AQUIFER TESTING

Introductory text (Introduction, Design, Field Observation) for this section on aquifer testing is from the University of Arkansas Field Hydrogeology course notes prepared by Van Brahana, U.S. Geological Survey)

References:

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Stallman, R.W., 1968, Aquifer-test design, observation and data analysis: U.S. Geological Survey Techniques of Water-Resources Investigation of the United States Geological Survey, book 3, chapter B1, 26 p.

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Fetter. C.W.,1988, Applied hydrogeology, Merrill Publishing Co.: Columbus, Ohio, 592 p.

Bouwer, H. and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 4, p. 423-428.

INTRODUCTION

Aquifer tests are controlled experiments in which the rock hydraulic properties are determined in the field. Numerous tests have been developed for different hydrogeologic conditions. Regardless of the particular formula used, there is a basic rationale that is common to all aquifer tests, and each test has a specific set of conditions that describe its proper use. Recognition of this common rationale greatly reduces the complexity of data handling and processing.

Aquifer tests typically may be considered as having three main components, 1) design, 2) field observations, and 3) data analysis. Each is important to the ultimate objectives of quantifying the hydraulic properties, boundary determination, indication of the general type of aquifer, and hypothesis testing. Successful aquifer tests typically have the following attributes:

1. The geology of the site is known (driller’s logs, geophysical logs, mapping)
2. The construction of the wells is known (width, depth, materials used, development)
3. Test design is consistent with measuring important aquifer properties
4. All measuring devices (time, discharge, and water level) are calibrated and verified
5. Discharge is accurately monitored
6. Prepumping variations in water levels are defined and explained, as are atmospheric and climatic effects on water levels during the time of the test
7. Data are plotted during the test

8. Testing rationale is flexible to accommodate changing conditions or anomalous responses
9. Data from the recovery portion of the test are compared to the pumping portion
10. Data are analyzed completely
11. All implied aquifer properties are reasonable, and the conceptual model is valid

DESIGN

The purpose of design is to improve the chance that a test will yield acceptably accurate values of the hydraulic coefficients (Stallman, 1968). Tests can be expensive (from several thousand dollars to greater than $1,000,000), and use of existing wells as data-observation sites is frequently done to keep costs to a minimum. Site evaluation, including inventory of wells and springs in an area is typically the first step in test design. Verify that potential data-collection sites are usable. Many existing wells have poor or no access to measure water levels because of pump wires, plumbing, small casing diameter, and other practical problems that prevent access to measure water levels. If wells other than the pumping well (control well) are inadvertently stressed during the test period, the resulting water levels will reflect a total response, and the calculated hydraulic properties of the aquifer will not be accurate.

Commonly used aquifer test and analysis methods are:

- Theis method
- Jacob Straight-line method
- Step-drawdown method
- Recovery method
- Slug test

Because of time and other limitations of this course, **we will focus on single-well slug tests.**

FIELD OBSERVATION

An aquifer test is an *in situ* field experiment in which the field hydrogeologist measures numerous aquifer responses to a known stress. The responses are water levels, and the stresses are either injection or withdrawal of known quantities of water or other material volumes from the aquifer. Mud, rain, bitter cold, insects, faulty equipment, and other environmental distractions may compete for the hydrogeologists' attention during the test. As much as possible, prepare fully prior to the test. Record data carefully, and graph and evaluate data during the test, for it's much easier to locate problems and explain anomalous hydraulic response at the time than at some later time in the office.

Data required to analyze an aquifer test are shown in the following table. Acceptable levels of tolerance for each measurement are shown in brackets.

1. Discharge from the pumped well [+- 10%]
2. Depth to water in pumped and observation wells referenced to measuring point [+-.01 ft]
3. Radial distance from pumped well to each observation well [+-0.5%]
4. Description and sketches of each measuring point {+-0.01%]
5. Elevations of measuring points [variable, depending on if the measuring point is surveyed, or if it is calculated using estimated topo elevations]
6. Total depths of all wells [1%]
7. Completion data for all wells (casing, screen, and other dimensions of length and width and materials [+-1%]
8. Location of all wells in plan [variable, but generally +-1%]

Data types 2 through 8 are collected prior to the test; data types 1 and 2 are monitored throughout the test, along with the time of measurement of each. Numerous test forms have been developed that simplify water-level data, time, and discharge collection.

