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Standard Guide for
Presentation of Water-Level Information From Ground-Water Sites[1]

This standard is issued under the fixed designation D 6000; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers a series of options, but does not specify a course of action. It should not be used as the sole criterion or basis of comparison, and does not replace or relieve professional judgment.

1.2 This guide summarizes methods for the presentation of water-level data from ground-water sites.

NOTE 1—As used in this guide, a site is meant to be a single point, not a geographic area or property, located by an *X*, *Y*, and *Z* coordinate position with respect to land surface or a fixed datum. A ground-water site is defined as any source, location, or sampling station capable of producing water or hydrologic data from a natural stratum from below the surface of the earth. A source or facility can include a well, spring or seep, and drain or tunnel (nearly horizontal in orientation). Other sources, such as excavations, driven devices, bore holes, ponds, lakes, and sinkholes, which can be shown to be hydraulically connected to the ground water, are appropriate for the use intended.

1.3 The study of the water table in aquifers helps in the interpretation of the amount of water available for withdrawal, aquifer tests, movement of water through the aquifers, and the effects of natural and human-induced forces on the aquifers.

1.4 A single water level measured at a ground-water site gives the height of water at one vertical position in a well or borehole at a finite instant in time. This is information that can be used for preliminary planning in the construction of a well or other facilities, such as disposal pits.

NOTE 2—Hydraulic head measured within a short time from a series of sites at a common (single) horizontal location, for example, a specially constructed multi-level test well, indicate whether the vertical hydraulic gradient may be upward or downward within or between the aquifer (see 7.2.1).

NOTE 3—The phrases "short time period" and "finite instant in time" are used throughout this guide to describe the interval for measuring several project-related ground-water levels. Often the water levels of ground-water sites in an area of study do not change significantly in a short time, for example, a day or even a week. Unless continuous recorders are used to document water levels at every ground-water site of the project, the measurement at each site, for example, use of a steel tape, will be at a slightly different time (unless a large staff is available for a coordinated measurement). The judgment of what is a critical time period must be made by a project investigator who is familiar with the hydrology of the area.

1.5 Where hydraulic heads are measured in a short period of time, for example, a day, from each of several horizontal locations within a specified depth range, or hydrogeologic unit, or identified aquifer, a potentiometric surface can be drawn for that depth range, or unit, or aquifer. Water levels from different vertical sites at a single horizontal location may be averaged to a single value for the potentiometric surface when the vertical gradients are small compared to the horizontal gradients.

NOTE 4—The potentiometric surface assists in interpreting the gradient and horizontal direction of movement of water through the aquifer. Phenomena such as depressions or sinks caused by withdrawal of water from production areas and mounds caused by natural or artificial recharge are illustrated by these potentiometric maps.

1.6 Essentially all water levels, whether in confined or unconfined aquifers, fluctuate over time in response to natural- and human-induced forces.

NOTE 5—The fluctuation of the water table at a ground-water site is caused by several phenomena. An example is recharge to the aquifer from precipitation. Changes in barometric pressure cause the water table to fluctuate because of the variation of air pressure on the ground-water surface, open bore hole, or confining sediment. Withdrawal of water from or artificial recharge to the aquifer should cause the water table to fluctuate in response. Events such as rising or falling levels of surface water bodies (nearby streams and lakes), evapotranspiration induced by phreatophytic consumption, ocean tides, moon tides, earthquakes, and explosions cause fluctuation. Heavy physical objects that compress the surrounding sediments, for example, a passing train or car or even the sudden load effect of the starting of a nearby pump, can cause a fluctuation of the water table **(1)**.[2]

1.7 This guide covers several techniques developed to assist in interpreting the water table within aquifers. Tables and graphs are included.

1.8 This guide includes methods to represent the water table at a single ground-water site for a finite or short period of time, a single site over an extended period, multiple sites for a finite or short period in time, and multiple sites over an extended period.

NOTE 6—This guide does not include methods of calculating or estimating water levels by using mathematical models or determining the

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[2] The boldface numbers in parentheses refer to a list of references at the end of this guide.

aquifer characteristics from data collected during controlled aquifer tests. These methods are discussed in Guides D 4043, D 5447, and D 5490, Test Methods D 4044, D 4050, D 4104, D 4105, D 4106, D 4630, D 4631, D 5269, D 5270, D 5472, and D 5473.

1.9 Many of the diagrams illustrated in this guide include notations to help the reader in understanding how these diagrams were constructed. These notations would not be required on a diagram designed for inclusion in a project document.

NOTE 7—Use of trade names in this guide is for identification purposes only and does not constitute endorsement by ASTM.

1.10 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 4043 Guide for Selection of Aquifer-Test Method in Determining of Hydraulic Properties by Well Techniques[3]

D 4044 Test Method (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers Systems[3]

D 4050 Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems[3]

D 4104 Test Method (Analytical Procedure) for Determining Transmissivity of Nonleaky Confined Aquifers by Overdamped Well Response to Instantaneous Change in Head (Slug Tests)[3]

D 4105 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method[3]

D 4106 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method[3]

D 4630 Test Method for Determining Transmissivity and Storage Coefficient of Low Permeability Rocks by in Situ Measurements Using the Constant Head Injection Test[3]

D 4631 Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by in Situ Measurements Using the Pressure Pulse Technique[3]

D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)[3]

D 5092 Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers[3]

D 5254 Practice for the Minimum Set of Data Elements to Identify a Ground-Water Site[3]

D 5269 Test Method for Determining Transmissivity of Nonleaky Confined Aquifers by the Theis Recovery Method[3]

D 5270 Test Method for Determining Transmissivity and Storage Coefficient of Bounded, Nonleaky, Confined Aquifers[3]

D 5408 Guide for the Set of Data Elements to Describe a Ground-Water Site; Part 1—Additional Identification Descriptors[3]

D 5409 Guide for the Set of Data Elements to Describe a Ground-Water Site; Part 2—Physical Descriptors[3]

D 5410 Guide for the Set of Data Elements to Describe a Ground-Water Site; Part 3—Usage Descriptors[3]

D 5447 Guide for Application of a Ground-Water Flow Model to a Site–Specific Problem[3]

D 5472 Test Method for Determining Specific Capacity and Estimating Transmissivity at the Control Well[3]

D 5473 Test Method for (Analytical Procedure for) Analyzing the Effects of Partial Penetration of Control Well and Determining the Horizontal and Vertical Hydraulic Conductivity in a Nonleaky Confined Aquifer[3]

D 5474 Guide for Selection of Data Elements for Ground-Water Investigations[3]

D 5490 Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information[3]

D 5609 Guide for Defining Boundary Conditions in Ground-Water Flow Modeling[3]

3. Terminology

3.1 All definitions appear in Terminology D 653.

3.2 *aquifer*, *n*—a geologic formation, group of formations, or part of a formation that is saturated and is capable of providing a significant quantity of water. **D 653 , D 5092**

3.3 *aquitard*, *n*—a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. **D 653**

3.4 *confined or artesian aquifer*, *n*—an aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer. **D 4050, D4104, D 4105, D 4106, D 5269, D 5609**

3.5 *hydrograph*, *n*—for ground water, a graph showing the water level or head with respect to time **(2)**.

3.6 *unconfined or water-table aquifer*, *n*—an aquifer that has a water table **(3)**. **D 4050, D 4105, D 4106, D 5609**

3.7 *water level*, *n*—for ground water, the level of the water table surrounding a borehole or well. The ground-water level can be represented as an elevation or as a depth below the ground surface. **D 4750**

3.8 *water table (ground-water table)*, *n*—the surface of a ground-water body at which the water pressure equals atmospheric pressure. Earth material below the ground-water table is saturated with water. **D 653, D 4750**

4. Summary of Guide

4.1 The Significance and Use section presents the relevance

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[3] *Annual Book of ASTM Standards*, Vol 04.08.

of the tables and diagrams of the water table and related parameters.

4.2 A description is given of the selection process for data presentation along with a discussion on water level data preparation.

4.3 Tabular methods of presenting water-levels:

4.3.1 Tables with single water levels, and

4.3.2 Tables with multiple water levels **(4)**.

4.4 Graphical methods for presenting water levels:

4.4.1 Vertical gradient at a single site,

4.4.2 Hydrographs,

4.4.3 Temporal trends in hydraulic head,

4.4.4 Potentiometric maps,

4.4.5 Change maps,

4.4.6 Water-table cross sections, and

4.4.7 Statistical comparisons of water levels.

4.5 Sources for automated procedures (computer-aided graphics) for basic calculations and the construction of the water-level tables and diagrams are identified.

4.6 Keywords.

4.7 A list of references is given for additional information.

5. Significance and Use

5.1 Determining the potentiometric surface of an area is essential for the preliminary planning of any type of construction, land use, environmental investigations, or remediation projects that may influence an aquifer.

5.1.1 The potentiometric surface in the proposed impacted aquifer must be known to properly plan for the construction of a water withdrawal or recharge facility, for example, a well. The method of construction of structures, such as buildings, can be controlled by the depth of the ground water near the project. Other projects built below land surface, such as mines and tunnels, are influenced by the hydraulic head.

