KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORT 2000-34

A REVIEW OF AQUIFER TESTS

by

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A Review of Aquifer Tests

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Division of Water Resources
Brown Bag Seminar
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Presentation Outline

- Introduction
- Field Equipment
- Analysis Methods
- Common Problems
- Some New Directions

Aquifer Tests

- Pumping Tests
  - large-scale hydraulic properties
    - transmissivity and storativity
  - hydraulic boundaries
    - laterally bounded system?
    - tight confining unit?
  - conditions at pumping well
    - well losses
- Slug Tests
  - bulk hydraulic properties
    - hydraulic conductivity
      - low-K units
  - well development
    - hydraulic connection with aquifer

Field Equipment

- Pump and Generator
  - lift and flow rate
- Measurement of Drawdown
  - electric tape plus stopwatch
  - transducer plus datalogger
    - absolute vs. gauge pressure
- Measurement of Flow Rate
  - calibrated bucket plus stopwatch
  - flowmeter
    - analog vs. digital

Analysis Methods

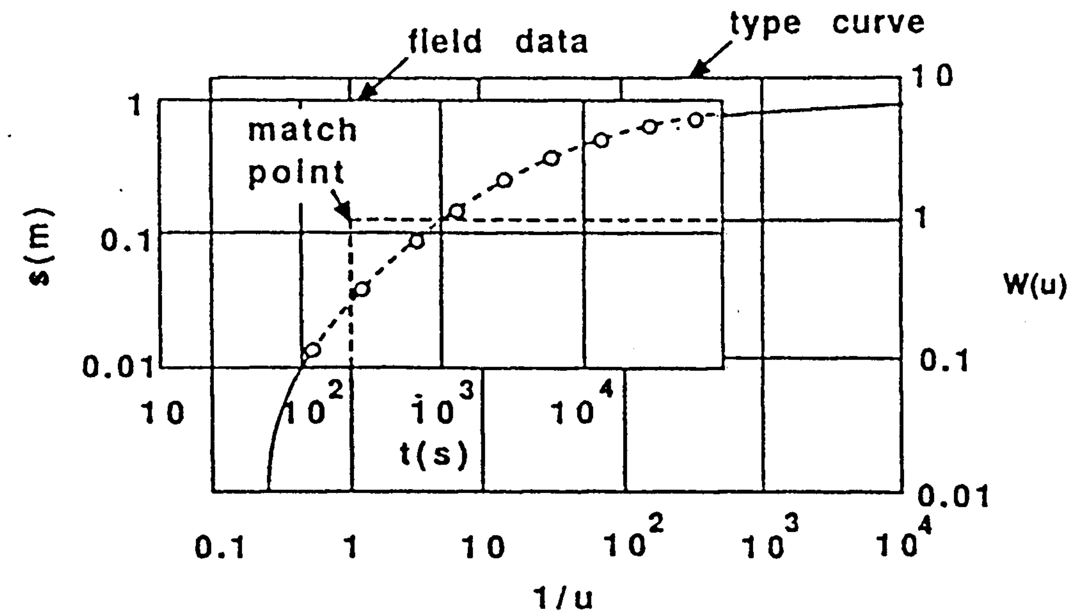
- Confined Aquifer
- Leaky Aquifers
- Unconfined Aquifers
- Recovery Methods
- Further Considerations

Analysis Methods

- Confined Aquifer
  - Theis method
    - log-log plot
    - type curve matching
      - type curve = theoretical response
    - total drawdown
  - Cooper-Jacob semilog method
    - semilog plot
      - straight line fit
    - changes in drawdown
  - Thiem method
    - quasi-steady-state conditions
      - same as Cooper-Jacob for distance