MULTIPLE-WELL AQUIFER TESTS

- Consist of measurement of a water-level response over time and (or) space (in one or more observation wells) to a known stress (pumping). The observed response is matched to a computed (ideal) response ad the corresponding hydraulic properties are determined. These properties are not measured directly.

- Can be used to determine horizontal hydraulic conductivity and storage of unconfined or confined aquifers with fully or partially penetrating wells. Used for wide range of aquifer permeabilities. Test wells can be used for simultaneous sampling. Tests a relatively large volume of the aquifer; more definitive of the bulk hydraulic properties of an aquifer (within the affected volume of the aquifer)

- Drawbacks include time and expense of the tests and disposal of water pumped during test (a particular concern for tests at hazardous-waste sites—safety, regulatory, cost issues)

BEFORE TEST BEGINS

- Objectives of test should be clearly defined
  EX: Is the test to define aquifer hydraulic parameters, be used for designing extraction-system operation, define aquifer interconnection, etc.

- Conceptual model of system should be defined (OTHERWISE, DOOMED FOR FAILURE)
  EX: Insufficient wells to define aquifer interconnection if that is objective of test (no wells in multiple aquifers or confining unit). If test is to define anisotropy of system, then number of wells insufficient if well network is for an isotropic system.

- Determine optimal number of wells and define background information needed before test begins
  This is related to defining the objectives of the test. Additional information that should be Defined are things such as nearby pumping centers, controlled surface water projects (such as locks and (or) dams), etc.

- The system of wells used in the test should be monitored before test begins.
  This is needed to determine background trends which are necessary to define true effects of the aquifer test versus other outside influences.
- Optimal pumping rates are determined prior to the test.
  This is usually done by a step-drawdown test in order to determine the pumping rates which stress the aquifer sufficiently to meet the objectives, without pumping the well dry.

COMPLETION OF TEST

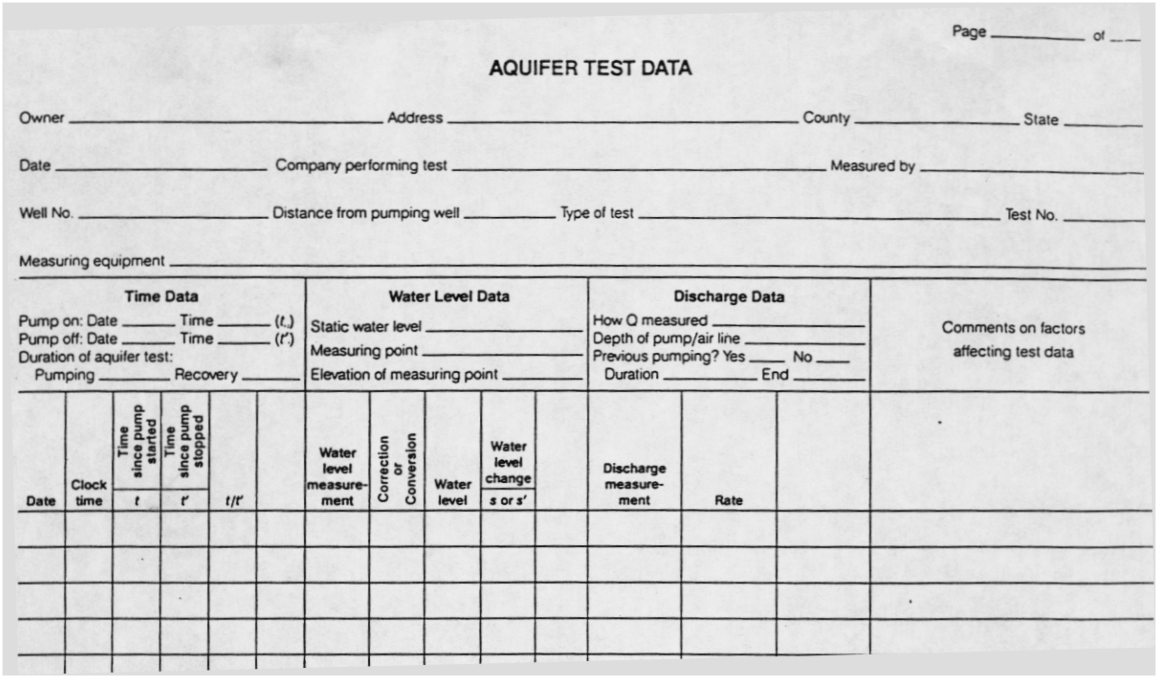
- Water level data is collected very frequently at the beginning of the test (commonly every 30 seconds) and decreases as the test goes on (to about every 30 minutes after 24 hours).