5.2 Monitoring the trend of the ground-water table in an aquifer over a period of time, whether for days or decades, is essential for any permanently constructed facility that directly influences the aquifer, for example, a waste disposal site or a production well.

5.2.1 Long-term monitoring helps interpret the direction and rate of movement of water and other fluids from recharge wells and pits or waste disposal sites. Monitoring also assists in determining the effects of withdrawals on the stored quantity of water in the aquifer, the trend of the water table throughout the aquifer, and the amount of natural recharge to the aquifer.

5.3 This guide describes the basic tabular and graphic methods of presenting ground-water levels for a single ground-water site and several sites over the area of a project. These methods were developed by hydrologists to assist in the interpretation of hydraulic-head data.

5.3.1 The tabular methods help in the comparison of raw data and modified numbers.

5.3.2 The graphical methods visually display seasonal trends controlled by precipitation, trends related to artificial withdrawals from or recharge to the aquifer, interrelationship of withdrawal and recharge sites, rate and direction of water movement in the aquifer, and other events influencing the aquifer.

5.4 Presentation techniques resulting from extensive computational methods, specifically the mathematical models and the determination of aquifer characteristics, are contained in the ASTM standards listed in Section 2.

6. Selection and Preparation of Water-Level Data

6.1 Water levels should be subject to rigorous quality-control standards. Correct procedures must be followed and properly recorded in the field and the office in order for the water table to represent that in the aquifer.

6.1.1 Field-quality controls include the use of an accurate and calibrated measuring device, a clearly marked and unchanging measuring point, an accurate determination of the altitude of the measuring point for relating this site to other sites or facilities in the project area, notation of climatic conditions at the time of measurement, a system of validating the water-level measurement, and a straight-forward record keeping form or digital device.

6.1.2 Digital recording devices must be checked regularly to ensure that a malfunction has not occurred. A properly operating device that transfers the data directly to a digital computer should alleviate any problems with the transposing of numbers.

NOTE 8—Many permanently installed digital devices record water levels at fixed intervals, for example every 15 min. Unless the device is designed to be activated when sudden changes occur, events that cause an instantaneous and short term fluctuation in the water table may not be recorded, for example, earthquakes and explosions. Continuous recording analog devices are used to detect these types of events.

6.1.3 Much of the problem in preparation of water-level measurements occurs in the office as the result of transposing numbers. This transposition can result when the numbers are manually transferred from a field form to an office data file, perhaps another form or a digital computer data bank. The accuracy of this transfer, and any succeeding transfers or computations, must be verified, preferably by a co-worker, or an independent QA/QC (quality assurance/quality control) officer.

6.2 To interpret the significance of the raw water-level data, usually the information is prepared by adjusting to other values by using simple mathematics. For example, the water-level values in relationship to the measuring point are reduced to the altitude of the water table by subtracting the water level (+ or −) from the altitude of the measuring point. This procedure applied to all water levels from sites in the project area reduces these water levels to a common plane for comparison.

6.2.1 Preparation of water-level data for interpreting upward or downward trends over a period of time may require the use of simple regression or moving average/mean computations. A common analysis of the water-level data involves the selection of yearly highs and lows for use in computing high and low trends.

6.2.2 A technique of presenting water levels is to give the value as below or above land surface. This method requires that the numerical relationship of the measuring point and land surface be determined and the value of the measuring point be subtracted (+ or −) from the water-level measurement. This information gives the relationship of a single water level to the land surface at a finite instant in time. At a long-termed monitoring site the fluctuations and trends are shown. These water levels cannot be completely related to other sites in the area without additional computation (determining altitude of water level).

6.2.3 On occasion, the interpretations of human-induced water-table fluctuations at a site are masked by natural events, such as oscillations caused by barometric pressure or ocean tide. The magnitude and frequency of these fluctuations can be determined by monitoring the barometric pressure, ocean tide, and water levels in wells outside the radius of influence of the principal monitored site.

7. Presentation of Water-Level Information

7.1 *Tabular Methods of Presenting Water Levels*—Tables of ground-water levels in project reports vary from single measurements included in lists of related information, for example, well inventory data (Practice D 5254, Guides D 5408, D 5409, D 5410, and D 5474), to tables that represent a long-term comprehensive record of the water levels at a site. The water levels can be presented as values in feet or metres as related to land surface or the altitude as related to mean sea level or other common level. These values can be for a time-interval, for example, daily or weekly, giving the high, low, mean, or median water level for each period. Other methods include presenting water levels for a specific time, for example, noon or midnight **(4)**.

7.1.1 *Tables with Single Water Levels*—A single water level is normally included as one of the data items in a table entitled the "description of selected wells" or "ground-water site-inventory data" in many project reports. This table contains pertinent information from selected ground-water sites of the studied area. Table 1 is an abbreviated example of a "ground-water site-inventory data."

NOTE 9—The data included with the water level varies depending upon the priorities of the project, however, the site identification is standard information in most tables. Computerized tabular procedures are normally designed to print any data item in any order from the ground-water site files.

7.1.2 *Tables of Multiple Water Levels from Single Sites*—The following are common types of tables used to present ground-water levels from single sites. The format usually depends upon the method and frequency of data collection.

NOTE 10—Each individual table commonly includes a heading of information that describes the ground-water site. This heading normally contains the site location, owner, aquifer, site or well characteristics, instrumentation, datum and measuring point, relevant remarks, period of record, and extremes for the period of record.

7.1.2.1 *Tables of High and Low Water Levels for a Selected Period*—The water levels are retrieved from the continuous analog or digital recorders. The period for selecting the water levels can be of any length, for example, daily, weekly, monthly, seasonally, semiannually, yearly, and for the total period of record. For aquifer testing, for example, it can be for a background period and stress period separately. The table of water levels can be the high, low, or both values for the selected period of record (see Table 2).

7.1.2.2 *Mean Water Levels for a Selected Period*—The water levels are retrieved from digital recording media and the mean water levels determined for a specific period by computer procedures. The mean water level can be determined from the analog recorders by use of electronic scanners or, with more difficulty, manually. The period for determining each water level may be daily, five-day, monthly, etc., and should be determined based on the objective of the project (see Table 3).

7.1.2.3 *Periodic Fixed-time Reading*—Periodic water levels can be selected from the records of analog or digital recorders. The interval between each selected water level may be daily, every fifth day and end of month, weekly, or monthly, with the selected time-of-day constant, for example, the noon reading (see Table 4).

7.1.2.4 *Intermittent Water-level Measurements*—Water levels are considered intermittent when determined manually by instruments such as a steel tape or an electronic water-detection device. These measurements are usually collected by field personnel on a periodic time schedule at ground-water sites where there is no continuous recorder (see Table 5).

7.1.3 *Tables of Water Levels from Multiple Sites*—Tables that include water levels from more than one ground-water site allow for comparison of data from related locations (see Table 6).

7.2 *Graphical Methods of Presenting Water Levels*—Methods to represent water levels include those at a single ground-water site for a finite or short period of time, a single site over an extended period of time, multiple sites for a finite or short period in time, and multiple sites over an extended period of time.

NOTE 11—The simplest category of the presentation of a water level is from a single ground-water site for a finite instant or short period in time. Water levels measured at a single ground-water site over a period of time give climatic trends and the effects of human and natural stresses on water in the aquifer. Water levels can be measured continuously by analog recorders or digital recorders and intermittently by a steel tape or electronic devices.

NOTE 12—To interpret hydraulic-head data over the area of a project or political entity, multiple ground-water sites need to be included in the analysis. These sites should be in the same aquifer, widely distributed, and the water levels measured during a short period.

NOTE 13—Multiple sites where ground-water levels are measured by a continuous recorder or periodically by other methods are valuable for

TABLE 1 Example Table—Sites With A Single Water Level[A]

Ground-Water Site Inventory					
Site ID	Owner	Geologic Unit	Altitude (in feet above msl)	Date	Water Level (in feet below lsd)
404240116025001	CARLIN TOWN GOVT	110VLFL	5950.	03/31/81	11.37
402100116352001	BEOWAWE FARMS	110VLFL	5650.	03/23/81	77.89
412421117303301	SHELTON SCHOOL	110VLFL	4582.	03/18/81	6.11
404940117475001	J BALLARD	110VLFL	4317.	12/11/80	22.30
374638087054101	OWENSBORO, CITY	1120TSH	405.	10/12/82	53.23

[A] Table adapted from Ref **(5)**.

TABLE 2 Example Table—Lowest Water Levels For A Site[A]

382150078424001. Local number, 41Q1.

LOCATION.—Lat 38°21′50″, long 78°42′40″, Hydrologic Unit 02070005, at Virginia Department of Highways and Transportation garage near McGaheysville. Owner: U.S. Geological Survey.

AQUIFER.—Conococheague limestone of Late Cambrian age.

WELL CHARACTERISTICS.—Drilled observation water well, diameter 6¼in., depth 310 ft, cased to 131 ft, open hole 131 to 310 ft.

INSTRUMENTATION.—Water-level recorder.

DATUM.—Elevation of land-surface datum is 1105 ft above National Geodetic Vertical Datum of 1929, from topographic map. Measuring point: Top edge of recorder shelf, 3.50 ft above land-surface datum.

PERIOD OF RECORD.—August 1970 to current year.

