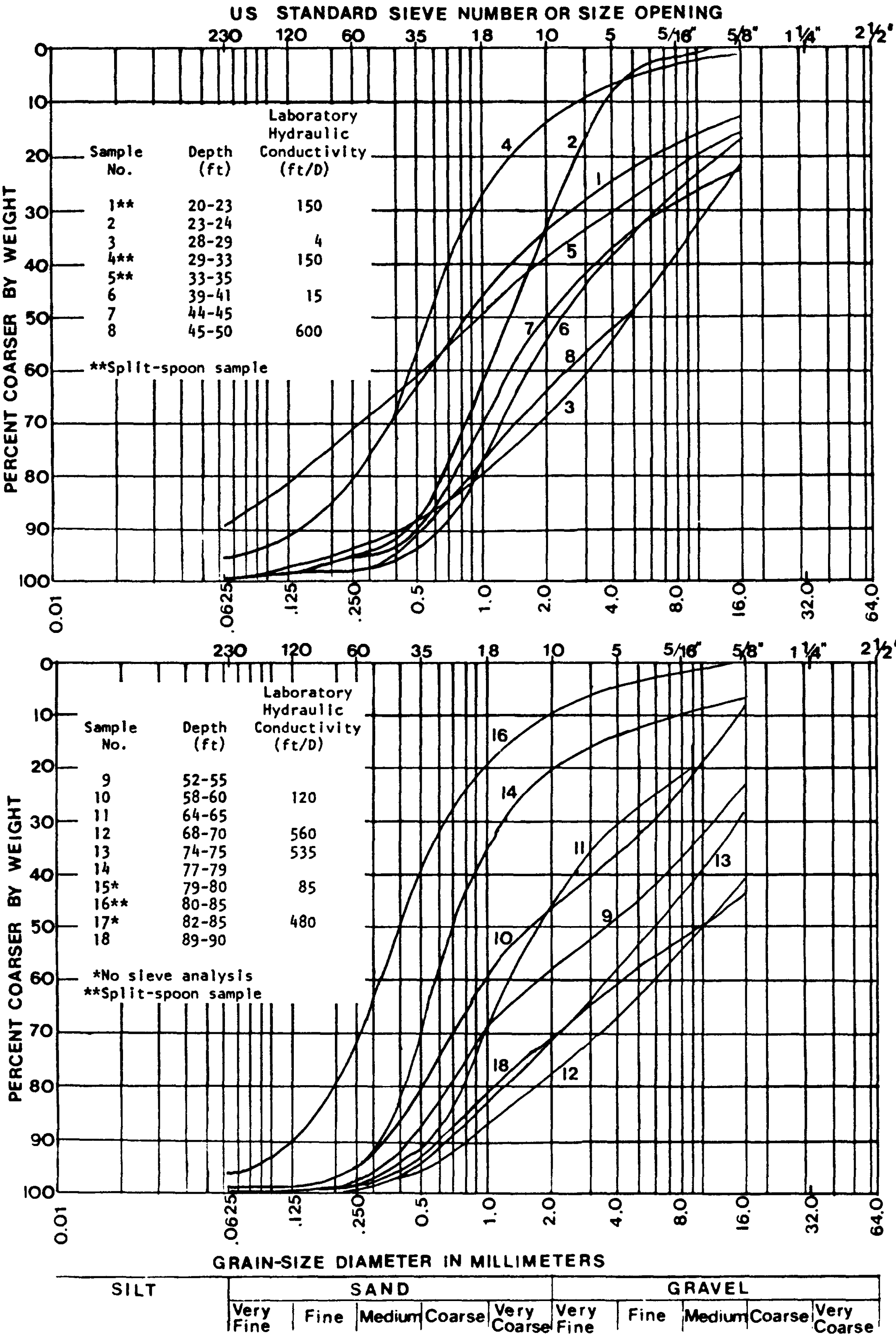



Figure 5.--Particle-size distribution and laboratory hydraulic conductivity of aquifer material from 8-inch well (Exeter 402).

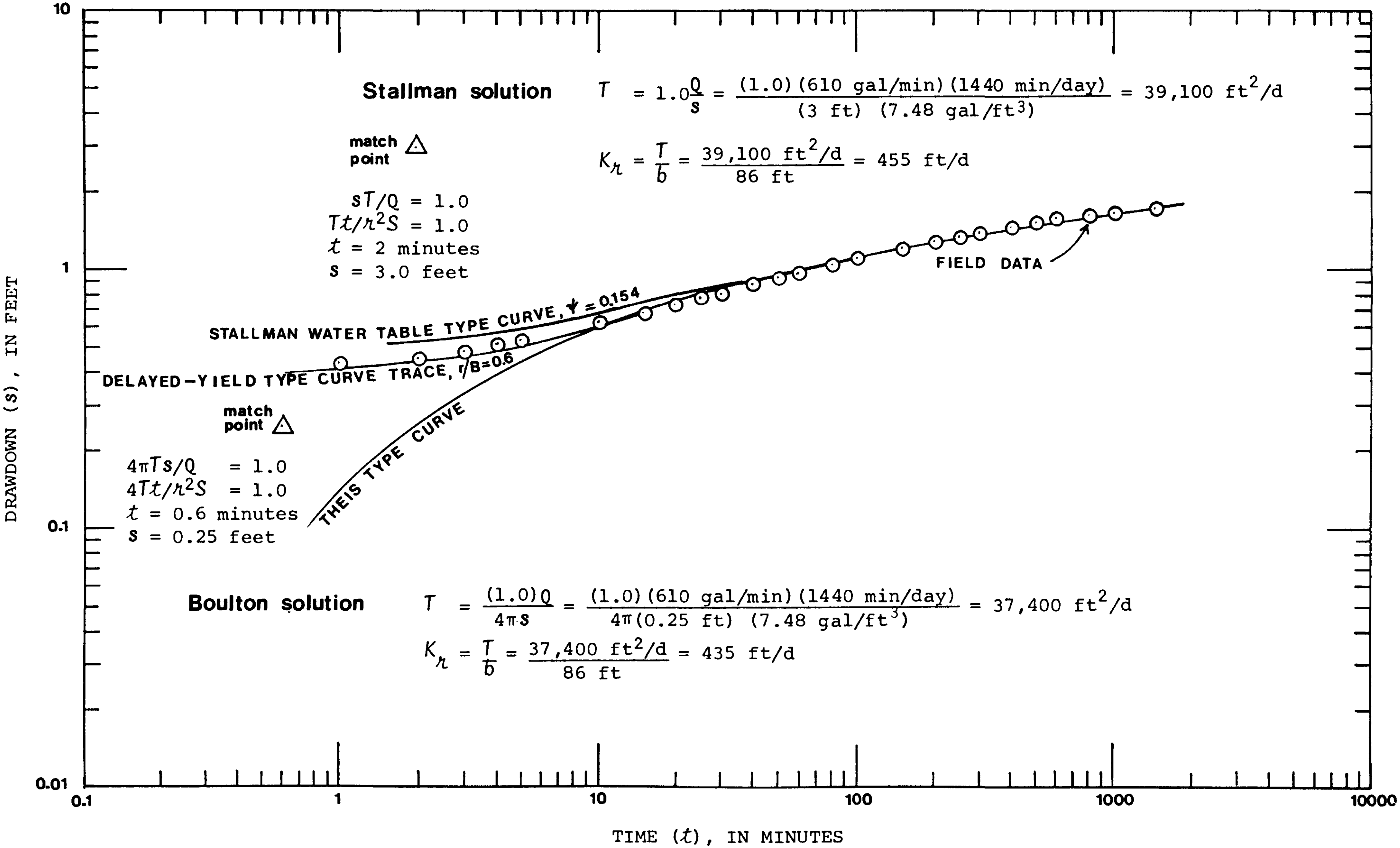



Figure 6.--Logarithmic plot of $s$ versus $t$ for observation well Exeter 397 at Wolf Rocks Trail test site.

Transmissivities determined by the Boulton and Stallman methods were in excellent agreement with the value estimated from the log of the 8-inch well. The transmissivity estimated from the lithologic log of pumping well EXW 402 was 37,600 $ft^2/d$ (table 6). Transmissivity was also estimated from specific-capacity data after adjusting drawdown in the pumping well for dewatering. No partial penetration correction was made as the pumping well was screened throughout most of the aquifer thickness. Transmissivity estimated from the adjusted specific capacity was 19,600 $ft^2/d$ (table 6). This value is probably low because of uncorrected drawdown in the pumping well due to well loss. If the drawdown could have been corrected for well loss, the transmissivity estimated from adjusted specific capacity would probably have been much closer to that determined from aquifer-test solutions and lithology.

The specific yield and the vertical hydraulic conductivity of the aquifer could not be determined because the single observation well was too close to the pumping well to provide meaningful values. Although the aquifer is anisotropic, the close agreement in transmissivity determined by the Boulton and Stallman methods indicates that the ratio of vertical to horizontal hydraulic conductivity is small, probably less than 1:5.

Results of analysis of the 18 aquifer tests, shown in table 6, indicate that the Wolf Rocks Trail site has the highest transmissivity of the 16 locations tested. However, it may not be feasible to use 70 feet of well screen in a gravel-packed well, as was used in the 8-inch test well. Use of a shorter well screen will cause drawdown to increase in the pumping well because of partial penetration, but the increased drawdown could be reduced by spacing screen sections. As an example, increased drawdown could be reduced by locating 10-foot sections of well screen near the top, center, and bottom of the aquifer with blank casing between the screened intervals.

## Hundred Acre Pond

The Hundred Acre Pond test site is in a valley flat 240 feet east of Hundred Acre Pond in the Chipuxet River valley (fig. 7). The water table is 28 feet below land surface at the 8-inch well, and the site is within 800 feet of a large swampy area to the north. The lithologic log of test well SNW 1118 indicates that bedrock is more than 94 feet below land surface. Test well SNW 1118 was drilled in August 1973 and pulled prior to the aquifer test in December 1973. The maximum saturated part of the stratified-drift aquifer, in the center of the Chipuxet River valley, may be as thick as 120 feet (fig. 8). However, figure 8 indicates that the average saturated thickness of the aquifer is 70 feet. Locations of generalized geologic sections of the Chipuxet River valley are shown in figure 2. The lithology of the aquifer at the Hundred Acre Pond site is shown in generalized geologic section B-B' in figure 8.