- Other data collected to support the test, such as discharge measurements of the pump, barometric pressure, etc.

- The tests usually consist of measurements of pumping and then recovery (once the pump is turned off)

- As a general rule of thumb, unconfined aquifers are pumped 3 days (and then recover for 3 days) and confined aquifers are pumped for 24 hours (and recover 24 hours). The periods of testing may be increased or decreased (not usually recommended) depending on the objectives of the test.

- Plot the data out in the field. This means some additional work, but can save re-doing the tests when problems are encountered.



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AQUIFER TEST DATA

Owner ______ Address ______ County ______ State ______

Date ______ Company performing test ______ Measured by ______

Well No. ______ Distance from pumping well ______ Type of test ______ Test No. ______

Measuring equipment ______

Time Data	Water Level Data	Discharge Data	Comments on factors affecting test data
Pump on: Date ____ Time ____ (t.) Pump off: Date ____ Time ____ (t') Duration of aquifer test: Pumping ____ Recovery ____	Static water level ____ Measuring point ____ Elevation of measuring point ____	How Q measured ____ Depth of pump/air line ____ Previous pumping? Yes ____ No ____ Duration ____ End ____	

Date	Clock time	Time since pump started t	Time since pump stopped t'	t/t'		Water level measurement	Correction or Conversion	Water level	Water level change s or s'		Discharge measurement	Rate		

Figure – Example of aquifer-test data sheet

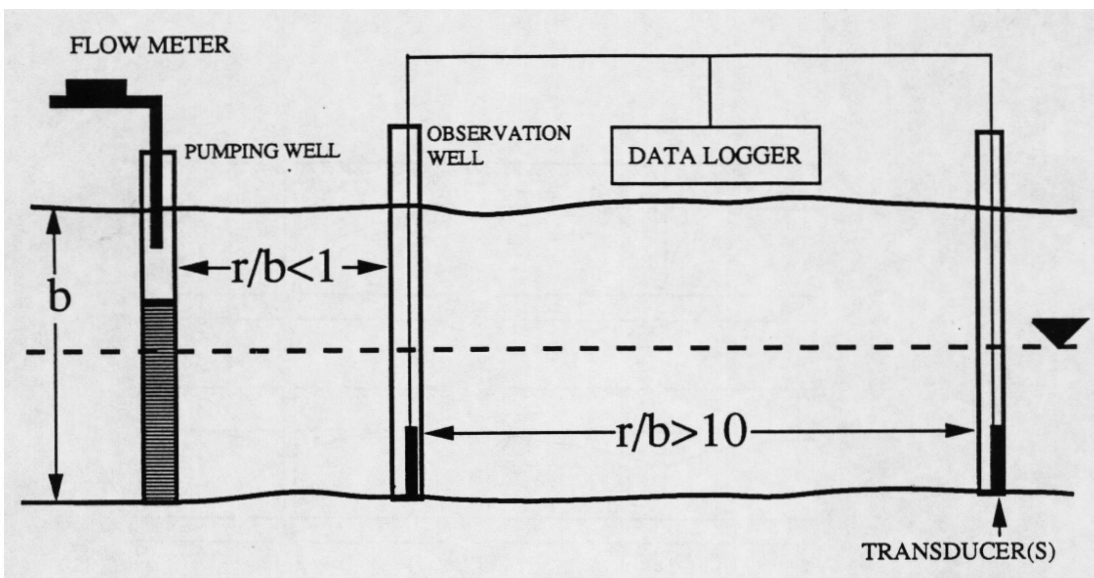

Figure – Suggested minimal arrangement for multiple-well aquifer tests in unconfined aquifers.