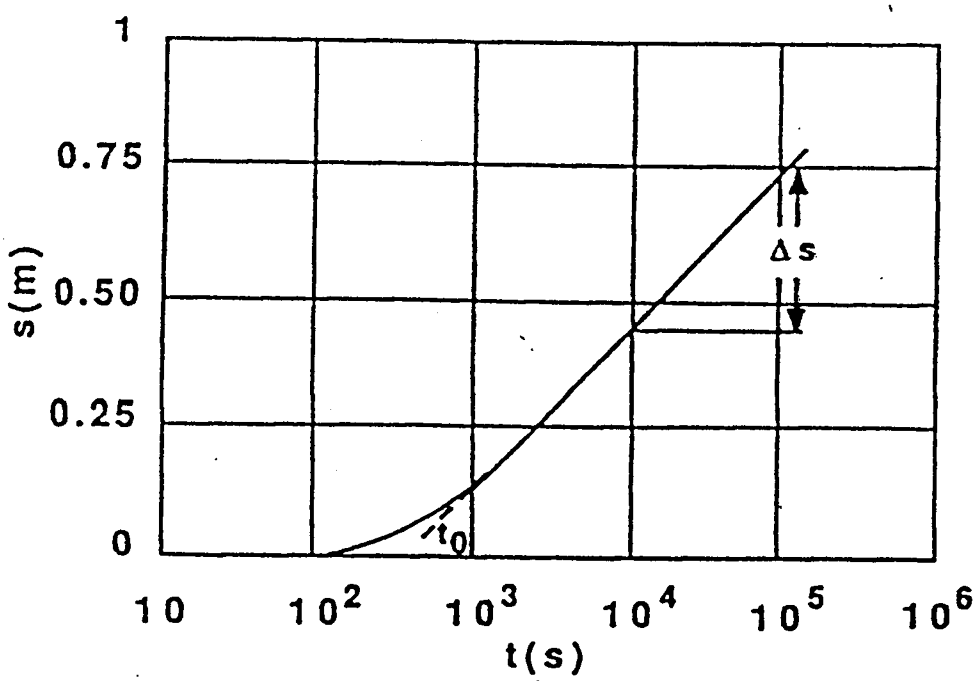
SCHEMATIC OF THEIS AND COOPER-JACOB METHODS FOR ANALYSIS OF DRAWDOWN FROM PUMPING TESTS IN CONFINED AQUIFER (FROM BUTLER (1990))

THEIS



$$T = \frac{QW(u)}{4\pi s} \qquad S = \frac{4uTt}{r^2}$$

COOPER-JACOB



$$T = \frac{2.3Q}{4\pi\Delta s} \qquad S = \frac{2.25Tt_0}{r^2}$$

Analysis Methods

- Leaky Aquifer
  - type curve methods
    - Walton
    - Hantush
    - Neuman and Witherspoon
  - some significant issues
    - representation of aquitard
      - aquitard storage
      - vertical boundaries