EXTREMES FOR PERIOD OF RECORD.—Highest water level recorded, 60.38 ft below land-surface datum, Dec. 26, 1972; lowest recorded, 87.18 ft below land-surface datum, Oct. 26, 1977.

Water Level, in Feet Below Land-Surface Datum, Water Year October 1982 to September 1983 Lowest Values

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
5	73.32	76.01	76.07	71.52	72.79	68.43	65.68	64.46	64.70	66.09	68.04	71.10
10	73.87	76.11	75.60	71.48	71.81	68.14	65.54	64.81	65.09	66.35	68.42	71.72
15	74.39	76.33	75.27	71.69	71.07	68.03	64.41	65.04	65.41	66.62	68.86	72.28
20	74.90	76.60	75.11	72.14	70.34	65.85	64.39	64.53	65.55	66.93	69.32	72.86
25	75.36	76.94	72.94	72.55	69.14	65.88	64.07	64.18	65.60	67.25	69.86	73.48
EOM	75.75	76.98	71.94	73.00	68.76	66.10	64.08	64.54	65.88	67.67	70.52	74.04

WTR YR 1983 HIGHEST 63.81 APR 27, 1983 LOWEST 76.98 NOV 28, 1982

[A] Table adapted from Ref **(5)**.

TABLE 3 Example Table—Mean Water Levels For A Site[A]

402208074145201. Local I.D., Marlboro 1 Obs. NJ-WRD Well Number, 25-0272.

LOCATION.—Lat 40°22′08″, long 74°14′52″, Hydrologic Unit 02030104, on the west side of New Jersey Route 79, 0.9 ml south of Morganville, Monmouth County, New Jersey. Owner: Marlboro Township Municipal Utilities Authority.

AQUIFER.—Farrington aquifer, Potomac-Raritan-Magothy aquifer system of Cretaceous age.

WELL CHARACTERISTICS.—Drilled artesian observation well, diameter 6 in., depth 680 ft, screened 670 to 680 ft.

INSTRUMENTATION.—Digital water-level recorder—60-minute punch.

DATUM.—Land-surface datum is 116.73 ft above National Geodetic Vertical Datum of 1929. Measuring point: Top edge of recorder shelf, 2.50 ft above land-surface datum.

REMARKS.—Water level affected by nearby pumping. Missing record from May 19 to July 4 was due to recorder malfunction.

PERIOD OF RECORD.—March 1977 to current year. Records for 1973 to 1977 are unpublished and are available in files of New Jersey District Office.

EXTREMES FOR PERIOD OF RECORD.—Highest water level, 144.06 ft below land-surface datum, Apr. 4, 1973; lowest, 190.49 ft below land-surface datum, July 29, 1983.

Water Level, in Feet Below Land Surface Datum, Water Year October 1983 to September 1984 Mean Values

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
5	178.44	168.09	161.50	159.63	158.03	158.25	157.72	156.94	...	170.00	169.37	172.95
10	177.44	166.41	161.52	159.12	158.47	158.16	158.17	156.95	...	169.11	168.93	172.67
15	173.78	166.48	160.28	158.45	158.27	157.79	158.00	157.42	...	171.58	168.45	171.39
20	172.68	165.34	160.07	158.25	158.09	157.50	157.99	...	...	170.39	169.50	171.09
25	171.04	164.31	159.81	157.83	158.05	157.69	157.39	...	...	169.74	171.15	172.76
EOM	170.22	163.51	160.20	157.95	157.94	156.78	157.81	...	...	167.63	174.11	171.45
MEAN	174.70	166.15	160.77	158.63	158.27	157.75	157.88	...	...	169.50	169.99	172.60

WTR YR 1984 MEAN 164.15 HIGH 155.71 MAY 5 LOW 182.94 OCT 1

[A] Table adapted from Ref **(5)**.

interpreting changes in aquifers caused by discharge and recharge events. These changes can be illustrated by maps and cross sections, and by the comparison of hydrographs.

7.2.1 *Vertical Gradient at a Single Site*—Multiple water levels can be measured within a short period of time from a series of vertical positions in different aquifers at a specially constructed ground-water site. The data gathered indicates the hydraulic gradient of the water **(5,6)**. Examples of the three gradient possibilities from tightly spaced piezometers in a single unit **(7)** are given in Fig. 1. An example of a downward gradient in eight aquifers **(8)** is given in Fig. 2.

NOTE 14—In Fig. 2, water levels at 143 ft (43.58 m), 305 ft (92.96 m), and 460 ft (140.21 m) were measured in 1961, others in 1959. These data are from an area where little development had taken place at the time of the water-level measurements.

NOTE 15—An example of a specially constructed well is a test hole where the water level is measured at progressively deeper positions in the aquifer or a series of aquifers. The well is open to the aquifer at progressively deeper depths and each opening is uniquely accessible for measurement of the water level by a pipe to the surface, or several piezometers or wells that are tightly spaced and each open at a different depth in the aquifer.

7.2.2 *Hydrographs*—The hydrograph is used to illustrate the fluctuation of the hydraulic head over a period of time at a ground-water site. Interpolated lines (areas of missing or indeterminate record) on hydrographs should be clearly identified. The hydrograph is accompanied commonly with time-related phenomena to help in the interpretation of the fluctuations, for example, precipitation. Recession curves of surface-water hydrographs are used to determine ground-water baseflow in the streams. Some examples of the hydrographs and combined phenomena for a ground-water site follow.

7.2.2.1 *Simple Hydrograph*—The basic hydrograph of the water table at a ground-water site displays the natural and human-induced fluctuations over a period of time. The example hydrograph shows fluctuations controlled by natural conditions from 1971 to 1976, those resulting from pumping

TABLE 4 Abbreviated Table—Noon Water Levels For A Site[A]

374638087054101. Map number 1.

LOCATION.—Lat 37°46′38″, long 87°05′41″, Hydrologic Unit 05140201, County Code 059, Owensboro East quadrangle, at Owensboro Municipal Utilities water treatment plant, 100 ft (30 m) south of south bank of Ohio River, 0.1 ml (0.2 km) northeast of Davies County High School. 0.3 ml (0.5 km) north of U.S. Highway 60, in Owensboro, Daviess County, Kentucky. Owner: Owensboro Municipal Utilities.

AQUIFER.—Glacial sand and gravel of Quaternary age. Aquifer code: 112OTSH.

WELL CHARACTERISTICS.—Drilled unused water-table well, diameter 12 in. (0.30 m), depth 104 ft (32 m), screened 74–104 ft (22.6–31.7 m).

DATUM.—Altitude of land-surface datum (from topographic map) is about 405 ft (123 m). Measuring point: Floor of recorder shelter 4.33 ft (1.32 m) above land-surface datum.

REMARKS.—Water level affected by pumping from nearby wells.

PERIOD OF RECORD.—February 1951 to current year.

EXTREMES FOR PERIOD OF RECORD.—Highest water level, 18.16 ft (5.54 m) below land-surface datum, May 5, 1983; lowest, 63.21 ft (19.27 m) below land-surface datum, Sept. 17, 1970.

Depth Below Land Surface (Water Level), (ft), Water Year October 1982 to September 1983 Instantaneous Observations at 1200

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	54.51	48.09	44.14	45.05	55.92	46.52	49.32	30.32	39.39	49.56	50.40	52.97
2	49.52	48.78	44.89	42.32	55.71	47.08	46.04	37.11	43.03	48.96	49.74	52.09
3	49.65	49.20	42.17	48.59	50.84	50.39	46.03	30.69	43.46	43.70	47.87	50.16
4	50.29	47.12	41.20	...	54.38	48.90	50.79	23.20	40.92	43.12	50.86	49.67
5	51.37	47.45	40.22	51.32	49.47	49.12	49.06	18.16	39.86	43.78	49.27	49.56
6	51.73	45.38	45.11	51.86	47.42	44.92	49.22	28.90	44.66	46.53	46.02	51.96
7	50.62	46.26	46.60	54.53	49.47	50.32	48.96	28.47	45.58	46.70	45.89	52.22
Water Levels for Days 8th through 28th Deleted for This Illustration												
29	49.24	45.13	45.73	54.57	...	46.92	41.06	31.82	46.42	51.62	52.73	52.46
30	47.34	48.89	45.69	54.85	...	47.53	36.55	34.78	47.30	49.14	51.46	52.77
31	47.37	...	44.73	55.99	...	50.07	...	36.29	...	48.82	52.22	...
MAX	54.51	49.71	53.19	58.00	55.92	51.26	56.44	38.75	50.57	54.70	54.38	53.72
MIN	46.74	43.70	40.22	42.32	44.76	44.76	36.55	18.16	39.39	43.12	45.89	45.21

WTR YR 1983 HIGH 16.16 MAY 5 LOW 58.00 JAN 20

[A] Table adapted from Ref **(5)**.

TABLE 5 Example Table—Intermittent Water Levels For A Site[A]

424202087542301. Local Number, RA-03/22E/21-0005.

LOCATION.—Lat 42°42′02″, long 87°54′23″, Hydrologic Unit 04040002. Owner: Chicago, Milwaukee, St. Paul, and Pacific Railroad Co., Racine County, Wisconsin.