EQUIPMENT FOR AQUIFER TESTING

- WATER LEVELS
  - Electric and (or) steel tapes
  - Pressure transducers and data logger
- WEATHER INSTRUMENTS
  - Rain gage – Measure recharge events. Especially important unconfined aquifers, those with shallow water tables
  - Barometers—Measure barometric pressure changes. Especially important for confined aquifers and tests in low permeability environments
  - Evaporation pans—Measures evaporation rates. May be important for dry, hot weather with shallow water tables and long-term aquifer tests.
  - Temperature—Measures air temperatures. May be important in determining when recharge events occur in freeze/thaw cycles.
  - Solar radiation—Measures solar output. May be important in determining when recharge events occur in freeze/thaw cycles and evaporation effects may occur in shallow, unconfined aquifer tests.
- PUMP-DISCHARGE MEASUREMENT DEVICES

BUCKET AND STOPWATCH The discharge is measured volumetrically and an estimate is made of unmeasured leakage. The accuracy of this method is dependent on the care with which the measurements are made. Under most circumstances, a measurement within 10% can be obtained and it is possible to get within 5% under good conditions.

IN-LINE FLOWMETERS The discharge is usually measured by an in-line paddlewheel arrangement that activates a counter. Most flowmeters, if properly installed and calibrated, will read between 2 and 8 percent of proper flow rates, although errors as high as 50 percent have been noted. Placement of meters, depth of flow in the discharge line, presence of air in the water, turbulence, and sediment can all play a factor in the accuracy of the flowmeter.

DOPPLER EFFECT FLOWMETER The doppler meter is an electronic-acoustic device that uses the same principle that is used in police radar systems. The meter measures the velocity of particles (e.g. sediment or air bubbles) in the water by measuring the doppler shift in ultrasonic waves bouncing off the particles. This meter is easy to use and can give accurate measurements under the correct conditions. Certain precautions need to be observed to minimize error, including locating the measuring site away from noises and vibrations of the pump, and away from pipe bends and constrictions. The site should be clean of paint, dirt and grease.

TRAJECTORY METHOD This method operates on the principle that the discharge from an end of the pipe will travel a distance horizontally before falling a certain vertical distance (usually 12 inches) proportional to the discharge rate.

FREE DISCHARGE PIPE ORIFICE Also known as a CIRCULAR ORIFICE WEIR. Discussed in detail in GROUND WATER MANUAL, U.S. Dept. of the Interior, Water and Power Resources Service provided. A piezometer (manometer) tube is attached to the discharge pipe from the pump. The tube is used to measure the water head (pressure) in the discharge pipe which is then used to calculate the pumping rate. This device is generally not used to measure pulsating flow from pumps such as a piston pump.

WEIRS/FLUMES The idea of a weir (as well as a flume) is to measure flow from a pump by constricting flow and measuring either a head (a weir) or a change in head (a flume). A good source of discussion of weirs and flumes is in Driscoll, 1986, GROUNDWATER AND WELLS, Published by Johnson Division. Accuracies are expected to plus or minus 10% or better.

- OTHER POSSBLE EQUIPMENT

  - Tracers—Usually injected into the aquifer to determine transport rate of contaminants And ground water. May also be used to determine zones of interconnection in complicated aquifer frameworks.
  - Downhole flowmeters—Used to measure flow directions *in situ* in wells. May be used to pinpoint transmissive zones and identify zones with aquifer interconnection.
  - In-line water-quality meters—Used to provide qualitative indicators of changes in water Quality during aquifer testing. May be used to provide indications of capturing contaminant plumes, localized changes of water quality, and provide different zones of water quality.

DUPLICATE ALL EQUIPMENT AND DOUBLE CHECK ALL MEASUREMENTS

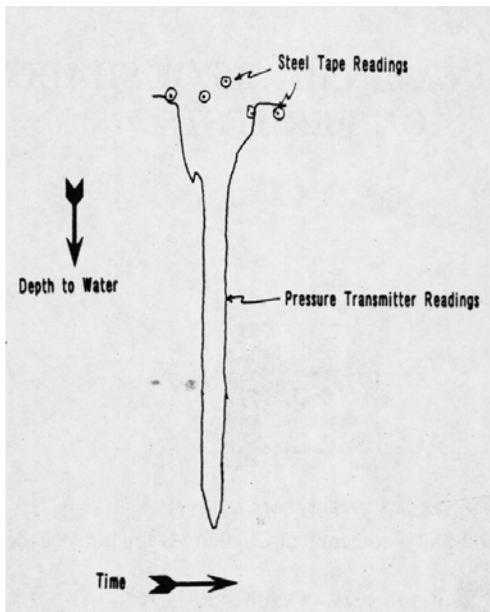

Figure – Illustration of need for double checking measurements.

WATER-LEVEL RESPONSE

CONE OF DEPRESSION

As the aquifer test proceeds, a cone of depression is created as the water is pulled from aquifer. The shape of the cone changes with different aquifer characteristics.