Five 2-1/2-inch diameter observation wells (fig. 7) were available for measuring drawdown during the aquifer test. Observation wells SNW 1114-1116 were in a line parallel to Hundred Acre Pond, and SNW 1112-1113 were in a line perpendicular to the pond. Observation wells were 140 to 302 feet from pumping well SNW 1111, and had 4 to 6 feet of screen. The screen in each observation well was in the same aquifer zone as the pumping well. Aquifer material collected by bailer from 8-inch well SNW 1111 indicated that fine sand was predominant near the water table and, also, at depths between 61 and 90 feet below land surface. Pumping well SNW 1111 was screened in granule to pebble gravel from 53 to 60 feet with 90 slot Johnson[1] screen. The well was developed by starting and stopping the pump, and letting the water level recover to near static level before restarting. The effectiveness of development can be appraised by a step-drawdown test (commonly referred to as a well-efficiency test). A step-drawdown test was made 1 day before the aquifer test. The step-drawdown test indicated incomplete development, with mild to severe clogging of the screen or aquifer material near the screen. During the aquifer test, SNW 1111 was pumped at 360 gal/min for 38 hours. Water was discharged into Hundred Acre Pond 240 feet west of SNW 1111.

[1] The use of a company name here is for identification purposes only and does not constitute endorsement by the U. S. Geological Survey.

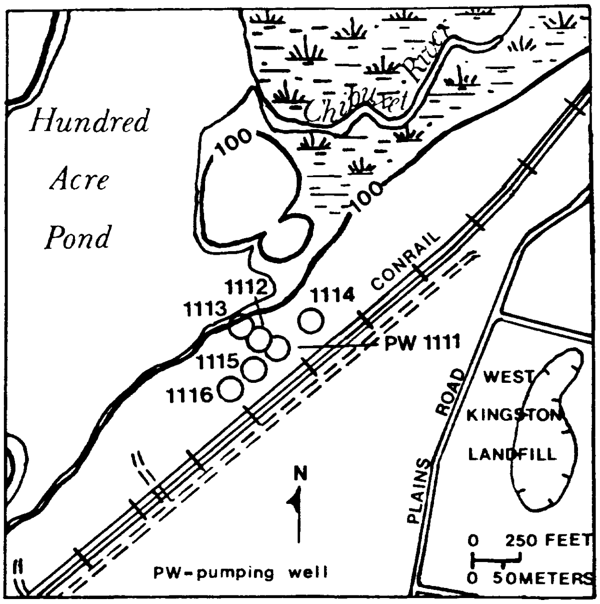



Figure 7.--Location of Hundred Acre Pond site

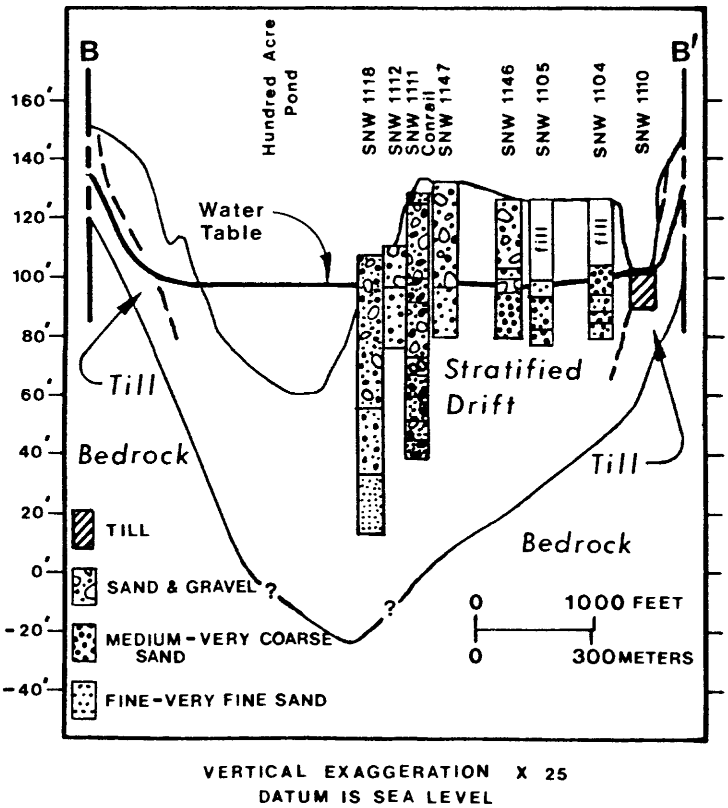



Figure 8.--Generalized geologic section (B-B') of the Chipuxet River valley at the Hundred Acre Pond site. (See figure 2 for line of section.)

Log-log plots of time-drawdown data were analyzed by the nonequilibrium formula (Theis, 1935), and the delayed yield formula (Boulton, 1954), and semilog plots of time-drawdown by the modified nonleaky confined formula (Cooper and Jacob, 1946). Transmissivities determined by these methods were 2 to 4 times (45,000 to 75,000 $ft^2/d$) higher than lithology would seem to support. Based on lithology and the closeness of Hundred Acre Pond to the test site (240 feet), recharge was expected to occur during the aquifer test. However, time-drawdown data did not indicate the effects of a recharge boundary, and the Hundred Acre Pond site was analyzed as a nonleaky system.

The hydraulic properties of the aquifer were determined by the Cooper and Jacob graphical method from the modified nonleaky confined formula. Drawdowns at the end of 1.58 days of pumping in observation wells SNW 1112-1116 (fig. 7) were plotted against the logarithms of their respective distances on semilog paper (fig. 9). The drawdown difference per log cycle, obtained from the slope of the straight line between observation wells SNW 1114 and 1116, was used to determine transmissivity and specific yield from the following equations:

$$T = 0.367\ Q/\Delta s \qquad (1)$$

$$S = 2.25\ T \frac{t}{(r_o)^2} \qquad (2)$$

where

$T$ = transmissivity, in square feet per day

$Q$ = discharge, in cubic feet per day

$\Delta s$ = drawdown difference per log cycle, in feet

$S$ = storage coefficient, fraction

$t$ = time after pumping started, in days

$r_o$ = intersection of straight-line slope with zero-drawdown axis, in feet

Transmissivity determined by the Cooper and Jacob method by equation 1 was 19,000 $ft^2/d$, and the horizontal hydraulic conductivity was 270 ft/d (table 6). The specific yield determined by equation 2 was 0.27.

Transmissivity was estimated from specific-capacity data and from the lithologic log of 8-inch well SNW 1111. A transmissivity of 20,000 $ft^2/d$ (table 6) was estimated from specific-capacity data after adjusting drawdown, determined from airline readings, in the pumping well for well loss, partial penetration, and dewatering. This value is in close agreement with that determined by the Cooper and Jacob graphical method.

A transmissivity of 8,100 $ft^2/d$ (table 6) was estimated from the lithologic log of SNW 1111, but is not believed to be representative of overall aquifer conditions.

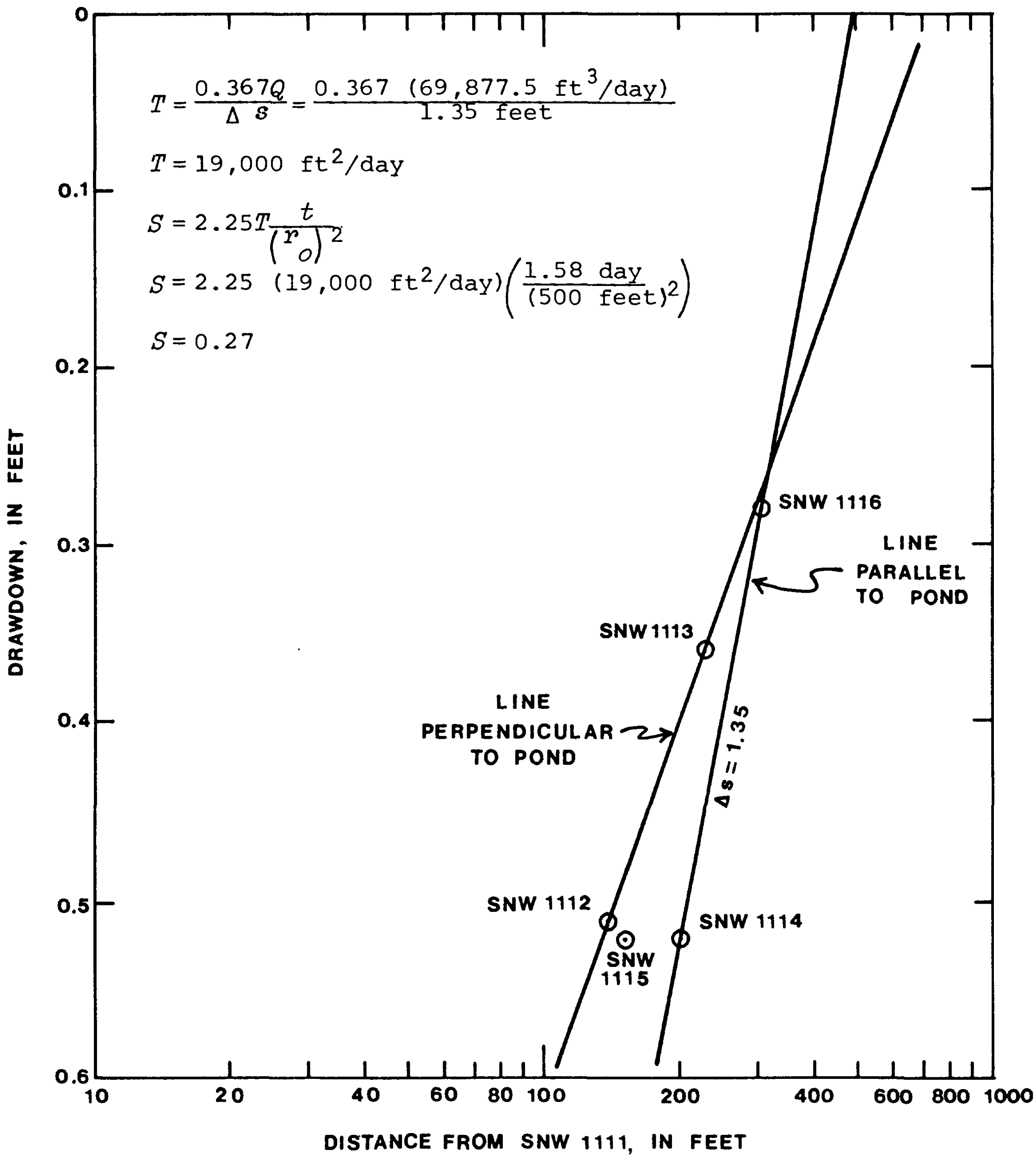



Figure 9.--Distance-drawdown plot of observation well data after 1.58 days of pumping in South Kingstown (SNW) 1111, at Hundred Acre Pond test site.