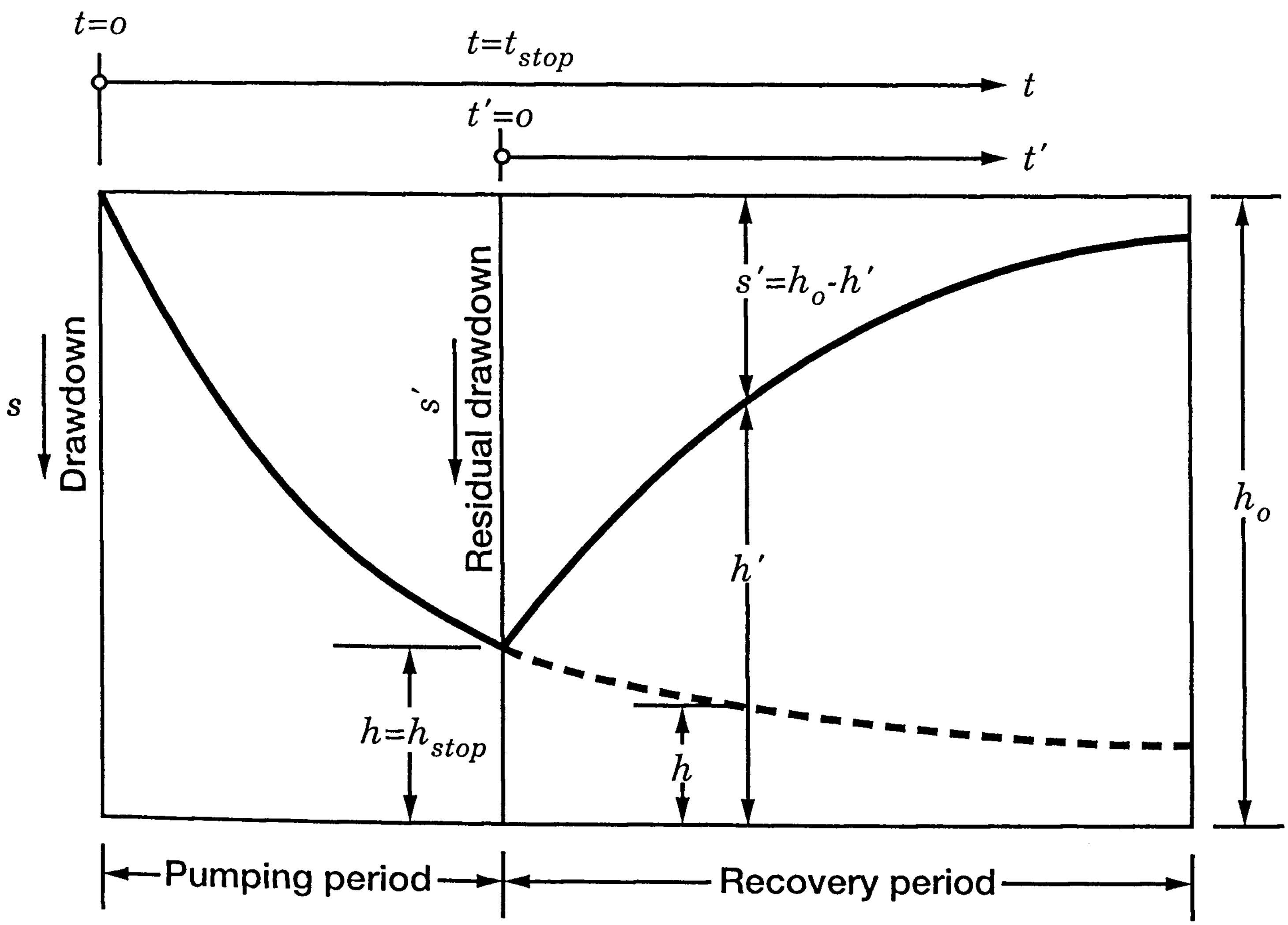
Analysis Methods

- Unconfined Aquifer
  - type curve methods
    - Boulton
    - Neuman
    - Theis with Jacob correction
  - some significant issues
    - vertical drainage
    - drawdown relative to aquifer thickness