General Rule of Thumb: The more permeable the aquifer, the shallower, but more extensive the cone of depression. The less permeable the aquifer, the steeper, less extensive the cone of depression

To determine the aquifer anisotropy, wells that are screened across the same zone are contoured.

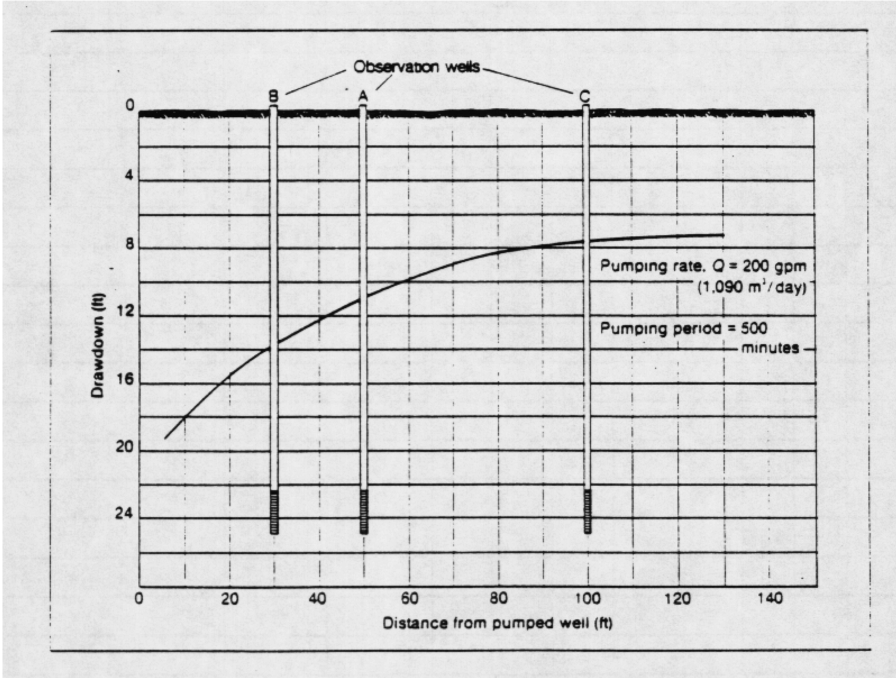

Figure – Cross section of a cone of depression.

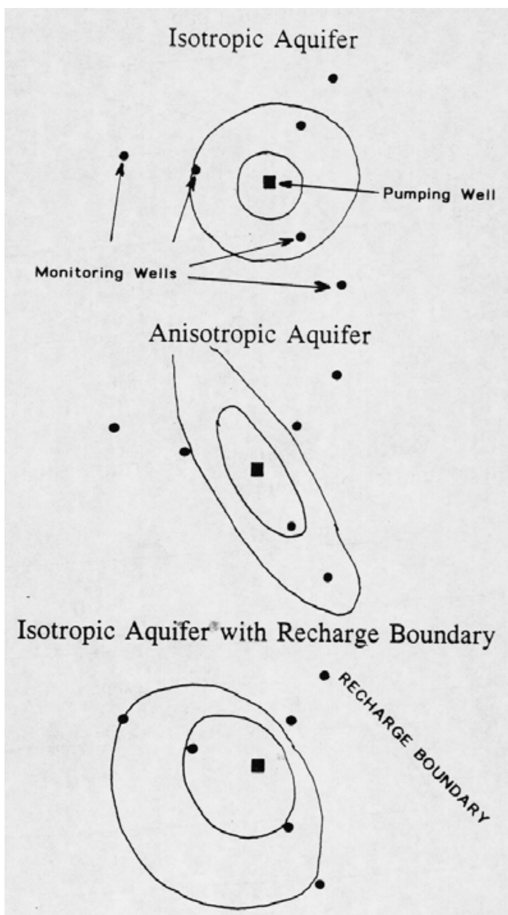

Figure – Conceptual drawings of cones of depression found during multiple-well aquifer tests.