AQUIFER.—Sandstone.

WELL CHARACTERISTICS.—Drilled unused artesian well, diameter 12 in. (0.30 m), depth 1,176 ft (358 m), cased to 586 ft (179 m), 10 in. (0.25 m) liner 976-1083 ft (297–330 m).

DATUM.—Altitude of land-surface is 730 ft (225 m) National Geodetic Vertical Datum of 1929. Measuring point: top of casing, 1.00 ft (0.30 m) above land-surface datum.

REMARKS.—Water level affected by regional pumping of wells.

PERIOD OF RECORD.—July 1946 to current year.

EXTREMES FOR PERIOD OF RECORD.—Highest water level measured, 109.00 ft (33.25 m) below land-surface datum, July 29, 1946; lowest water level measured, 264.70 ft (80.68 m) below land-surface datum, Mar. 3, 1981.

Water Level, in Feet Below Land-Surface Datum, Water Year October 1980 to September 1981

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
FEB 12	257.00	MAR 17	256.63	MAY 1	262.50	JUN 1	263.30	JUN 29	262.70	SEP 15	263.30
MAR 3	264.70	APR 6	257.40								

[A] Table adapted from Ref **(5)**.

withdrawals that began in 1976, and those caused by seasonal variations in pumping that are apparent from 1984 to 1988 (see Fig. 3) **(9–11)**.

NOTE 16—The water level measurements in Fig. 3 average two values per year. These intermittent values are connected by interpolated lines to simulate a continuous hydrograph. Water levels determined by a nearly continuous digital recorder would result in a continuous hydrograph.

7.2.2.2 *Hydrograph Compared with Precipitation that Results in Natural Recharge*—Precipitation that results in recharge to an unconfined aquifer can be analyzed by comparison of the timing and amount of rainfall with the hydrographs of shallow wells in the area. A method of displaying this relationship is by combining a water-table graph and a precipitation line or bar plot onto a single illustration. The time scales for the two sets of data are equal, and the water-table and precipitation data are scaled to emphasize the relationship of the values (see Fig. 4) **(1,12–18)**.

NOTE 17—Rapid response to recharge events is evident where the travel path from the land surface to the aquifer is short or unrestricted, for example, a shallow sand formation or a karst topography. Heavy rainstorms can cause entrapment of air between the recharge water at the surface and a shallow water table. This recharge surge can increase the pressure of the trapped air creating a rapid decline in the water table and a resultant rise of water in open observation wells. The water table will rise when the entrapped air escapes by breaching the recharged water and continue to rise as the recharge water reaches the water table. In aquifers where restrictions occur, for example, intermediate clay layers or aquitards, the response can be dampened or delayed because of a much longer travel time.

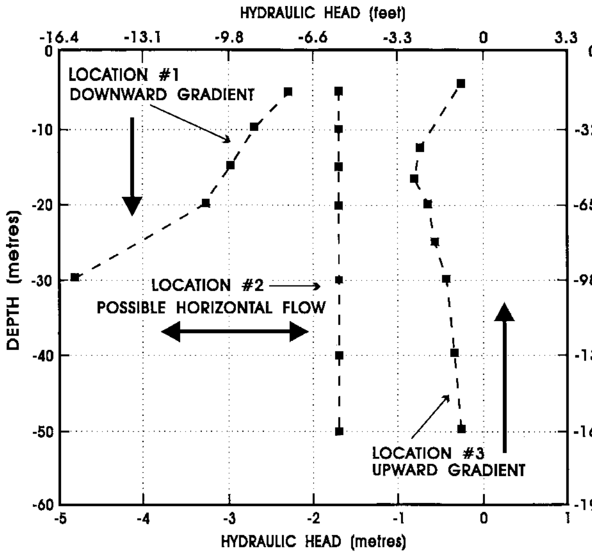
7.2.2.3 *Hydrograph Compared with Artificial Recharge to the Aquifer*—Artificial recharge to aquifers can occur from methods that spread water on the land's surface, for example, irrigation, or from techniques that direct the water below the land's surface, for example, recharge wells and pits. This type of recharge can be monitored by wells in the area and

TABLE 6 Abbreviated Table—Water Levels From Multiple Sites[A]

LOCATION.—State of Nevada.
WELL DEPTH.—Depths are referenced to Land-surface Datum (LSD).
PERIOD OF RECORD.—Interval shown spans period from earliest measurement to latest measurement, and may include intervals with no record.
WATER LEVELS.—Levels above LSD are listed as negative values.

Site ID	Well Depth (Ft)	Period of Record	Water Levels (Feet Below Land Surface)					
			Highest	Date	Lowest	Date	Current	Date
415800118370001	200.	1968-	45.58	03/20/68	56.80	05/01/69	51.55	03/17/81
413630119520001	70.	1968-	10.22	03/13/72	14.66	04/10/79	12.34	04/07/81
403200119490001	111.	1966-	37.91	09/15/66	54.97	04/17/79	54.41	03/24/81
402700119250001	109.	1966-	45.20	04/09/69	50.11	03/26/81	50.11	03/23/81
405211119202901	134.	1979-	29.53	04/17/79	31.25	03/23/81	31.25	03/23/81
405208119161501	15.	1967-	3.77	04/16/73	14.21	03/23/81	14.21	03/23/81
405208119161502	66.	1967-	−2.25	06/14/67	9.37	03/23/81	9.37	03/23/81
412954117495001	250.	1971-	50.96	04/30/73	78.11	04/29/71	58.24	03/17/81
413310117482002	95.	1948-	36.54	04/21/48	116.58	03/23/77	72.17	03/17/81
413320117482001	160.	1949-	16.55	01/20/50	123.19	03/23/77	91.85	03/17/81

[A] Table adapted from Ref **(5)**.



NOTE 1—Location No. 2 is fabricated to simulate horizontal flow.

FIG. 1 Hydraulic Gradient at Three Ground-Water Locations (adapted from Ref (8))

illustrated by hydrographs (see Fig. 5) **(19–21)**.

7.2.2.4 *Hydrograph Compared with Barometric Pressure*—A change in barometric pressure causes water levels to fluctuate in open wells. The effects of barometric pressure often mask other influences that cause fluctuations of the water table. By plotting the hydrograph and barometric pressure on an equal time scale, the correlation of oscillations can be demonstrated (see Fig. 6) **(22–28)**.

NOTE 18—The effect of barometric pressure can be removed from the water-table fluctuations by subtracting the value determined from multiplying the "barometric efficiency" (BE) times the amount of water-table fluctuation. The BE is a decimal number determined by dividing the change in water level (ΔW) by the change in barometric pressure (ΔB) over an interval of time ($BE = \Delta W/\Delta B$). These two values must be in the same units to calculate the BE, for example, if the water levels are in metres, then convert the barometric pressure to metres of water at 4°C (1000 millibars pressure = 10.197 m of water at 4°C).

7.2.2.5 *Hydrograph Compared with Withdrawals from the Aquifer*—Water withdrawals from an aquifer can result in the fluctuation and decline of the hydraulic head. The hydraulic head fluctuates depending upon the periodic oscillation in the amount of water withdrawn and decline when the water removed is more than water recharged to the aquifer. A hydrograph from a ground-water site compared with the withdrawal amounts displays the effect on the hydraulic head in the aquifer (see Fig. 7) **(22, 22–34)**.

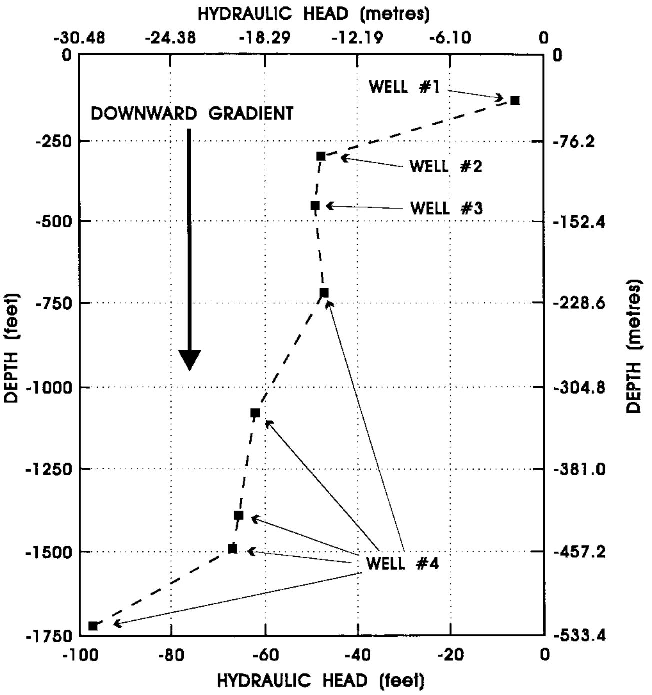


FIG. 2 Hydraulic Gradient at a Ground-Water Location (data from four wells) (adapted from Ref (9))

7.2.2.6 *Hydrograph Compared with Tidal Effects*—The hydraulic head fluctuates semidiurnally in response to tides in the solid earth and in large bodies of surface water. The tides are caused by the gravitational attraction of the moon and sun upon the earth (see Fig. 8) **(5, 35–38)**.