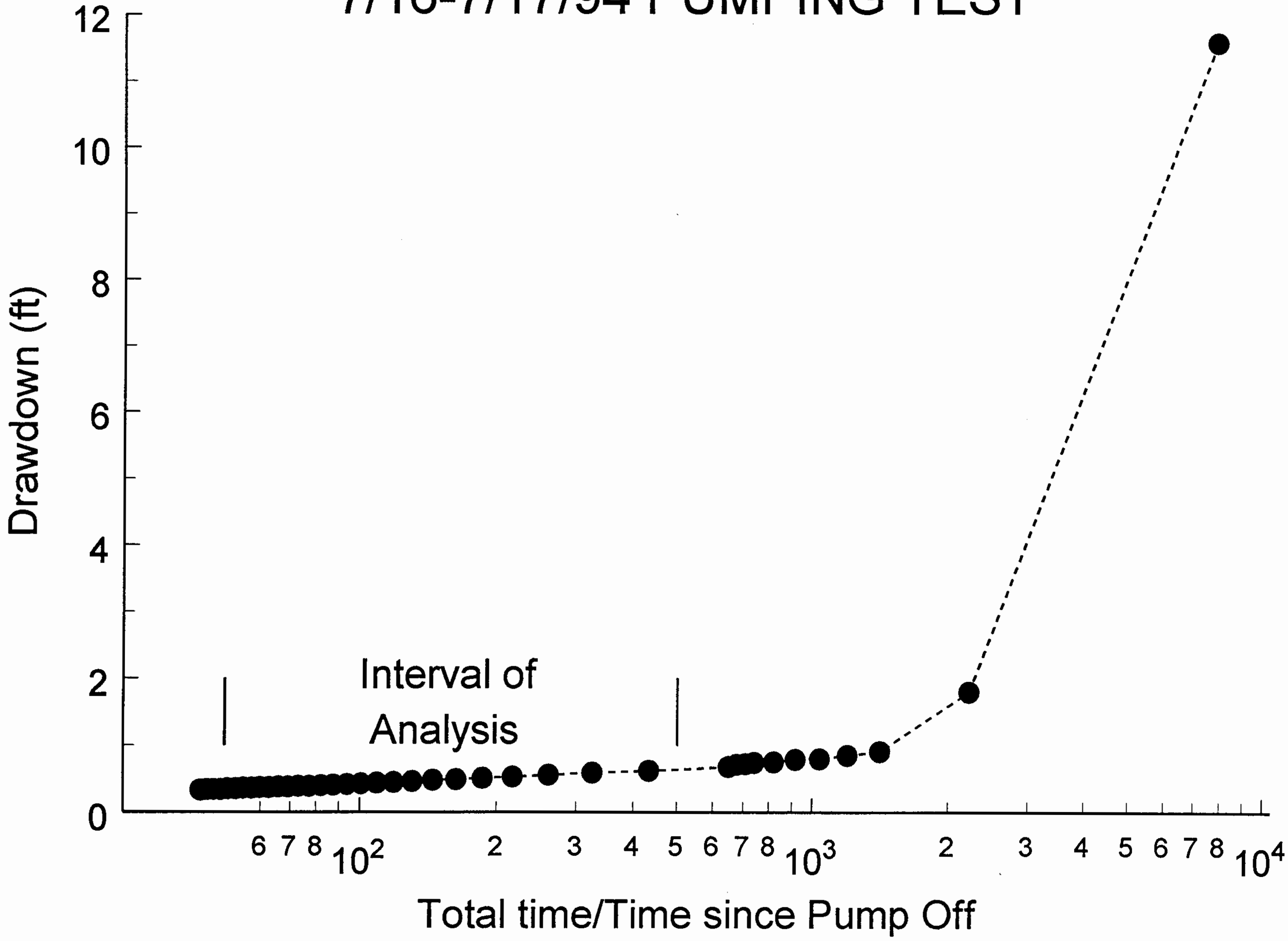
Analysis Methods

- Recovery Analyses
  - justification
    - useful at pumping well
      - no pump-induced noise
      - negligible well losses
    - relatively insensitive to pumping rate variations
  - Theis recovery method
    - semilog plot
      - straight line fit
      - changes in drawdown

SCHEMATIC OF PUMPING AND RECOVERY PERIODS IN CONFINED AQUIFER (FROM BATU (1998))