## Thirty Acre Pond

An anisotropic, water-table aquifer composed primarily of coarse sand and gravel, at the southeast corner of Thirty Acre Pond (fig. 10), constitutes the most favorable withdrawal site in the Chipuxet River ground-water reservoir. The University of Rhode Island has derived its water supply from this site for 45 years. The lithologic log of SNW 1128 indicates that refusal, probably bedrock, is 158 feet below land surface (fig. 3). Figure 11 indicates that the saturated thickness of the aquifer averages 120 feet, and has a maximum known thickness of 136 feet. A generalized geologic section (C-C') of the Chipuxet River valley is shown in figure 11. The longitudinal geologic section (A-A') shown in figure 3 illustrates the lithologic heterogeneity of this complexly interbedded aquifer system. For location of geologic sections C-C' and A-A', see figure 2.

Two 8-inch diameter wells, SNW 1133 (fig. 10a) on the southeast corner of Thirty Acre Pond, and SNW 1137 (fig. 10c) on the southwest corner of the pond, were drilled and pumped to determine aquifer hydraulic properties. Subsequent to the test on SNW 1133, a new 24- X 18-inch gravel-packed well, SNW 1151 (fig. 10b), was constructed in 1974. This new well presently (1983) supplies the majority of water to the university, which uses about 0.75 Mgal/d.

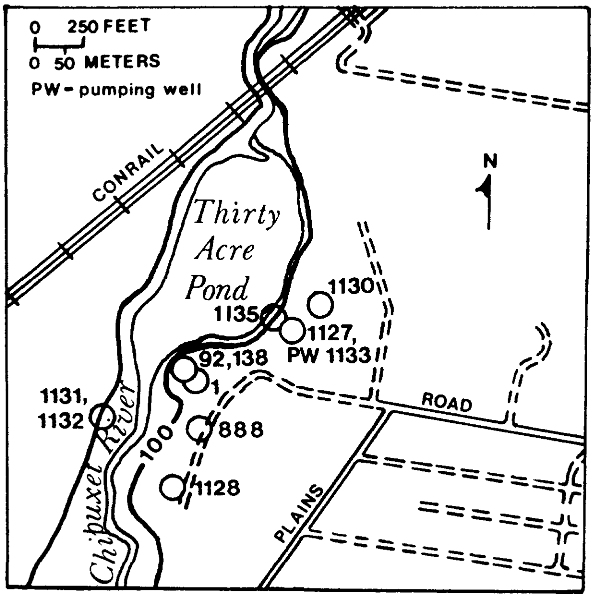
### South Kingstown Wells 92, 138, and 888

Prior to 1974, the University of Rhode Island derived its water supply from one dug well, SNW 1, and three 24- X 18-inch gravel-packed wells, SNW 92, 138, and 888 (fig. 10b). The low yield of SNW 138 led to its abandonment in 1958 when SNW 888 was drilled. Wells SNW 92 and 888 have been on standby use since 1977, when SNW 1151 became the main supply well. Both wells penetrate most of the aquifer thickness (120 feet) while SNW 138, located 12.3 feet east of SNW 92, only penetrates the upper 60 feet of aquifer. Each well was pumped when installed, however, time-drawdown data from observation and pump wells was either unusable or not collected. Transmissivities at these well sites were estimated from lithology and (or) specific-capacity data (table 6).

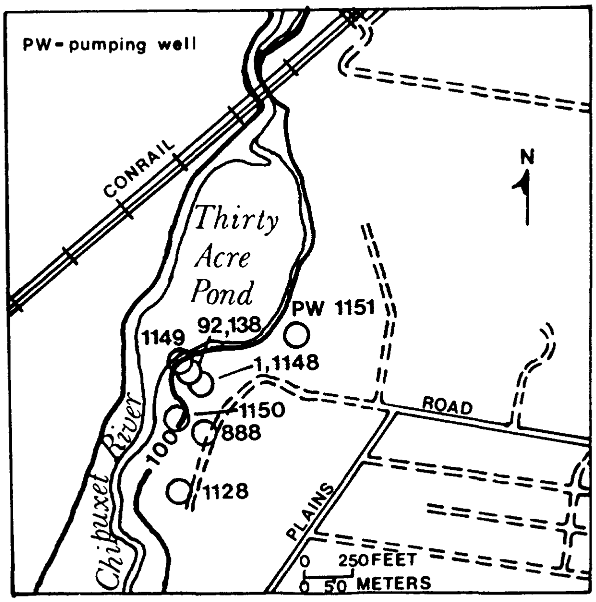
### South Kingstown Wells 1133 and 1151

Four 2-1/2-inch diameter observation wells SNW 1127, 1128, 1130, and 1131 (fig. 10a) and supply wells SNW 92 and 888 were available for measuring drawdown during the aquifer test on 8-inch well SNW 1133. These wells were located 5 to 980 feet from SNW 1133 and had 4 to 25 feet of screen. Two wells (SNW 1127 and 1130) had screens in the same aquifer zone as SNW 1133. The other wells were screened deeper in the aquifer, approximately 20 to 60 feet below the screened interval in SNW 1133. Pumping well, SNW 1133, was screened from 80 to 85 feet with 120-slot Johnson screen and from 85 to 95 feet with 160-slot screen. The well was developed by surging and pumping at 150 gal/min for 10 hours. A step-drawdown test was made 3 days prior to the aquifer test to determine the effectiveness of development. The step-drawdown test indicated incomplete development, with mild to severe clogging of the screen or material near the screen. During the aquifer test, SNW 1133 was pumped at 650 gal/min for 4 days. Water was discharged into a swampy area near the Chipuxet River 440 feet southwest of the pumping well.

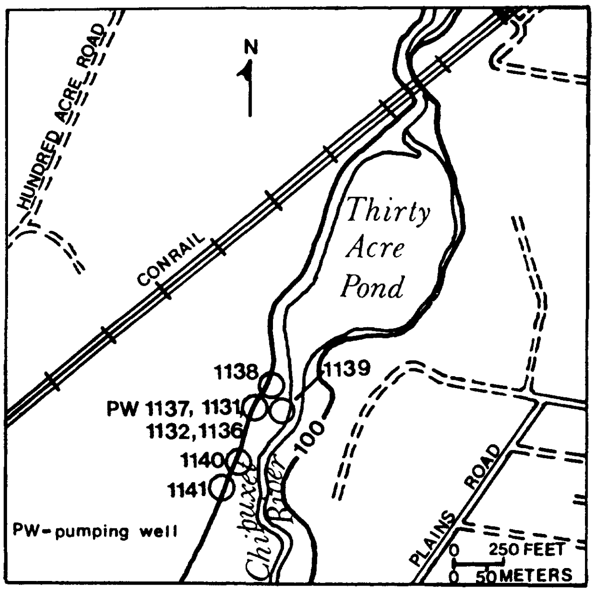
SNW 1151, a new 24- X 18-inch gravel-packed well, was screened from 75 to 85 feet with 160-slot Johnson screen and from 85 to 95 feet with 240-slot screen. This well was developed by surging with a double surge block while pumping at 200 to 300 gal/min for 46 hours. A step-drawdown test was made prior to the aquifer test. SNW 1151 was pumped for 2 hours each at rates of 710, 1080, and 1400 gal/min. The step-drawdown test indicated that SNW 1151 was properly developed, but that slight clogging of the screen or well wall was taking place. Because the water was slightly dirty after the third step, development was extended for an additional 2-1/2 days. Much very fine to fine sand and some silt was removed from the well by starting and stopping the pump at a rate of 1400 gal/min. Specific capacity of the gravel-packed well, which had dropped from 101 to 82 (gal/min)/ft by the end of the step-drawdown test, improved to 122 (gal/min)/ft with the additional development. Transmissivity, based on the improved specific capacity, was estimated to be 26,700 $ft^2/d$. During the aquifer test, SNW 1151 was pumped at 910 gal/min for 48 hours. Water was discharged over a steep bank into Thirty Acre Pond 40 feet west of the pumping well. Wells SNW 92, 888, and 1128, used as observation wells during the 8-inch test, were also used to measure drawdown during the aquifer test of SNW 1151.




(a)




(b)




(c)

Figure 10.--Location of Thirty Acre Pond sites for (a) 8-inch pumping well SNW 1133, (b) 24- X 18-inch pumping well SNW 1151, and (c) 8-inch pumping well SNW 1137.