NOTE 19—Fluctuations are obvious in confined aquifers that are next to an ocean where a rising tide compresses the underlying sediments (rising hydraulic head) and a falling tide allows the underlying sediments to expand (falling hydraulic head). The water table in unconfined aquifers near large surface water bodies fluctuates caused by the actual movement of water in the aquifer. Fluctuations caused by earth tides are obscure, but

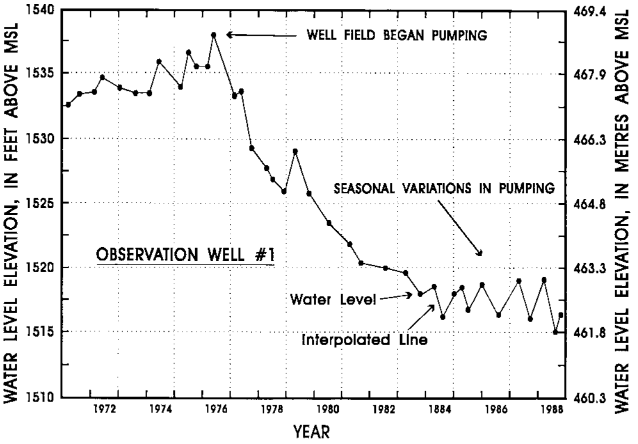


FIG. 3 Example of Simple Hydrograph (adapted from Ref (10))

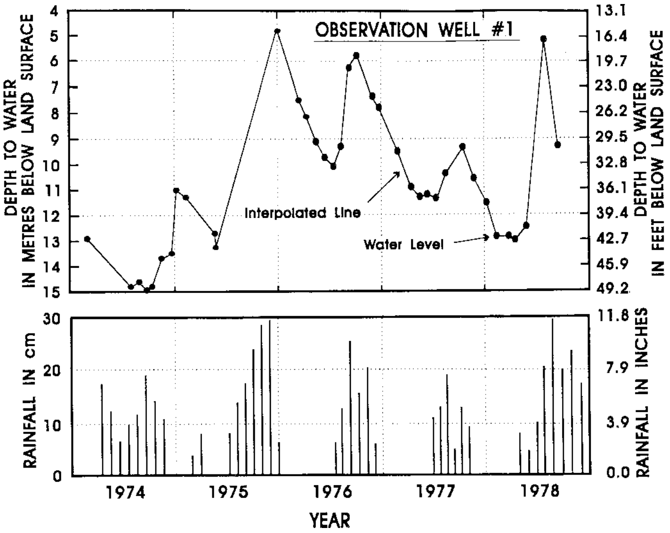


FIG. 4 Hydrograph and Precipitation Plot (adapted from Ref (13))

can be detected in confined aquifers of inland areas by mathematically removing the influence of other causes of hydraulic-head oscillations, such as the barometric pressure.

7.2.2.7 *Hydrograph Compared Earthquakes, Explosions, and Loading Effects*—Shock waves radiating out from earthquakes and explosions travel through the earth and along the earth's surface causing the elastic crust to compress and expand, resulting in a fluctuation of the hydraulic head (see Fig. 9). Loading effects on underlying sediments, for example, a train that moves through the area, can cause the hydraulic head to oscillate in response **(37, 39–45)**.

7.2.2.8 *Hydrograph Compared with Water Quality Parameters*—The fluctuation of the hydraulic head in an aquifer can indicate the movement of water containing natural- and human-induced chemical constituents toward an area of lower hydraulic pressure. A comparison of the hydrograph and a time-plot of the chemical constituents at a ground-water site can help in the interpretation of the origin and rate of movement of these constituents (see Fig. 10) **(20, 31, 46–51)**.

NOTE 20—Some of the constituents in the ground water can originate from natural leaching because of recharge oscillations caused by climatic cycles. Artificial recharge of water from surface spreading or injection by pits or wells can leach or induce ions into the ground water. Water that has a high concentration of dissolved solids, for example, seawater, is denser than fresh water and, therefore, will have a slight difference in the water table when compared to bordering fresh water.

7.2.2.9 *Hydrograph Compared with Surface Stream*—The water table in unconfined aquifers that are next to and interconnected with streams and lakes, react rapidly to changes in the surface-water stage. The amount of fluctuation in the surface-water stage and the ground-water table is similar if the observation well is close to the stream (see Fig. 11). These fluctuations are dampened if the observation well is at some greater distance from the surface-water body. Oscillations in confined aquifers are caused by the loading effect of rising and falling surface-water stages (see 7.2.2.6 on tidal effects) **(33, 52–54)**.

7.2.2.10 *Hydrograph Compared with Air Temperature*—The water table in unconfined aquifers that are a few feet or metres below lands surface fluctuate in response to the thermal gradient between the mean air and ground-water temperatures, in that the capillary moisture and soil vapor move toward the medium having the lowest temperature (see Fig. 12) **(1,55,56)**.

NOTE 21—When the mean daily air temperature remains below freezing over time, the upward moving water freezes in the near surface soil material, forming a frost layer. Because of this water transfer, the ground-water table declines. Soon after the mean daily temperature rises above freezing, melted water from the frost layer moves downward as recharge causing a rise in the ground-water table. During the spring and summer months, evapotranspiration causes diurnal fluctuations of the shallow water table. If no recharge occurs during this period, the general trend of the water table will be downward.

7.2.2.11 *Hydrograph with Fluctuations Caused by Unusual Phenomenon*—The sudden rise of a hydraulic head may be a clue to a problem that has affected the aquifer, for example, a defective casing of a gas well that has allowed natural gas to escape into the aquifer (see Fig. 13). An undefined change of the hydraulic head may indicate a movement of water from one aquifer to another having a lower water table, perhaps from a failed casing or improperly constructed well **(57)**.

7.2.2.12 *Hydrograph with Boxplots of Water Levels, Precipitation, Surface Water, and Evaporation*—An association of ground water, surface water, and precipitation time-series graphs with statistical boxplots offers a useful combination for data interpretation. The boxplots concisely illustrate the median, 25th percentile, 75th percentile, skewness, and the outside and far-outside values for each of those data sets (see Fig. 14) **(58)**.

7.2.2.13 *Multiple Hydrographs*—Hydrographs from multiple ground-water sites of an area can be compared to interpret the rate of water movement in an aquifer and between several aquifers (see Fig. 15) **(18, 59–65)**.

NOTE 22—Hydrographs from precisely positioned ground-water sites in an aquifer of a project area can be compared to determine the effect of distance from an impacted locality on the water table, for example, the water levels of monitoring wells for a recharge pit. The elapse-time effects of natural or artificial recharge can be evaluated by comparing hydrographs from a shallow and the underlying aquifers. The effects of distance from fluctuating surface-water bodies on adjacent aquifers can be shown by comparing the hydrographs.

7.2.3 *Temporal Trends in Hydraulic Head*—The temporal trend of hydraulic head is dictated by many factors that

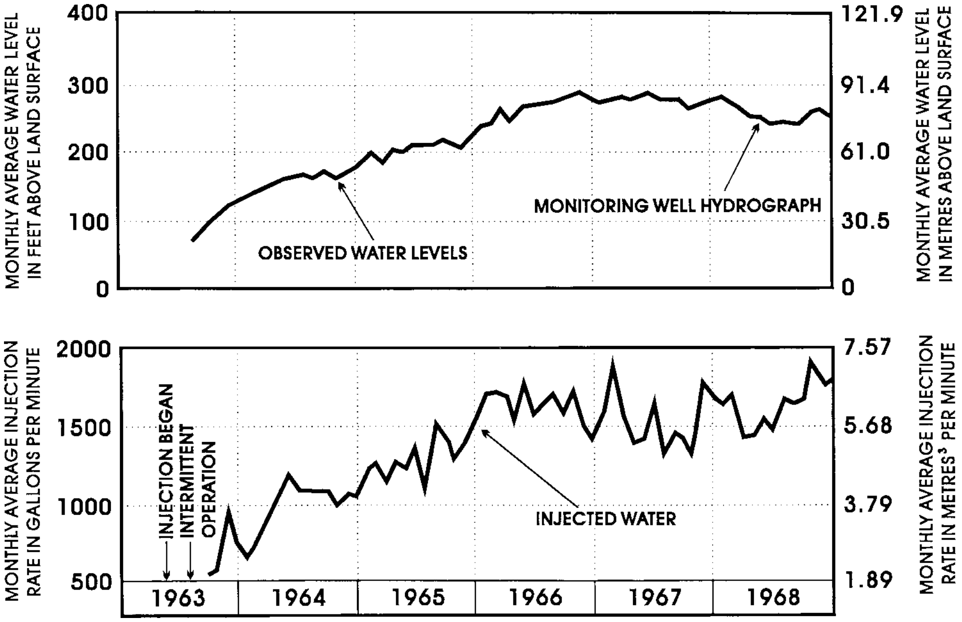


FIG. 5 Hydrograph Showing Effects of Artificial Recharge by Injection Well (adapted from Ref (20))