TREGO COUNTY SITE
RECOVERY PLOT
7/16-7/17/94 PUMPING TEST



Analysis Methods

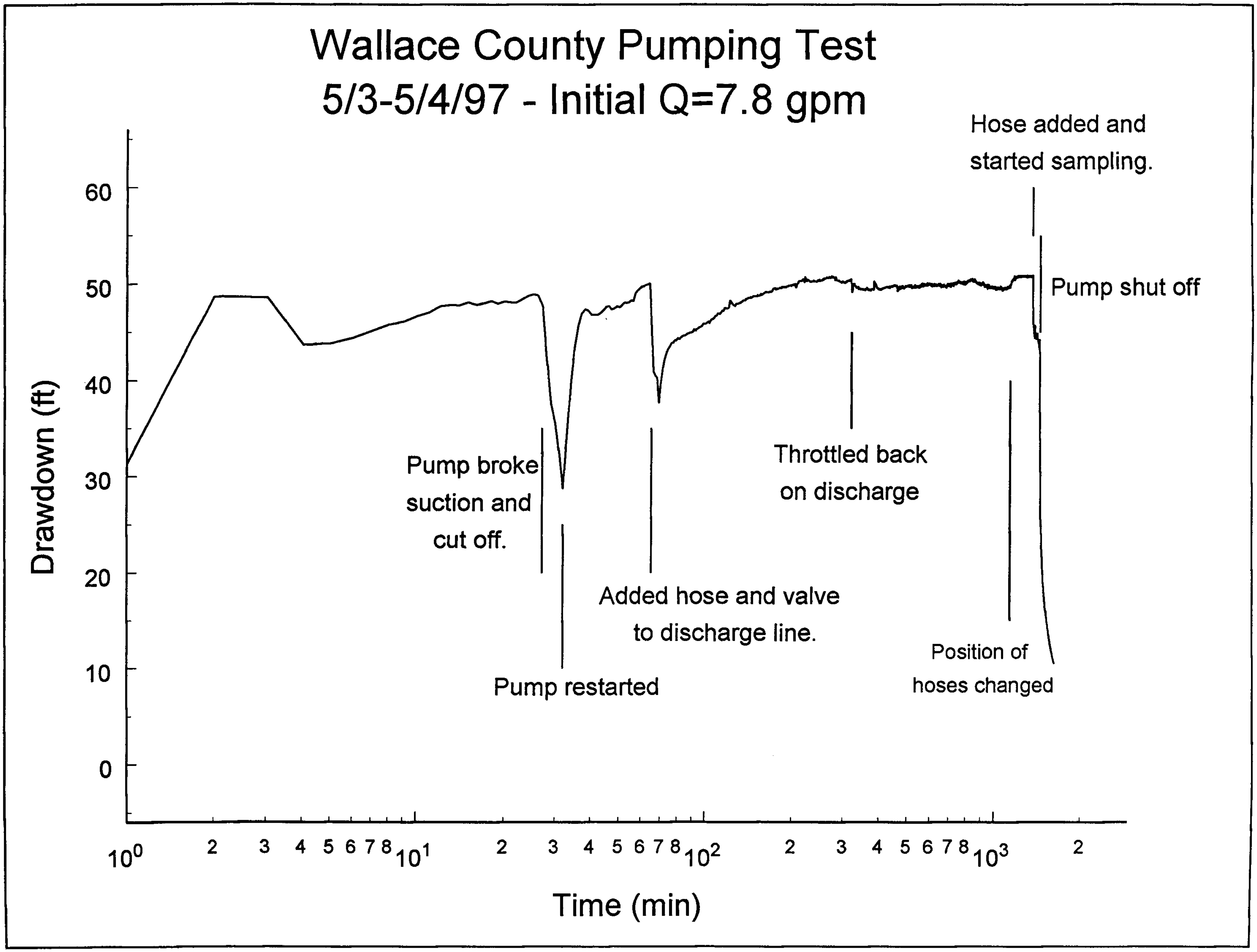
- Further Considerations
  - method selection
    - nonuniqueness
    - test design
    - well logs
  - estimation of aquifer thickness
    - well logs
  - additional mechanisms
    - wellbore storage
    - well losses
    - partial penetration
    - lateral boundaries