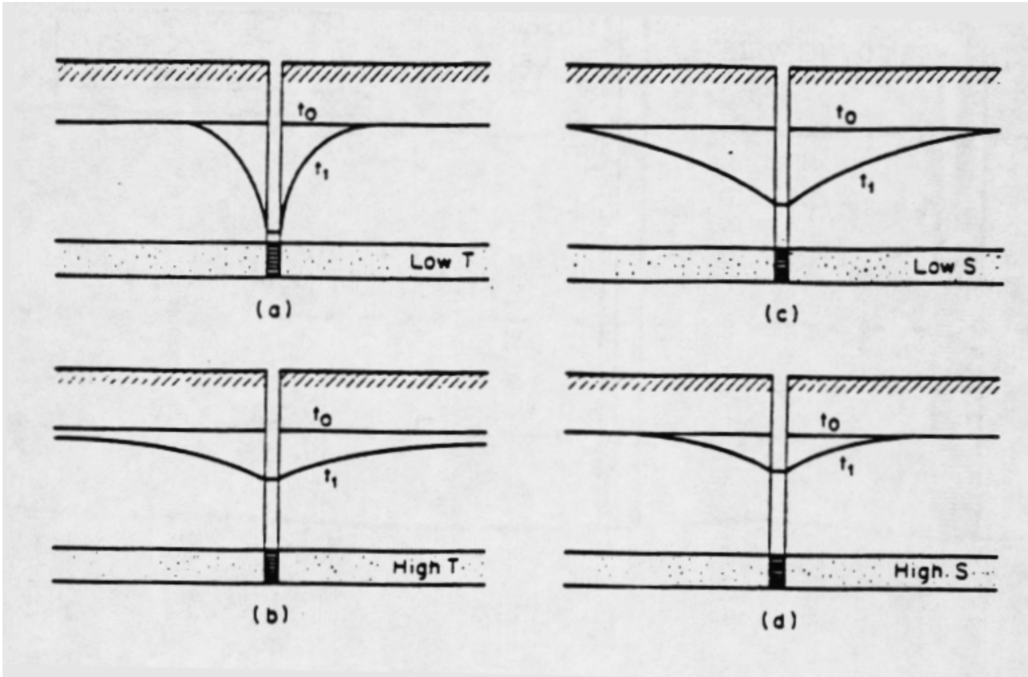

Figure – Comparison of drawdown at given time for aquifers of: (a) low transmissivity, (b) high transmissivity, (c) low storage, (d) high storage.

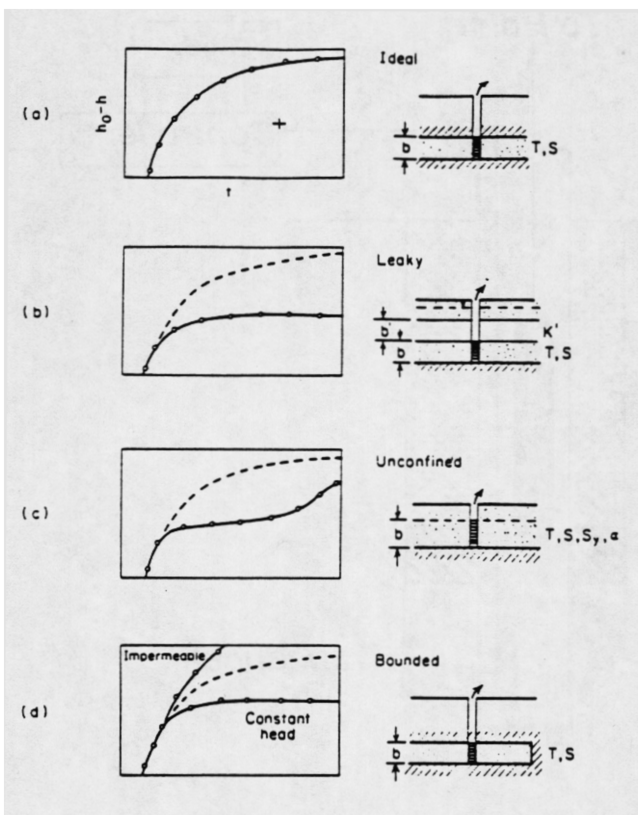

Figure – Comparison of log-log plots of drawdown versus time for (a) confined (ideal), (b) confined (leaky), (c) unconfined, and (d) bounded aquifers.