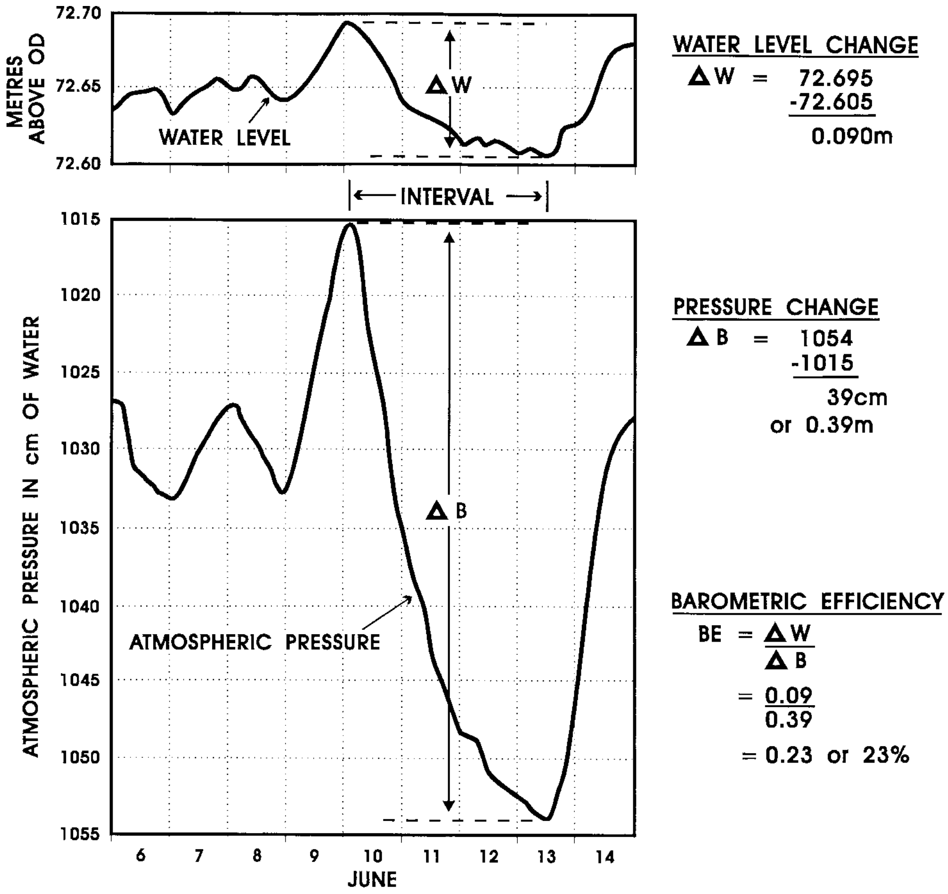
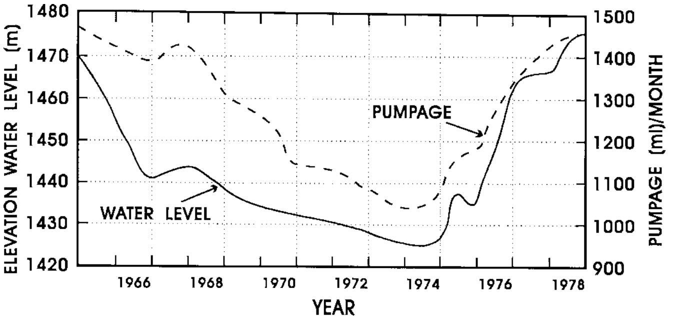


FIG. 6 Hydrograph with Barometric Efficiency (adapted from Refs (23,24))

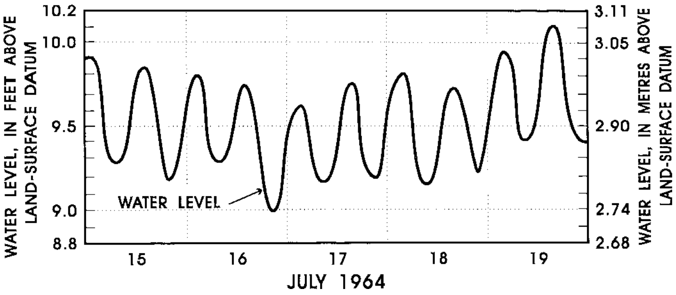
contribute to the stress of an aquifer, for example, recharge of water to and discharge of water from the aquifer. All longer-term hydrographs exhibit a trend, either downward, level, upward, or cyclical.

7.2.3.1 *Trend Hydrograph*—At ground-water sites where the water level is measured by a continuous recorder, the trend can be determined by selecting the high, computing the mean, or selecting the low water level from a fixed period, for example, a day, week, month, or year, and plotting these values as a hydrograph. At ground-water sites where water levels are



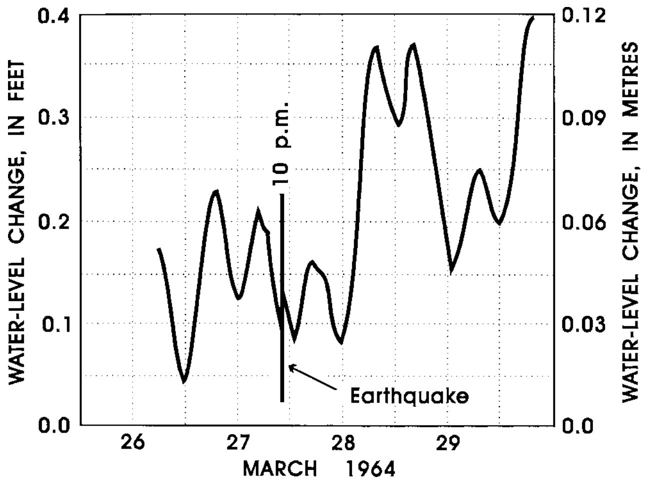
NOTE 1—This is a mined area where pumpage is for dewartering the mine. Pumpage exceeded recharge before 1975 resulting in a decline of the water level. Abnormally high rainfall beginning in 1975 resulted in increase recharge and a rise of the water level. Pumpage was increased to control the rise of the water level.

FIG. 7 Hydrograph with Pumpage (adapted from Ref (30))



NOTE 1—This is an artesian aquifer.

FIG. 8 Hydrograph Showing Tidal Effects (adapted from Ref (36))

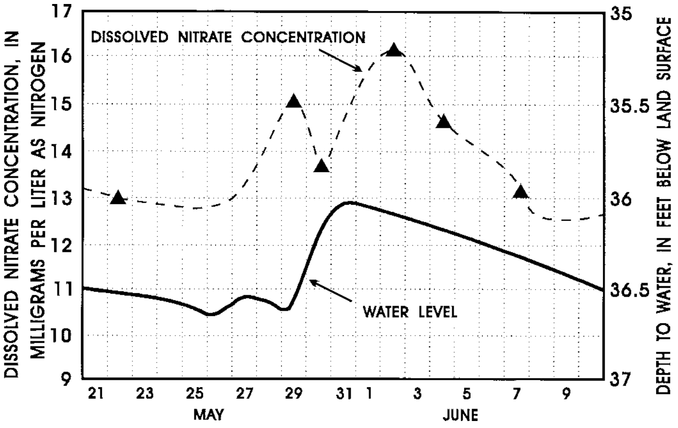


NOTE 1—March 27, 1964 Alaskan earthquake, well at Vincent Dome, Iowa.

FIG. 9 Hydrograph With Seismic Fluctuation (adapted from Ref (40))

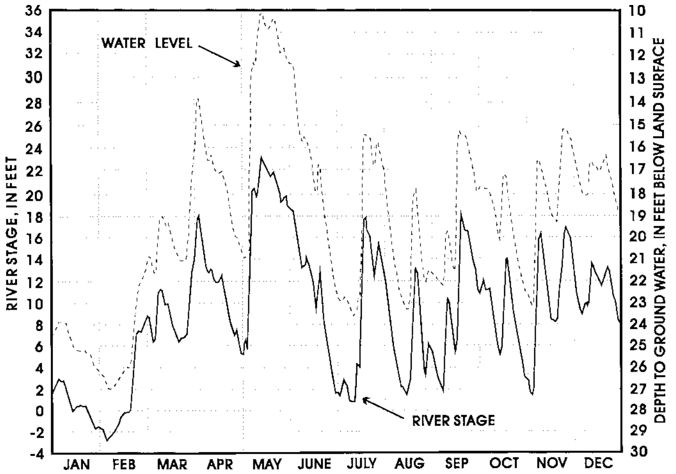
measured intermittently, the trend can be determined by selecting water levels from the same yearly period, for example, January or June, and plotting these values as a hydrograph (see Fig. 16) **(4,61,66–73)**.

7.2.4 *Potentiometric Maps*—Maps that illustrate the potentiometric surface commonly show the altitude of the hydraulic head as related to mean sea level (msl) or a fixed level in the vicinity of the project (see Fig. 17) **(9,74–80)**.



NOTE 1—The rise in water level and nitrate concentration is the result of a storm. Graph lines are interpolated. To convert to metres, multiply feet value times 0.3048. |a9 = Analysed dissolved nitrate concentration.

FIG. 10 Hydrograph and Graph of Dissolved Nitrate Concentration (adapted from Ref (47))



NOTE 1—Well, screened in alluvium, is 1700 ft from the river. To convert to metres, multiply feet value times 0.3048.