Common Problems

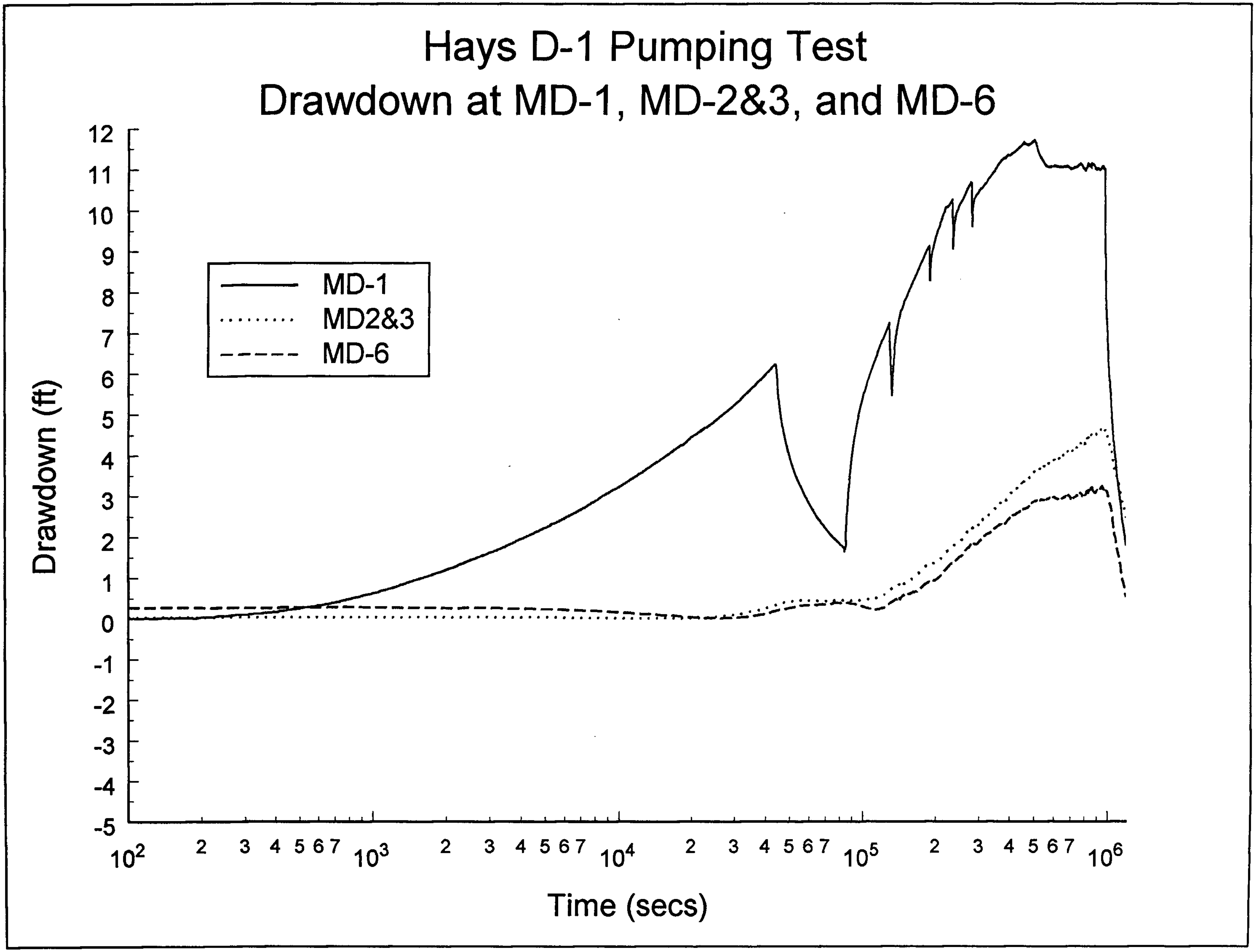
- Variable Pumping Rate
- Nearby Pumping Wells
- Drawdown at the Pumping Well
- Barometric Pressure
  Fluctuations

Common Problems

- Variable Pumping Rate
  - examples
    - Wallace County
    - Hays Dakota Well Field
  - options
    - measure and incorporate
    - analyze unaffected interval
    - use recovery data