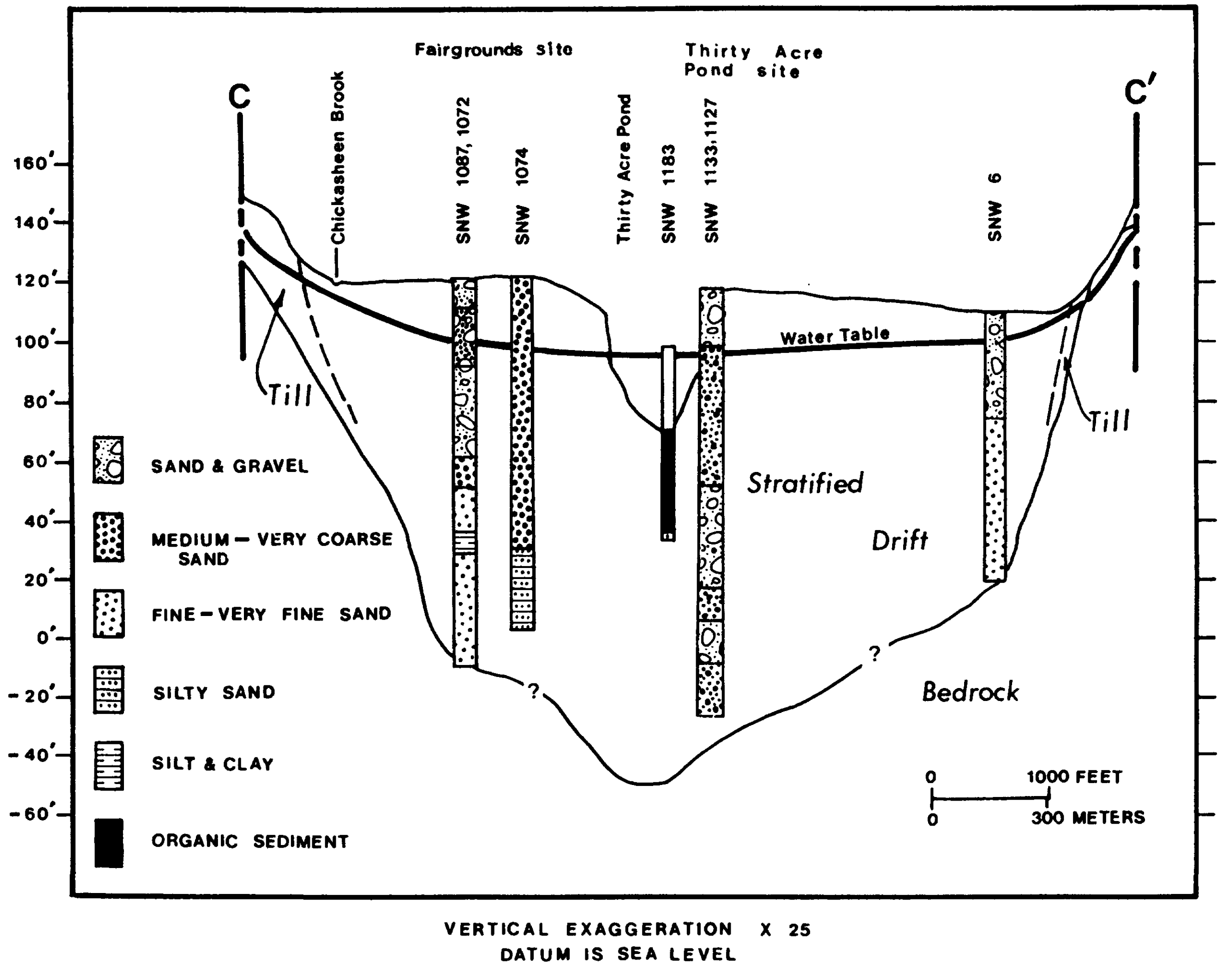



Figure 11.--Generalized geologic section (C-C') of the Chipuxet River valley through the Thirty Acre Pond site and the Fairgrounds site. (See figure 2 for line of section.)

Hydraulic properties of the aquifer were determined by analysis of drawdown data from the test on SNW 1133 using methods by Cooper (1963), Jacob (1946b), and Cooper and Jacob (1946). The Cooper method is described in Lohman (1979, p. 31-32), the Jacob method is described in Walton (1962, p. 5-6), and the Cooper and Jacob method is described in Walton (1962, p. 9). The unconfined aquifer, at Thirty Acre Pond, can be analyzed as a leaky confined system. A 30-foot layer of silt and organic sediment at the bottom of the pond impedes the vertical movement of water.

The Cooper method is for nonsteady radial flow in a leaky confined aquifer. Figure 12 shows the flow equation, curve match points, and calculations used to determine aquifer transmissivity by pumping 8-inch well SNW 1133. A transmissivity of 19,200 $ft^2/d$, and a horizontal hydraulic conductivity of 275 ft/d, covering a small body of the aquifer, was determined by the Cooper method with a type curve for constant *r* (radius) using single observation well SNW 1130 (fig. 10a). Observation well SNW 1130 was 152 feet northeast of SNW 1133. When observation wells are at varying distances and directions from a pumping well (fig. 10a), an average transmissivity covering a larger, more representative body of the aquifer can be determined by the Cooper method with a type curve match for a constant *t* (time). The average transmissivity determined for a constant time of 4 days was 24,900 $ft^2/d$ (table 6) using observation wells SNW 92, 1128, 1130, and 1131 shown in figure 10a. The horizontal hydraulic conductivity of the stratified-drift aquifer was 355 ft/d and the vertical hydraulic conductivity was 6 ft/d (table 6). The ratio of vertical to horizontal hydraulic conductivity of the aquifer is 1:60.

Transmissivity at this site was also determined by the Jacob method. This method is intended for steady-state flow in an isotropic confined aquifer with vertical movement of water through a semipervious confining bed. Under steady-state leaky confined conditions, discharge is balanced by leakage. Drawdown curves for observation wells SNW 92, 1128, and 1131 flattened out similar to the curve for SNW 1130 shown in figure 12, and drawdown became independent of time. The aquifer reached a steady-state condition and well discharge from SNW 1133 was balanced by leakage from Thirty Acre Pond. The coefficient of storage cannot be determined by the Jacob method because under such conditions of flow, the entire yield of the well is derived from leakage. Transmissivity of the aquifer was calculated from the following equation:

$$T = \frac{0.16\, Q\, K_o(r/\beta)}{s} \qquad (3)$$

where:

$T$ = transmissivity, in square feet per day
$Q$ = discharge, in cubic feet per day
$K_o(r/\beta)$ = modified Bessel function of the second kind and zero order
$s$ = drawdown in observation well, in feet

Transmissivity determined by the Jacob method using equation 3 was 27,000 $ft^2/d$, and the horizontal hydraulic conductivity was 387 ft/d (table 6). A transmissivity of 25,800 $ft^2/d$, and a horizontal hydraulic conductivity of 370 ft/d (table 6) were also determined by the Jacob method for gravel-packed well SNW 1151. Hydraulic properties for the new 24- X 18-inch supply well are shown for comparing results with the 8-inch test well located at the same site.

Transmissivity determined by the Cooper and Jacob graphical method for the modified nonleaky confined formula is supplemental to that determined by the type curve methods just presented. Drawdowns, at the end of 4 days of pumping, in observation wells SNW 92, 1128, 1130, and 1131 at distances of 152 to 980 feet from SNW 1133 (fig. 10a) were plotted against the logarithms of their respective distances on semilog paper. Pumping time was long enough for the distance-drawdown plot of field data to yield a straight-line graph. Observation wells used in this analysis were located parallel to the recharge source, to account for induced recharge from Thirty Acre Pond. Drawdown difference per log cycle, obtained from the slope of the straight line, was used to determine transmissivity. Transmissivity determined by the Cooper and Jacob method by equation 1 was 27,000 $ft^2/d$, and horizontal hydraulic conductivity was 385 ft/d (table 6). A transmissivity of 28,600 $ft^2/d$ and a horizontal hydraulic conductivity of 410 ft/d (table 6) were determined, by this same method, for the test on SNW 1151. Transmissivities determined by the nonleaky confined equation are in close agreement with those determined by the Cooper method using the leaky confined equation because of the low infiltration rate of the bottom sediment in Thirty Acre Pond.

Cooper solutions for nonsteady radial flow in a leaky confined aquifer at constant $r$ and constant $t$.

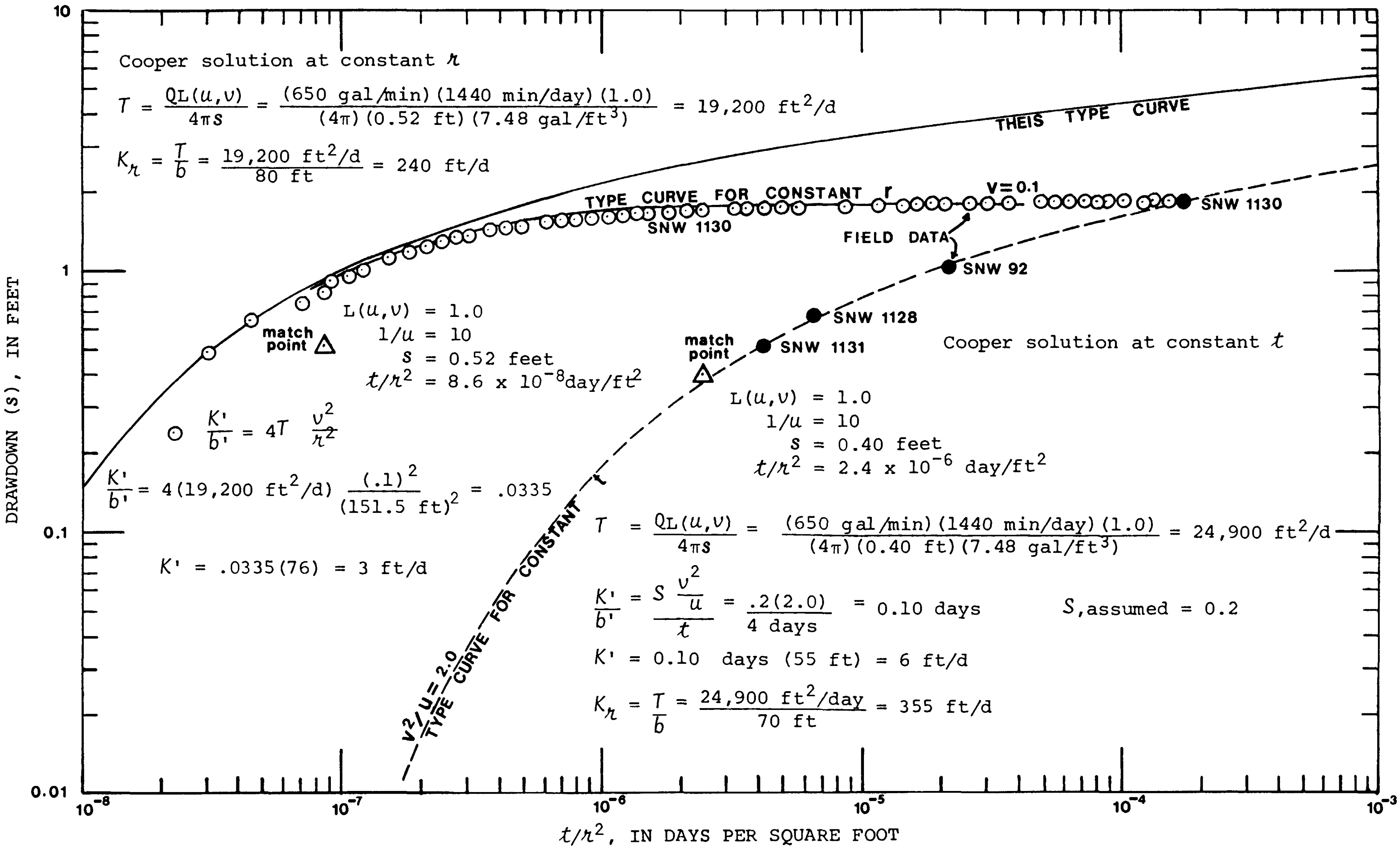



Figure 12.--Logarithmic plot of $s$ versus $t/r^2$ in observation wells due to pumping well SNW 1133, at Thirty Acre Pond test site.