FIG. 11 Hydrographs of River Stage and Water Levels in a Well (adapted from Ref (53))

NOTE 23—Potentiometric maps help in the interpretation of the hydraulic gradient, direction of water movement, and losing and gaining of surface-water bodies. The water levels used on the map need to be measured in a short-time period. These plots can be drawn on topographic maps or aerial photos to show the relationship of the hydraulic head to surface topography and cultural features **(81)**.

NOTE 24—In addition to the consideration of QA/QC items discussed in Section 6, some factors that must be avoided in constructing potentiometric maps include:

(*1*) Contouring of water levels from wells screened at different depths in aquifers with vertical hydraulic gradients,

(*2*) Over-simplified contours, for example, straight-line,

(*3*) Over-interpreted contours, for example, more curves than justified by number of data points,

(*4*) Extrapolation of contours well beyond data points,

(*5*) Contouring of data values from substantially different time periods,

(*6*) Contours adjusted to "fit" the contaminant plume as a means of justifying a contaminant pathway, and

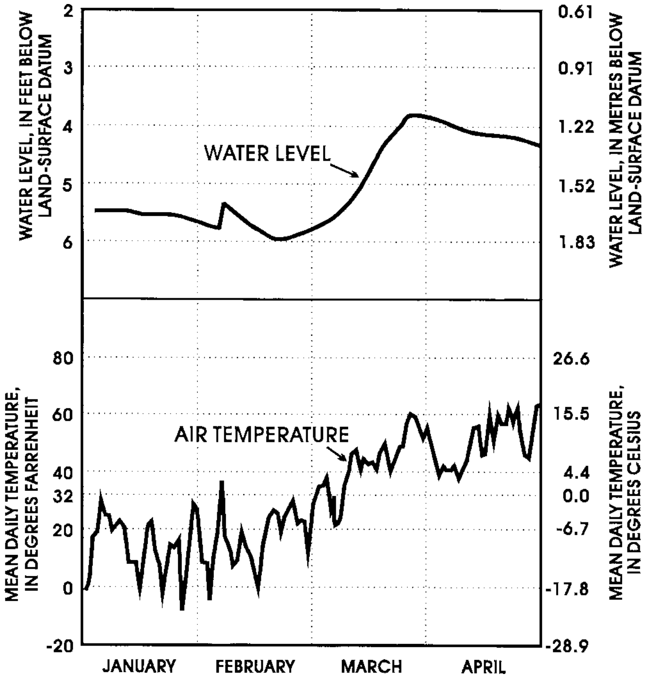
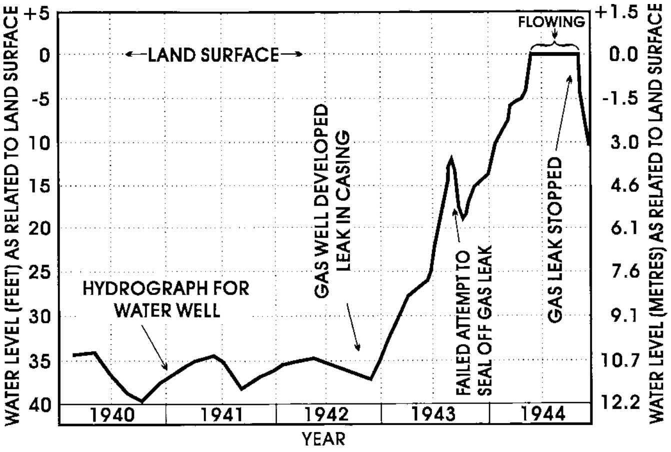


FIG. 12 Water Levels and Air Temperatures (adapted from Ref (56))



NOTE 1—Gas well was located five miles from water well.

FIG. 13 Hydrograph With Fluctuations Caused by Unusual Phenomenon (adapted from Ref (58))

(*7*) Contouring of water levels impacted by liquid phase contaminants without proper adjustment of the contours.

7.2.5 *Depth to Water Maps*—Maps that illustrate the depth of water below the land surface are useful for construction projects where the concern is intersecting the unconfined water surface, for example, by basements, disposal pits, or mines. These maps can also provide information about natural features, including the relationship of surface-water bodies and wetland areas to the ground-water table (see Fig. 18) **(82)**.

7.2.6 *Change Maps*—The change of the potentiometric surface over time, for example, one or ten years, helps in the interpretation of the effects of natural- and human-induced stresses on the aquifer (see Fig. 19) **(28,82–85)**.

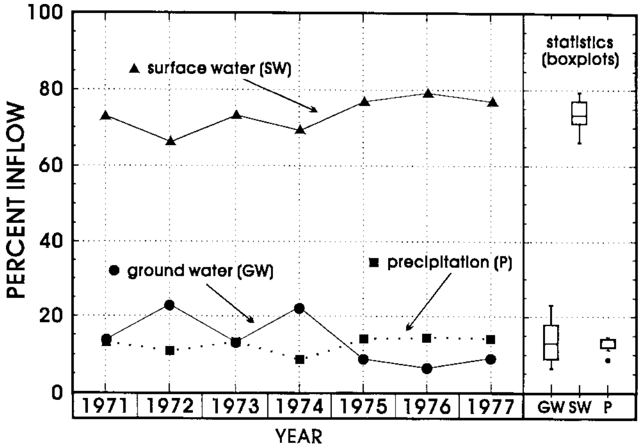


FIG. 14 Inflow to a Lake from Ground Water, Surface Water, and Precipitation Sources with Statistics Given by Boxplots (adapted from Ref (59))

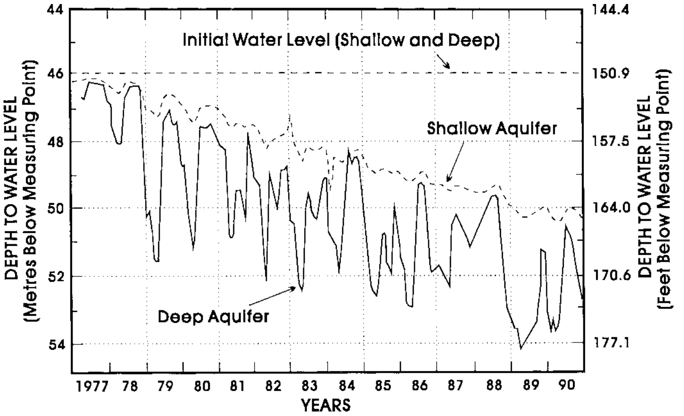


FIG. 15 Multiple Hydrographs Comparing Shallow and Deep Aquifers (adapted from Ref (60))

NOTE 25—The change map (Fig. 19) is a plot of the difference in the hydraulic head of an area over a period of one year. The map is constructed by subtracting the water levels from a potentiometric surface of the later time (June 1990) from those of the earlier time (June 1989). Positive plotted values on the change map show a rising hydraulic head (indicating recharge) and negative values show a falling hydraulic head (indicating discharge).

7.2.7 *Water-table Cross Sections*—A vertically oriented cross-section through several sites shows an exaggerated shape of the aquifers, the ground-water table, and the hydraulic gradient as they relate to land surface features (see Fig. 20) **(8,9,22,76,82,86–89)**.

NOTE 26—Cross-sections of unconfined aquifers commonly show the relationship of surface features, for example, pits, lakes, streams, and cultural structures, with the sub-surface materials, for example, aquifer configuration, depth and gradient of water surface, ground-water flow net, location and construction features of wells, and chemical characteristics of the water **(22)**. Cross-sections of confined aquifers tend to place less emphasis on the surface features that have little effect on conditions in the aquifer.

7.2.8 *Statistical Comparisons of Water Levels*—Ground-water table data can be analyzed by many common statistical methods to determine trends and to correlate these data with related natural and human-caused factors (see Fig. 21) **(4,28,90–94)**.

NOTE 27—Basic statistics, for example, mean, median, high, and low

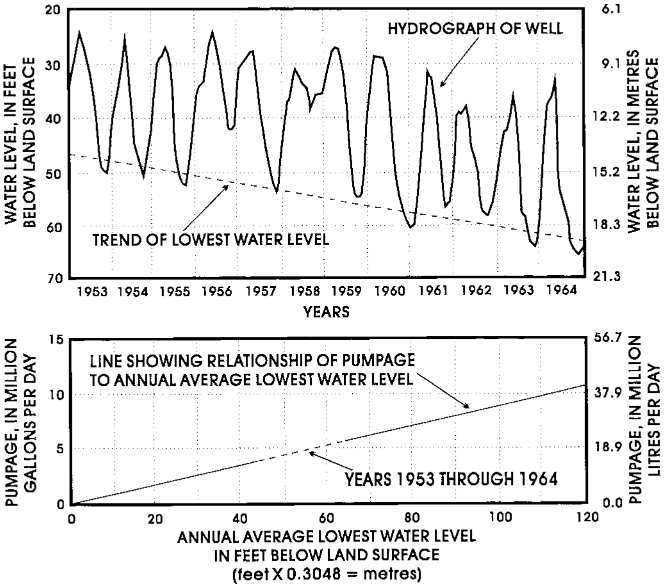


FIG. 16 Hydrograph Showing Water Level Trend and Graph Showing Relationship of Trend to Pumpage (adapted from Ref (67))