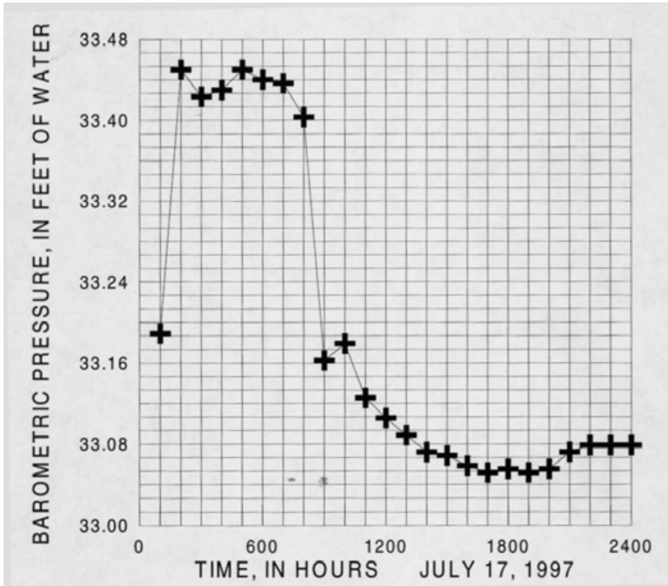

Figure – Example of change in barometric pressure during an aquifer test

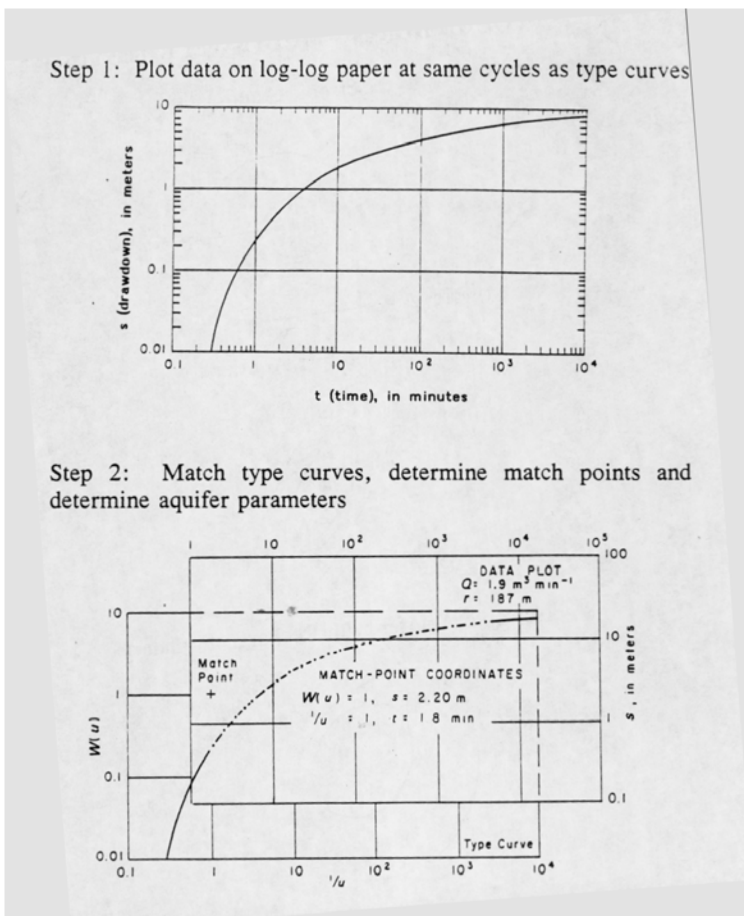

Figure – Plotting of field data and comparing to type curves to determine aquifer hydraulic properties.