South Kingstown Well 1137

An aquifer test was also made on the southwest corner of Thirty Acre Pond on SNW 1137. Observation wells measured during the test are shown in figure 10c. Each observation well was screened in the same aquifer zone as the 8-inch well with 5 feet of screen. The 8-inch well was screened from 42 to 45 feet with 30-slot Johnson screen, 45 to 50 feet with 100-slot screen, and 50 to 55 feet with 40-slot screen. SNW 1137 was developed by surging and pumping at 150 gal/min for 10 hours. Much very fine to fine sand was removed from the well during development. Although no step-drawdown test was made, some indication of the magnitude of drawdown caused by well loss can be determined from the difference in drawdown between the pumping well and an observation well during the aquifer test. The observation well should be screened in the same interval as the pumping well and within 2 to 6 feet of the pumping well. Based on a drawdown difference of 17 feet during the aquifer test in an observation well 6 feet from SNW 1137, development was considered to be incomplete and clogging of the screen or material near the screen was probably severe. SNW 1137 was pumped at 100 gal/min for 2 days and water was discharged into a swamp near the Chipuxet River 120 feet east of the pumping well. Drawdown was affected by recharge after 3 minutes of pumping. During the first 3 minutes of the test, drawdown was erratic because of difficulty adjusting the pumping rate to 100 gal/min. Because drawdown was erratic during the early part of the test, transmissivity was determined by analysis of recovery data.

Unaffected by recharge, early time-recovery data (first 3 minutes) from SNW 1138 and 1139 were analyzed by the Theis (1935) nonequilibrium formula for nonleaky confined conditions, which is described in Walton (1962, p. 6). Divergence of later time-recovery data from the type-curve trace were also analyzed. Transmissivities determined from early and later time-recovery data were similar.

The nonequilibrium formula may be written as:

$$T = \frac{0.08\, Q\, W(u)}{s} \qquad (4)$$

where:

$T$ = transmissivity, in square feet per day

$Q$ = discharge, in cubic feet per day

$W(u)$ = $W$ (well) function of $u$

$s$ = drawdown in observation well, in feet

$u$ = $r^2 S/4\,Tt$ (5)

$r$ = distance from observation well to pumped well, in feet

$S$ = storage coefficient

$t$ = time, in minutes

Transmissivity determined by equation 4 for nonleaky confined conditions ranges from 5,000 to 7,700 $ft^2/d$ and the horizontal hydraulic conductivity ranges from 100 to 150 ft/d. See table 6 for hydraulic properties determined from individual observation wells. A transmissivity of 6,200 $ft^2/d$ was estimated from specific-capacity data for SNW 1137. Transmissivity estimated from the lithologic log of SNW 1137 is 10,000 $ft^2/d$.

The Rhode Island Water Resources Board did not test the lower aquifer because water samples from SNW 1131, screened from 120 to 125 feet, and SNW 1141, screened from 132 to 140 feet, contained 0.34 and 0.39 milligrams per liter of dissolved manganese. Manganese greater than 0.05 milligrams per liter exceed the secondary maximum contaminant level for public drinking water supplies (U.S. Environmental Protection Agency, 1977, p. 17146).

## Fairgrounds

The Fairgrounds aquifer-test site is in a valley flat 1200 feet west of the Chipuxet River and Thirty Acre Pond (fig. 13). The water table is 22 feet below land surface, and refusal (probably bedrock) is 130 feet below land surface. The lithologic logs of SNW 1072, 1074, and 1087 indicate that material above 70 feet is composed of coarse sand and gravel. Fine sand between 70 and 85 feet changes to predominantly very fine sand, silt, and clay at 85 feet and continues to 130 feet. The coarse sand and gravel above 70 feet forms a water-table aquifer. A generalized geologic section (C-C') of the Chipuxet River valley is shown in figure 11.

Three 2-1/2-inch diameter observation wells (fig. 13) were available for measuring drawdown during the test. Observation wells SNW 1072, 1074, and 1073 were 2.5, 580, and 1153 feet northeast of 8-inch well SNW 1087. Each observation well was screened with 7 to 12 feet of screen in the same aquifer zone as SNW 1087. SNW 1087 was screened in coarse sand from 60 to 70 feet and fine sand from 70 to 85 feet. The well was screened from 60 to 65 feet with 30-slot screen and from 65 to 85 feet with 20-slot screen. A step-drawdown test was not made, and data on development was not available. During the aquifer test, SNW 1087 was pumped at 290 gal/min for 4.2 days. Water was discharged onto the ground 1250 feet northeast of the pumping well, within 100 feet of observation well SNW 1073. Problems during the test rendered some data unusable. The first problem was with water, from the discharge line, that infiltrated the upper part of the aquifer causing the water table near SNW 1073 to rise. Because of the rising water table in the aquifer, water-level data from SNW 1073 could not be analyzed. The second problem was lack of early time-drawdown data. The first water-level measurements were not made until 30 minutes after pumping started. Log-log plots of time-drawdown data between 30 minutes and 4.2 days were too flat to determine aquifer hydraulic properties with any degree of certainty.

The hydraulic properties of the aquifer at the Fairgrounds were determined from distance-drawdown data by a graphical method by Cooper and Jacob (1946) that is described in Walton (1962, p. 9). Drawdowns observed after 4.2 days of pumping in SNW 1072 and 1074 (fig. 13) were plotted against the logarithms of their respective distances on semilog graph paper. The pumping time was long enough for the distance-drawdown plot of field data to yield a straight-line graph. The drawdown difference per log cycle, obtained from the slope of the straight line, was used in determining the transmissivity. The transmissivity of the aquifer was determined from the modified nonleaky confined formula given in equation 1 in the Hundred Acre Pond section of this report. Transmissivity determined by the Cooper and Jacob graphical method was 8,900 $ft^2/d$, and the horizontal hydraulic conductivity was 140 ft/d (table 6). A specific yield (storage coefficient) of 0.13 was determined with equation 2 in the Hundred Acre Pond section. The specific yield was determined after 4.2 days of pumping using the distance ($r_0$) obtained from extending the straight-line slope of the distance-drawdown plot to the zero-drawdown axis.

Additional estimates of transmissivity were made from specific-capacity data and the driller's lithologic log of the 8-inch pumping well. No step-drawdown test was made to determine the efficiency of SNW 1087. However, drawdown in observation well SNW 1072, 2.5 feet from SNW 1087, suggests that drawdown in the pumping well caused by well loss was 4 feet. Drawdown due to well loss may have been caused by incomplete development in the fine sand in the screened interval between 70 and 85 feet. Specific-capacity data was adjusted for well loss, partial penetration, and dewatering before estimating transmissivity. Transmissivity estimated from adjusted specific-capacity data was 8,400 $ft^2/d$. This value is in close agreement with 8,900 $ft^2/d$ determined by the Cooper and Jacob graphical method. A somewhat higher transmissivity of 12,000 $ft^2/d$ was estimated from the driller's lithologic log of SNW 1087.

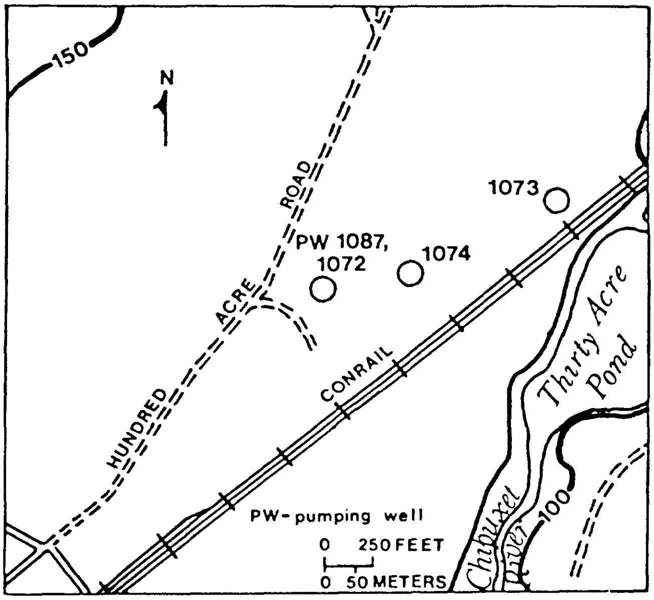



Figure 13.—Location of Fairgrounds site.

## Liberty Lane

The Liberty Lane site is in a valley flat 400 feet west of the Chipuxet River and 1,100 feet south of Liberty Lane (fig. 14). Three 8-inch diameter test wells, SNW 1082, 1085, and 1086 were drilled and pumped to determine hydraulic properties of the aquifer. Only tests at SNW 1082 and SNW 1085 are described in detail. SNW 1086 was tested but in combination with SNW 1085, and is described in less detail. The water table is 4 to 9 feet below land surface, and refusal (probably bedrock) is 218 feet below land surface. Medium to coarse sand and gravel above 90 feet forms a water-table aquifer. Material below 90 feet is predominantly fine to very fine sand, silt, and clay. The lithologic heterogeneity of this complexly interbedded aquifer system can be seen in longitudinal geologic section A-A' shown in figure 3. Generalized geologic section D-D' (fig. 15) and longitudinal geologic section A-A' show the predominance of fine grained material below 90 feet. See figure 2, in the general hydrogeology section, for location of generalized geologic sections D-D' and A-A'.