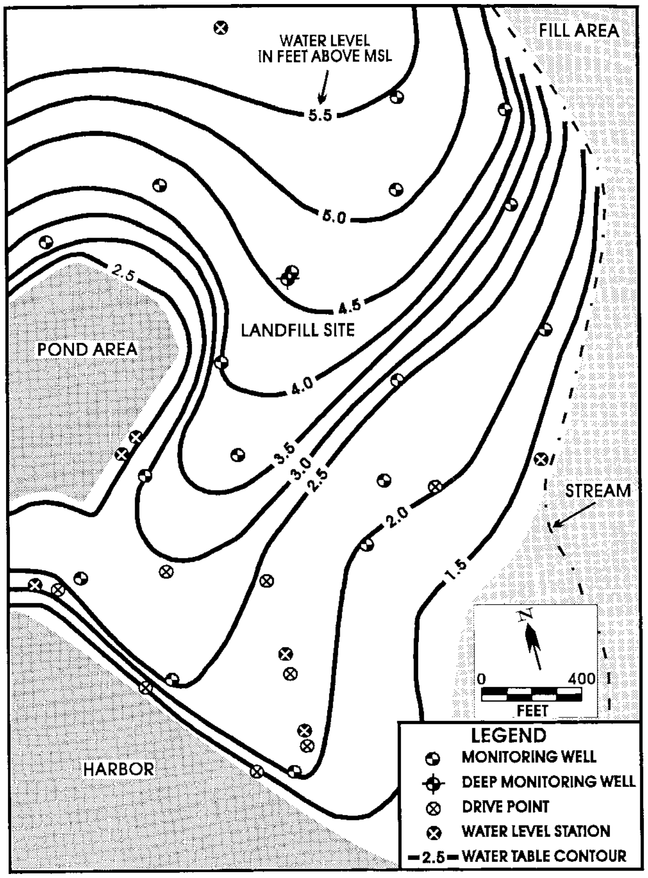


FIG. 17 Potentiometric Map at Landfill Facility (adapted from Ref (75))

values are commonly used to determine the long-term trends of the hydraulic head. A long-term average hydrograph, for example, from 20 wells, can be determined for a project area or these same water levels can be shown on a hydrograph for a single year **(93)**. Probability plots for minimum spring time or differences between springtime minimum and

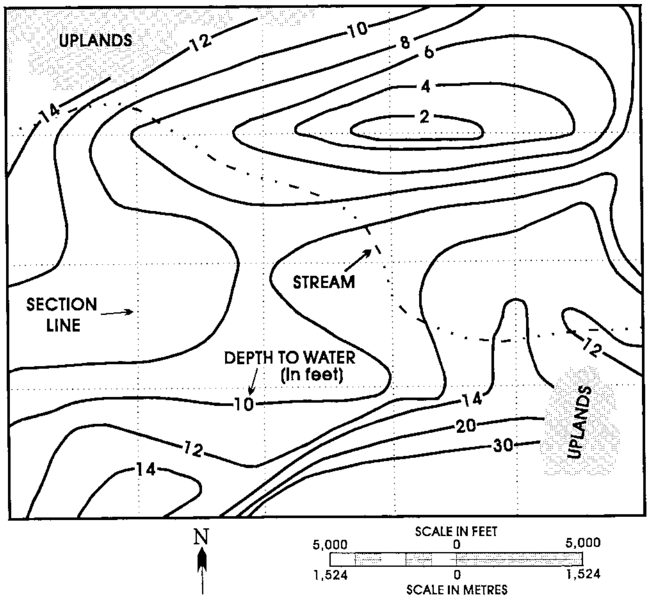


FIG. 18 Map Showing Depth to Water Below Land Surface (adapted from Ref (83))

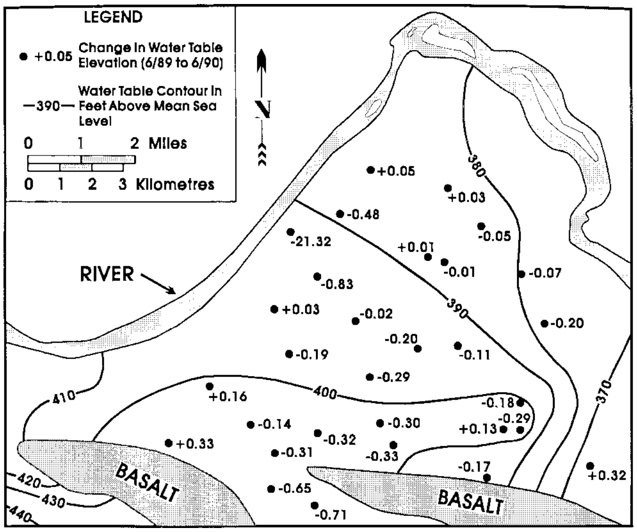


FIG. 19 Water Level Change Map and Potentiometric Surface (adapted from Ref (29))

fall-time maximum water table can be determined from long-term records **(90)**. Cumulative departures in pumpage and precipitation rates versus average water table can be plotted to compare interdependence of the data **(91)**. Correlation analyses between water table fluctuations and related data, for example, river stages, precipitation, or barometric pressure, can be valuable in detecting the cause of the fluctuations **(28)**. Maps showing the seasonal deviation of the water table from the long-term mean of selected shallow wells can indicate areas of drought and above normal precipitation conditions, for example, for a state **(4)**.

8. Automated Procedures for Water-Level and Hydraulic Head Graphics

8.1 *Introduction*—Information concerning the availability of computer software for displaying water level and hydraulic head data in a tabular and graphic format can be obtained from scientific software clearing houses.

8.1.1 Packages of software marketed by Rockware contain routines for plotting graphs, contour maps, and cross-sections

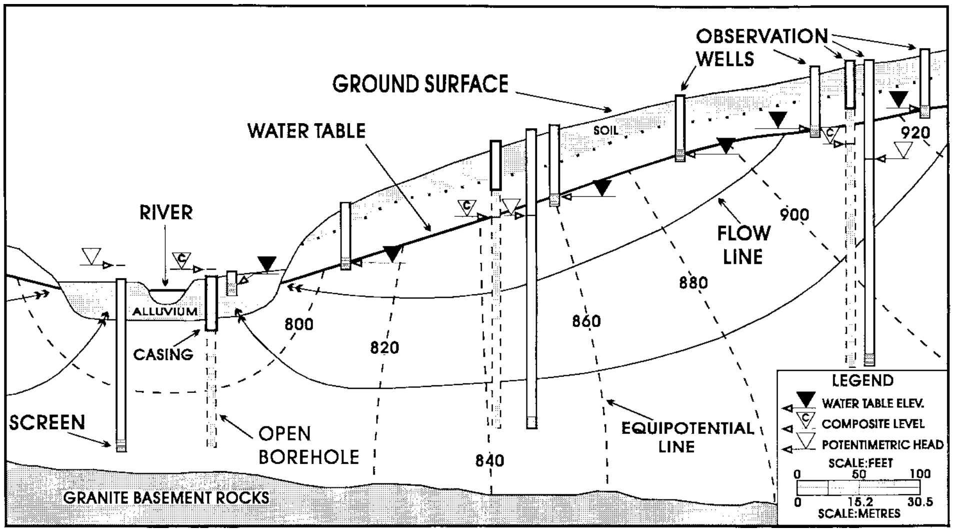


FIG. 20 Water-level Cross Section (adapted from Ref (77))

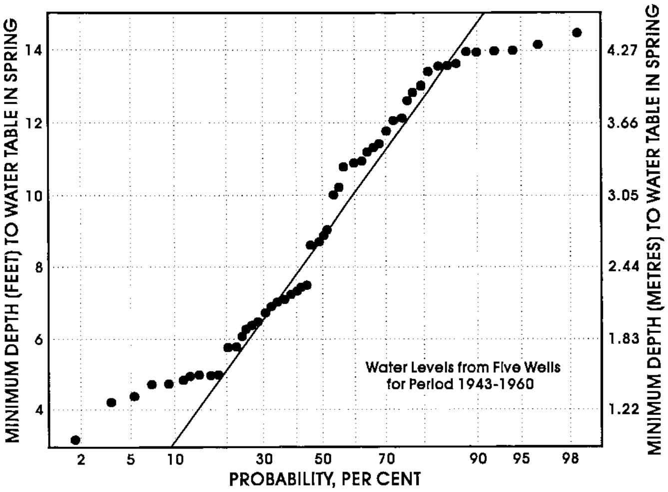


FIG. 21 Probability of Spring Minimum Depths to Water Table (adapted from Ref (91))

of ground-water level data on a desktop computer **(95)**.

8.1.2 Packages of software marketed by Scientific Software Group contain routines for plotting graphs, contour maps, and cross-sections of ground-water level data on a desktop computer (see Ref **(96)**).

8.1.3 The International Ground Water Modeling Center supplies various types of ground-water software.

8.1.4 Donley Technology, a software information company, documents numerous environmental and hydrologic packages.

9. Keywords

9.1 aquifer; confined aquifer; ground water; hydraulic head; hydrograph; potentiometric surface; unconfined aquifer; water level; water table

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