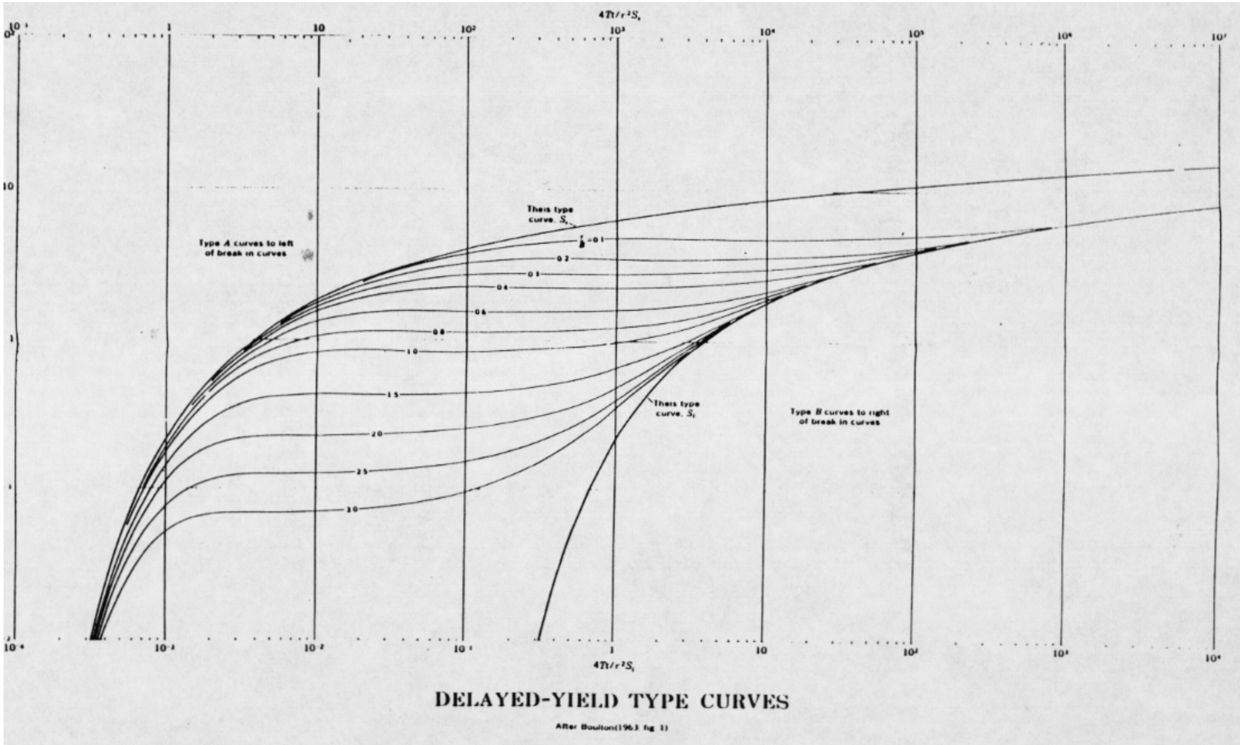

Figure – Example of type curves (for delayed-yield system)

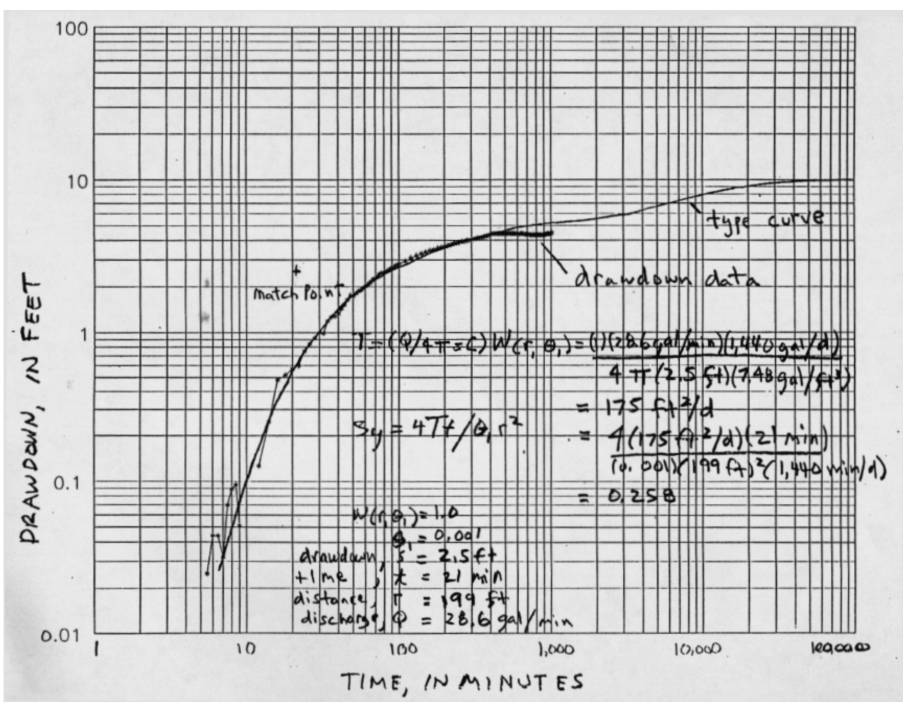

Figure – Example of field data plotted against a type curve (dual-porosity system)