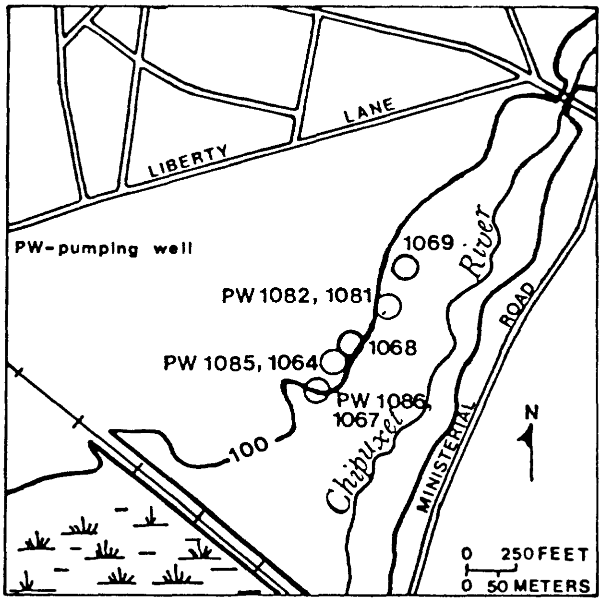



Figure 14.—Location of the Liberty Lane sites.

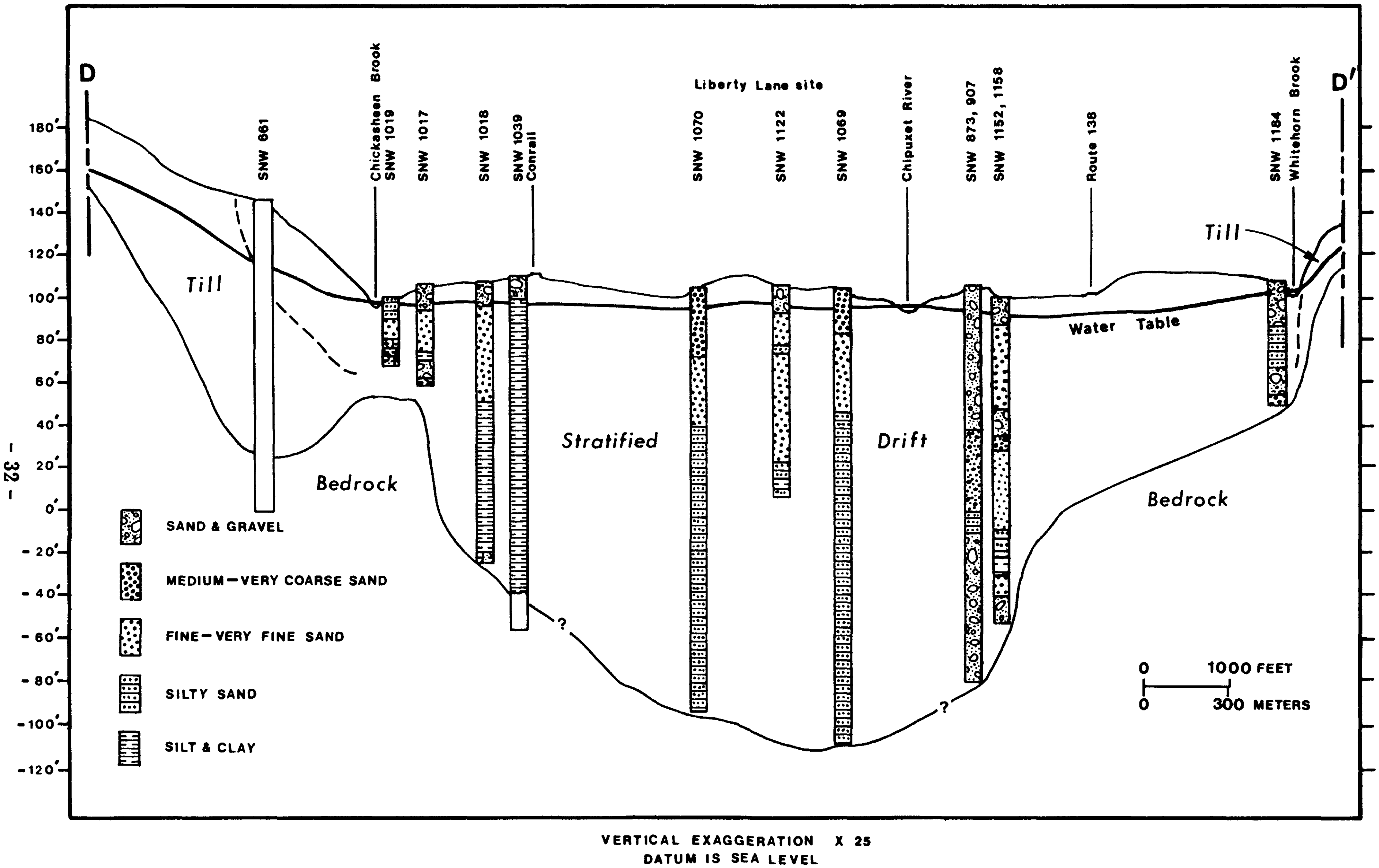



Figure 15.--Generalized geologic section (D-D') of the Chipuxet River valley near the Liberty Lane site. (See figure 2 for line of section.)

## South Kingstown Well 1082

Five 2-1/2-inch diameter observation wells, SNW 1064, 1067, 1068, 1069, and 1081 (fig. 14), were available for measuring drawdown during the test on SNW 1082. Observation wells were 2.5 to 438 feet from the pumping well and had 10 to 15 feet of screen. Two wells (SNW 1067, 1081) were screened at the same interval as SNW 1082. One well (SNW 1069) was screened 10 feet higher in the aquifer than the pumping well, and two wells (SNW 1064, 1068) were screened 4 and 9 feet lower than SNW 1082. Eight-inch well SNW 1082 was screened from 40 to 70 feet. No step-drawdown test was made, and data on development was not available. During the test, SNW 1082 was pumped at 550 gal/min for 5.2 days. Water was discharged onto the ground 250 feet east of the pumping well where it drained into the Chipuxet River.

The hydraulic properties of the aquifer near SNW 1082 were determined by analyses of drawdown data using methods by Cooper and Jacob (1946), Boulton (1954), and Stallman (1963, 1965). Results of analyses are summarized in table 6. The Stallman method is based on the concept of vertical movement in an anisotropic, unconfined aquifer. Aquifer properties were determined from drawdown data from two observation wells. Observation well SNW 1068 is 176 feet southwest of SNW 1082, and observation well SNW 1069 is 219 feet northeast of SNW 1082. Transmissivities determined by the Stallman method range from 8,100 $ft^2/d$ southwest of pumping well SNW 1082 to 9,500 $ft^2/d$ northeast of the pumping well. The specific yield ranges from 0.16 to 0.17. The horizontal hydraulic conductivity ranges from 125 to 145 ft/d, and the vertical hydraulic conductivity ranges from 8 to 27 ft/d. The ratio of vertical to horizontal hydraulic conductivity of the aquifer ranges from 1:5 to 1:16. For comparison, a transmissivity of 7,700 $ft^2/d$ was determined by Boulton's delayed yield method, from observation well SNW 1068. This is the same well from which a transmissivity of 8,100 $ft^2/d$ was determined by the Stallman method.

Transmissivity, hydraulic conductivity, and specific yield determined by the Stallman or Boulton methods were derived from analysis of single observation wells. Analyses of data were also made with multiple observation wells. Using multiple wells, hydraulic properties of the aquifer were determined by the Cooper and Jacob (1946) graphical method, by the modified nonleaky confined formula (see equation 1). Hydraulic properties determined by the Cooper and Jacob method are supplemental to those determined by type curve analysis. However, they are important as they represent average values covering a larger body of the aquifer than those obtained by single well analysis. Drawdowns observed, at the end of 5.2 days of pumping at 550 gal/min, in observation wells SNW 1064, 1067, 1068, and 1069 (fig. 14), were plotted against the logarithms of their respective distances from SNW 1082 on semilog paper. The pumping time was long enough for field data to yield a straight line on the distance-drawdown graph. Transmissivity determined by the Cooper and Jacob graphical method was 9,000 $ft^2/d$, horizontal hydraulic conductivity was 140 ft/d, and specific yield was 0.11. Aquifer hydraulic properties determined by all three methods of analysis are in good agreement with each other. Estimates of transmissivity were also made from specific-capacity data adjusted for partial penetration and dewatering and from the driller's lithologic log. Estimates of transmissivity from adjusted specific-capacity data and the driller's log of SNW 1082 were 9,000 $ft^2/d$ and 12,600 $ft^2/d$.

## South Kingstown Well 1085

Drawdown was also measured in observation wells SNW 1064, 1067, 1068, and 1069 during the aquifer test on SNW 1085. Observation wells were located from 2.2 to 489 feet from the pumping well. Three observation wells were screened in the same aquifer interval as pumping well SNW 1085, and one (SNW 1069) was screened 34 feet higher. Eight-inch well SNW 1085 was screened from 65 to 90 feet. No step-drawdown test was made, and data on development were not available. During the aquifer test, SNW 1085 was pumped at 610 gal/min for 1 day. Water was discharged onto the ground 350 feet east of SNW 1085 where it drained into the Chipuxet River.

Drawdown data from the test on SNW 1085, located 400 feet southwest of SNW 1082, was analyzed by Stallman's (1963, 1965) method. Transmissivities determined by Stallman's method range from 13,700 $ft^2/d$ in a northeast direction from pumping well SNW 1085 to 17,000 $ft^2/d$ in a southwest direction, and the storage coefficient ranges from 0.07 to 0.11. The aquifer horizontal hydraulic conductivity ranges from 160 ft/d in a northeast direction to 200 ft/d in a southwest direction. The vertical hydraulic conductivity ranges from 11 ft/d in a northeast direction to 24 ft/d in a southwest direction. The ratio of vertical to horizontal hydraulic conductivity of the aquifer ranges from 1:8 to 1:14. Hydraulic properties determined from individual observation wells are summarized in table 6.

Estimates of transmissivity were also made from specific-capacity data adjusted for partial penetration and dewatering, and from the driller's lithologic log. Because no step-drawdown test was made to verify drawdown caused by well loss, the estimate of transmissivity from adjusted specific-capacity data is low. Estimates of transmissivity for SNW 1085 from adjusted specific-capacity data and the driller's log were 10,900 $ft^2/d$ and 15,500 $ft^2/d$.

### South Kingstown Well 1086

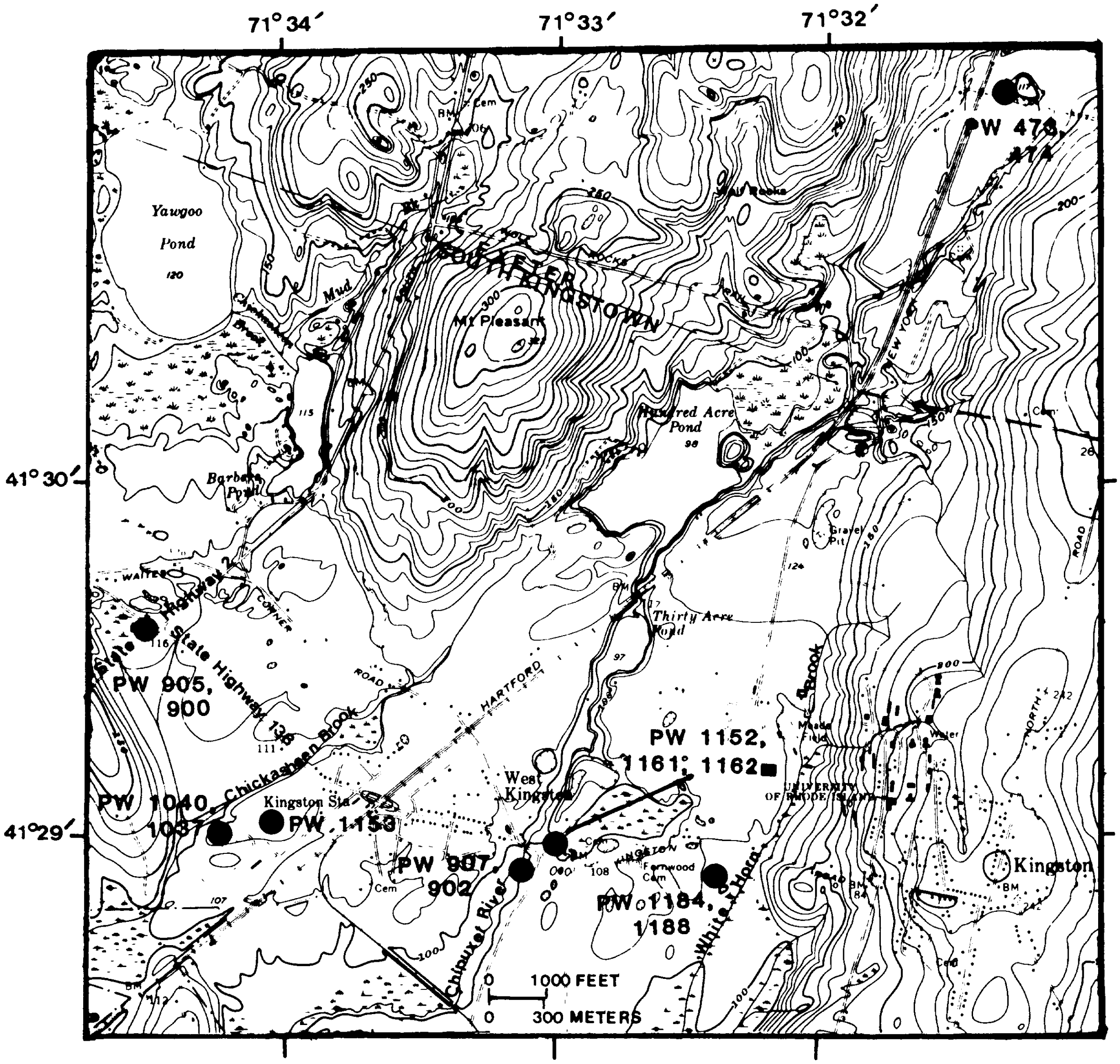
Eight-inch well SNW 1086, located (fig. 14) 150 feet southwest of SNW 1085, was tested only in combination with SNW 1085. A combined pumping rate of 1,000 gal/min, 610 gal/min from SNW 1085 and 390 gal/min from SNW 1086, was maintained for 7 days. No step-drawdown test was made to determine the efficiency of SNW 1086, and data on development were not available. Lithology indicates that the aquifer becomes progressively finer grained to the southwest of SNW 1086. Because SNW 1086 was not pumped separately, the hydraulic properties of the aquifer at SNW 1086 could not be determined by analytical methods. However, a transmissivity of 6,000 $ft^2/d$ was estimated from specific-capacity data from drawdown in observation well SNW 1067, 2.5 feet from SNW 1086, during the combined test. Drawdown was corrected for well interference from SNW 1085. A somewhat higher transmissivity of 10,000 $ft^2/d$ was estimated from the lithologic log of 8-inch well SNW 1086.

## Miscellaneous Sites

Analysis of aquifer-test drawdown and recovery data from seven pumping wells at five miscellaneous locations (fig. 16) indicate that aquifer transmissivity ranges from 6,600 to 28,700 $ft^2/d$, and horizontal hydraulic conductivity ranges from 90 to 400 ft/d. Five pumping wells (EXW 473, SNW 1040, 1152, 1153, and 1184) are existing supply wells and two (SNW 905 and 907) are 8-inch test wells. The hydraulic properties of the aquifer at individual sites are summarized in table 6. The supply wells range in diameter from 8-inch to 24- X 18-inch gravel packed, and were tested at rates ranging from 205 to 725 gal/min.

### South Kingstown Wells 907 and 1152

The most favorable miscellanous site tested in the Chipuxet River ground-water reservoir is near the intersection of Plains Road and State Highway 138 (fig. 16). At this site, the aquifer has a saturated thickness of 170 feet and is composed of coarse sand and gravel above 68 feet and also below 115 feet. The upper and lower sand and gravel layers are separated by 47 feet of fine sand, silt, and clay. Two pumping wells were located at this site, 8-inch test well SNW 907 and Kingston Fire District well SNW 1152, an 18- X 12-inch gravel-packed public-supply well. Public-supply well SNW 1152 pumps an average of 105 gal/min. Separate aquifer tests were run on the upper, lower, and combined upper and lower sand and gravel layers. Combination wells screened in both the upper and lower sand and gravel layers should have higher yields than wells screened only in the upper aquifer material.




Based from U.S. Geological Survey
1:24,000 Kingston, 1957; and Slocum, 1955

Contour interval 10 feet
Datum is sea level

Figure 16.--Location of "Miscellaneous Sites" showing pumping wells (PW) Exeter 473, South Kingstown 905, 907, 1040, 1152, 1153, 1184, and observation wells.

The hydraulic properties of the combined upper and lower aquifer layers were determined by the Cooper and Jacob graphical method with the modified nonleaky confined formula. During the test, SNW 907 was screened from 10 to 62 feet (upper layer) and from 124 to 176 feet (lower layer). The well was pumped at 395 gal/min for 24 hours, and water was discharged into the Chipuxet River. Several short, 1 to 4 hour, pumping tests were run to develop the pumping well. However, no step-drawdown test was made to determine suspected well loss caused by incomplete development of the entire length of the long well screen sections. The only observation well available to measure during the test on the combined layers was SNW 902. Observation well SNW 902 was 5.3 feet from SNW 907, and screened from 15 to 18 feet. Water-level data from observation well SNW 902 showed only the effects of pumping in the upper sand and gravel layer, and could not be used to determine hydraulic properties for the combined aquifer layers. Drawdown data from pumping well SNW 907 was inconsistent, and recovery data was used to determine aquifer hydraulic properties.

Recovery data in SNW 907 was plotted on semilog paper against logarithms of time after pumping stopped. The time-recovery plot of field data yielded a straight-line graph. The difference per log cycle, obtained from the slope of the straight line, was used to determine transmissivity. Transmissivity was determined from the following equation:

$$T = 0.183\ Q/\Delta s \tag{6}$$

and the storage coefficient from equation:

$$S = 2.25\ \frac{t_o}{(r)^2} \tag{7}$$

where

$T$ = transmissivity, in square feet per day

$Q$ = discharge, in cubic feet per day

$\Delta s$ = drawdown or recovery difference per log cycle, in feet

$S$ = storage coefficient, fraction

$t_o$ = intersection of straight-line slope with zero-drawdown axis, in days

$r$ = distance from pumped well to observation well, in feet

Transmissivity determined by the Cooper and Jacob method with equation 6 was 28,700 $ft^2/d$, and horizontal hydraulic conductivity was 170 ft/d (table 6). The storage coefficient determined from pumping well SNW 907 was unrealistic for a water-table aquifer and is not shown in table 6.

Estimates of transmissivity were also made for the combined aquifer layers from specific-capacity data adjusted for partial penetration and dewatering, and from the lithologic log. Transmissivity estimated from adjusted specific-capacity data was 10,700 $ft^2/d$ (table 6). This value is believed to be low because of uncorrected drawdown, in the pumping well, due to well loss. A transmissivity of 33,700 $ft^2/d$ (table 6) was estimated from the lithology of SNW 907 and is in better agreement with the Cooper and Jacob solution.

During the test of the lower sand and gravel layer, water was pumped from SNW 907 at 380 gal/min for 4 hours. During this test, it was necessary to close off the upper screen between 10 and 62 feet with a rubber seal. The rubber seal was supposed to prevent water from the upper screen from entering the pump intake. Because of suspected leakage around the seal, it was not possible to determine the transmissivity of the lower sand and gravel layer with any degree of accuracy by analytical solution. However, by subtracting the transmissivity determined by the analytical method for the upper layer from the transmissivity of the combined aquifer layers gives a dynamic estimate of transmissivity for the lower layer of 7,500 $ft^2/d$. A somewhat higher transmissivity of 17,000 $ft^2/d$ was estimated for the lower sand and gravel layer from the lithologic log of SNW 907.

The hydraulic properties of the upper sand and gravel layer were determined using methods by Stallman (1963, 1965) and Cooper and Jacob (1946). During the test, SNW 1152 was screened from 48 to 63 feet. A step-drawdown test was not made, and data on development were not available. Well SNW 1152, located 400 feet northeast of SNW 907 (fig. 16), was pumped at 515 gal/min for 66 hours. Drawdown data were analyzed from two 2-1/2-inch open end observation wells, SNW 1161 and 1162, located 50 and 100 feet from pumping well SNW 1152. Transmissivity, determined by the Stallman method, was 21,000 $ft^2/d$, and horizontal hydraulic conductivity was 400 ft/d (table 6). The vertical hydraulic conductivity ranges from 48 ft/d near SNW 1161, to 52 ft/d near SNW 1162 (table 6). The ratio of vertical to horizontal hydraulic conductivity of the upper sand and gravel layer is 1:8. For comparison, transmissivity and horizontal hydraulic conductivity determined from semilog plots of time-drawdown data using the Cooper and Jacob graphical method was 21,600 $ft^2/d$ and 400 ft/d. Although the test was run for 66 hours, the pumping time was too short to determine the true water-table storage coefficient of the aquifer. Individual values of hydraulic properties and methods of analysis are shown in table 6.

Estimates of transmissivity were also made for the upper sand and gravel layer from specific-capacity data adjusted for partial penetration and dewatering, and the lithologic log of pumping well SNW 1152 (table 6). Transmissivity estimated from adjusted specific-capacity data was 6,600 $ft^2/d$, and the estimate from lithology was 6,200 $ft^2/d$. These estimates are extremely low and are included to show the varied range between estimated transmissivities, and those determined by analytical method.

### South Kingstown Wells 1040 and 1153

The old Kingston Fairgrounds area was considered the second most favorable miscellaneous site tested in the Chipuxet River ground-water reservoir. The site consists of two industrial wells, SNW 1040, a 24- X 18-inch gravel-packed well, and SNW 1153, an 8-inch well (fig. 16). Chickasheen Brook is 300 feet west of SNW 1040 and 600 feet west of SNW 1153. These wells are in an anisotropic, water-table aquifer composed mostly of coarse sand and gravel. Although bedrock is 108 feet below land surface, the base of the stratified-drift aquifer is considered to be at 65 feet. Material below 65 feet consisted of silty sand and clay. SNW 1040 was screened from 45 to 65 feet in fine to coarse sand, and SNW 1153 was screened from 52 to 62 feet in medium to coarse gravel. Step-drawdown tests were not made on either well, and data on development were not available. During the first test in 1960, SNW 1040 was pumped at 725 gal/min for 45.5 hours. The pumping rate was increased to 910 gal/min for an additional 2 hours. Drawdown data from two 2-1/2-inch diameter observation wells, SNW 1026 and 1037, were used to determine hydraulic properties of the aquifer from the test at SNW 1040. SNW 1026 was screened from 42 to 60 feet and SNW 1037 was screened from 54 to 64 feet. During the second test in 1974, SNW 1153, 650 feet east of SNW 1040, was pumped at 300 gal/min for 24 hours. Observation wells were not drilled for the test at SNW 1153.

The hydraulic properties of the aquifer at SNW 1040 were determined by analyses of drawdown data with a modified method by Hantush (1960). Hantush's modified method is for nonsteady flow in an isotropic confined aquifer, with vertical movement of water stored in the semipervious confining bed. Water discharged onto the ground 120 feet from SNW 1040, and Chickasheen Brook provided recharge to the aquifer and a constant head boundary on the system. Transmissivity determined by the Hantush method was 14,000 $ft^2/d$, and the horizontal hydraulic conductivity was 235 $ft^2/d$ (table 6). A transmissivity of 13,800 $ft^2/d$ estimated from specific-capacity data adjusted for well loss, partial penetration, and dewatering was in good agreement with that determined by the Hantush modified method. The adjustment for well loss was made with data obtained from increasing the pumping rate during the last 2 hours of the test. A somewhat lower transmissivity of 9,000 $ft^2/d$ was estimated from the driller's lithologic log of SNW 1040.

The lack of observation wells and the inadequacy of a well defined time-drawdown response plot of field data in the 8-inch pumping well, made it impossible to determine the hydraulic properties of the aquifer by analytical solution during the test at SNW 1153. Therefore, the transmissivity was estimated from adjusted specific-capacity data and lithology of the driller's log of SNW 1153. A transmissivity of 6,000 $ft^2/d$ was estimated from specific-capacity data adjusted for partial penetration and dewatering. Drawdown used to estimate transmissivity from specific-capacity data could not be adjusted for well loss because no step-drawdown test was made to determine the efficiency of the pumping well. The estimate from specific-capacity data is believed to be extremely low. Transmissivity estimated from lithology was 13,400 $ft^2/d$. This value is in close agreement with that determined by analytical solution and adjusted specific-capacity data at nearby pumping well SNW 1040, and is considered representative of the transmissivity of the aquifer near SNW 1153.

### South Kingstown Well 1184

Supply well SNW 1184 (fig. 16), at the Kingston sewage pumping station, was pumped at 182 to 205 gal/min for 1 day. Hydraulic properties of the aquifer were determined by the Cooper and Jacob (1946) graphical method with the modified nonleaky confined formula. The Cooper and Jacob method is described in Walton (1962, p. 9). Drawdowns observed, throughout 9 hours of pumping at a constant rate of 205 gal/min in observation well SNW 1188, were plotted against logarithms of time after pumping started on semilog paper. The only observation well available for the test, SNW 1188, was located 5 feet from 12- X 8-inch gravel-packed pumping well SNW 1184. Although pumping time was short, 9 hours was long enough for the time-drawdown plot of the field data to yield a straight-line graph. The drawdown difference per log cycle, obtained from the slope of the straight line, was used to determine transmissivity.

Transmissivity determined by the Cooper and Jacob method with equation 6 was 6,900 $ft^2/d$, and horizontal hydraulic conductivity was 145 ft/d (table 6). A true water-table storage coefficient could not be determined near SNW 1184 with 9 hours of pumping. However, a storage coefficient of 0.009 was computed from equation 7, and is shown to indicate what to expect with early drawdown data from tests conducted in the stratified-drift aquifer. Estimates of transmissivity were also made from specific-capacity data adjusted for partial penetration and dewatering, and from the driller's lithologic log. Transmissivity estimated from the adjusted specific-capacity data and the driller's log of SNW 1184 was 4,700 $ft^2/d$ and 4,800 $ft^2/d$.

This site is of special interest because, although SNW 1184 only pumped 182 to 205 gal/min, the area did produce as much as 2,800 gal/min from a cluster of closely spaced wells during a 4-month dewatering operation. Eight 12-inch diameter wells, each 45 feet deep, were screened in fine to medium sand and some silt with 10 to 12 feet of screen. These wells were pumped to dewater an excavation approximately 100 X 100 feet to a depth of 32 feet. Pumping began on April 1, 1976, at a combined rate of 2,800 gal/min, but dropped to 1,260 gal/min by June 9, 1976. Water was discharged into White Horn Brook, 300 feet east of SNW 1184, through three discharge lines. The dewatering operation illustrates that, in those parts of the stratified-drift aquifer where material is fine grained and a single well will not yield the amount of water needed, several properly designed and developed wells could be used to obtain the desired yield.

### South Kingstown Well 905

The aquifer at the intersection of State Highways 2 and 138 has a saturated thickness of 100 feet. The aquifer is composed primarily of very fine to very coarse sand above 51 feet and medium sand to pebble gravel below 53.5 feet. A semi-confining layer of silt and very fine sand exists between 51 and 53.5 feet. One 2-1/2-inch diameter observation well, SNW 900, was available for measuring drawdown during the test. This well is 10 feet deep, open ended, and 5 feet southeast of SNW 905. Eight-inch well SNW 905 was screened from 13 to 37 feet and 55 to 76 feet while pumping 290 gal/min for 24 hours. Water was discharged into a culvert 600 feet west of SNW 905. Hydraulic properties were determined by analysis of drawdown data from SNW 900 with a method by Stallman (1963, 1965). Transmissivity and horizontal hydraulic conductivity determined by Stallman's vertical movement method is 6,600 $ft^2/d$ and 90 ft/d. Estimates of transmissivity were also made from specific-capacity data adjusted for partial penetration and dewatering, and from the lithologic log. Estimates of transmissivity from adjusted specific-capacity data and the log of SNW 905 were 6,800 $ft^2/d$ and 8,300 $ft^2/d$.

Exeter Well 473

In the northern part of the study area, an aquifer test was made on EXW 473 in the town of Exeter (fig. 16). EXW 473 is an unused 24- X 18-inch gravel-packed well owned by the Tuckahoe Turf Farm. The saturated thickness at EXW 473 is 70 feet. One 2-1/2-inch diameter observation well, EXW 474, was available for measuring drawdown during the test. The observation well was 84.5 feet deep and 2 to 5 feet from EXW 473. The pumping well was screened from 74 to 84 feet in medium sand and gravel with 120-slot screen and pumped at 460 gal/min for 24 hours. A step-drawdown test was not made on EXW 473, and data on development were not available. Hydraulic properties of the aquifer were determined by the Cooper and Jacob (1946) graphical method with the modified nonleaky confined formula. Drawdowns observed in EXW 474 were plotted against logarithms of time after pumping started on semilog paper. The drawdown difference per log cycle, obtained from the slope of the straight-line graph for the early time-drawdown plot of the field data, was used to determine transmissivity. Later time-drawdown data was not used because of suspected recharge from a nearby kettle hole pond. Transmissivity determined by the Cooper and Jacob method with equation 6 is 7,700 $ft^2/d$, and the horizontal hydraulic conductivity is 110 ft/d (table 6). An attempt was made to determine the specific yield of the aquifer by extending the straight-line slope from the semilog plot to the zero-drawdown axis. However, the calculated value of $6 \times 10^{-11}$ is not meaningful and, therefore, is not given in table 6. The specific yield could not be determined. Estimates of transmissivity were also made from specific-capacity data adjusted for partial penetration and dewatering, and from the driller's lithologic log. Transmissivity estimated from adjusted specific-capacity data and the driller's log of EXW 473 is 5,400 $ft^2/d$ and 6,800 $ft^2/d$.

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