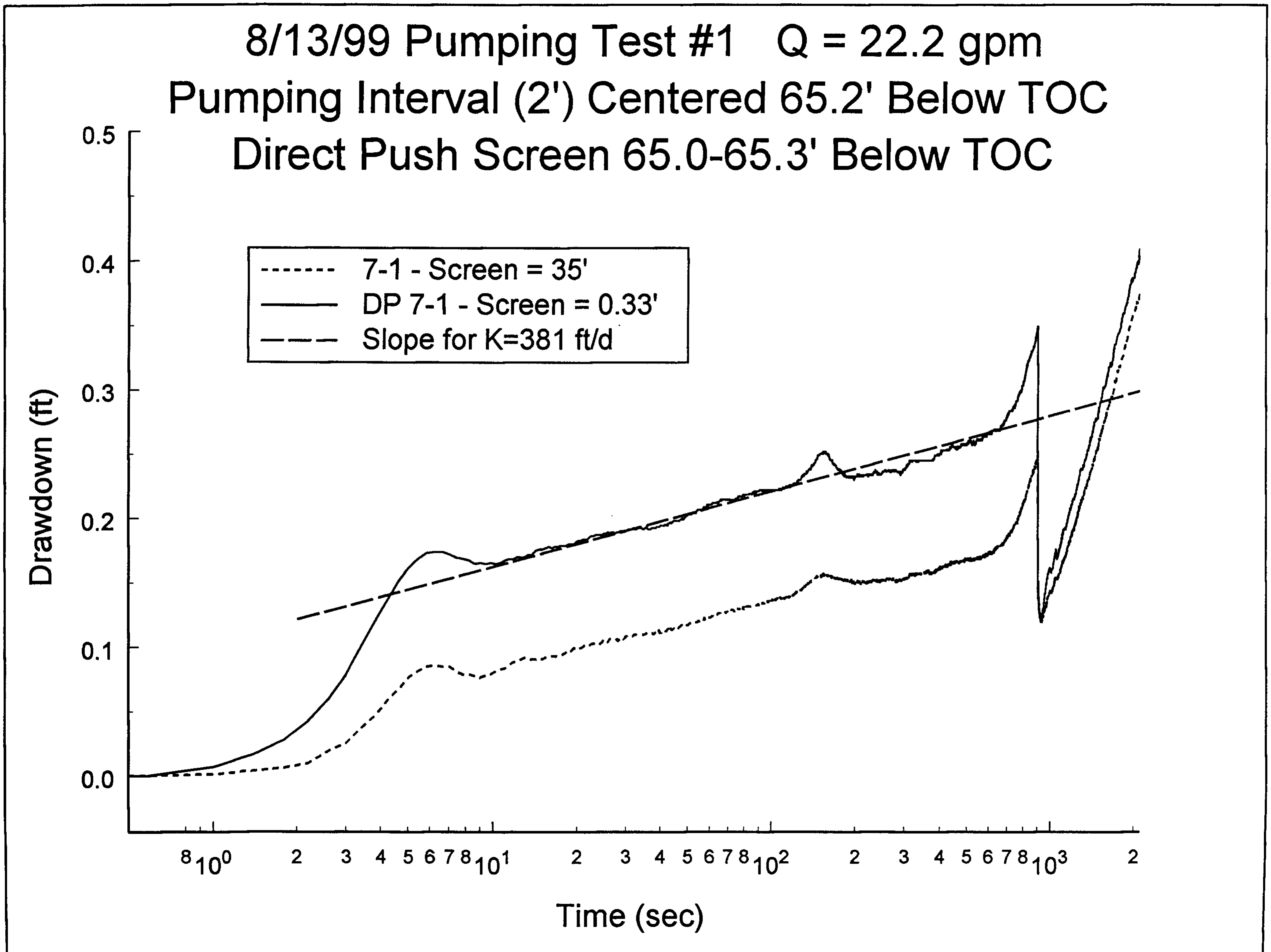


Wallace County Pumping Test
5/3-5/4/97 - Initial Q=7.8 gpm
Drawdown (ft)
Time (min)
0
10
20
30
40
50
60
10^0
2
3
4
5
6
7
8
10^1
2
3
4
5
6
7
8
10^2
2
3
4
5
6
7
8
10^3
2
Pump broke suction and cut off.
Pump restarted
Added hose and valve to discharge line.
Throttled back on discharge
Position of hoses changed
Hose added and started sampling.
Pump shut off

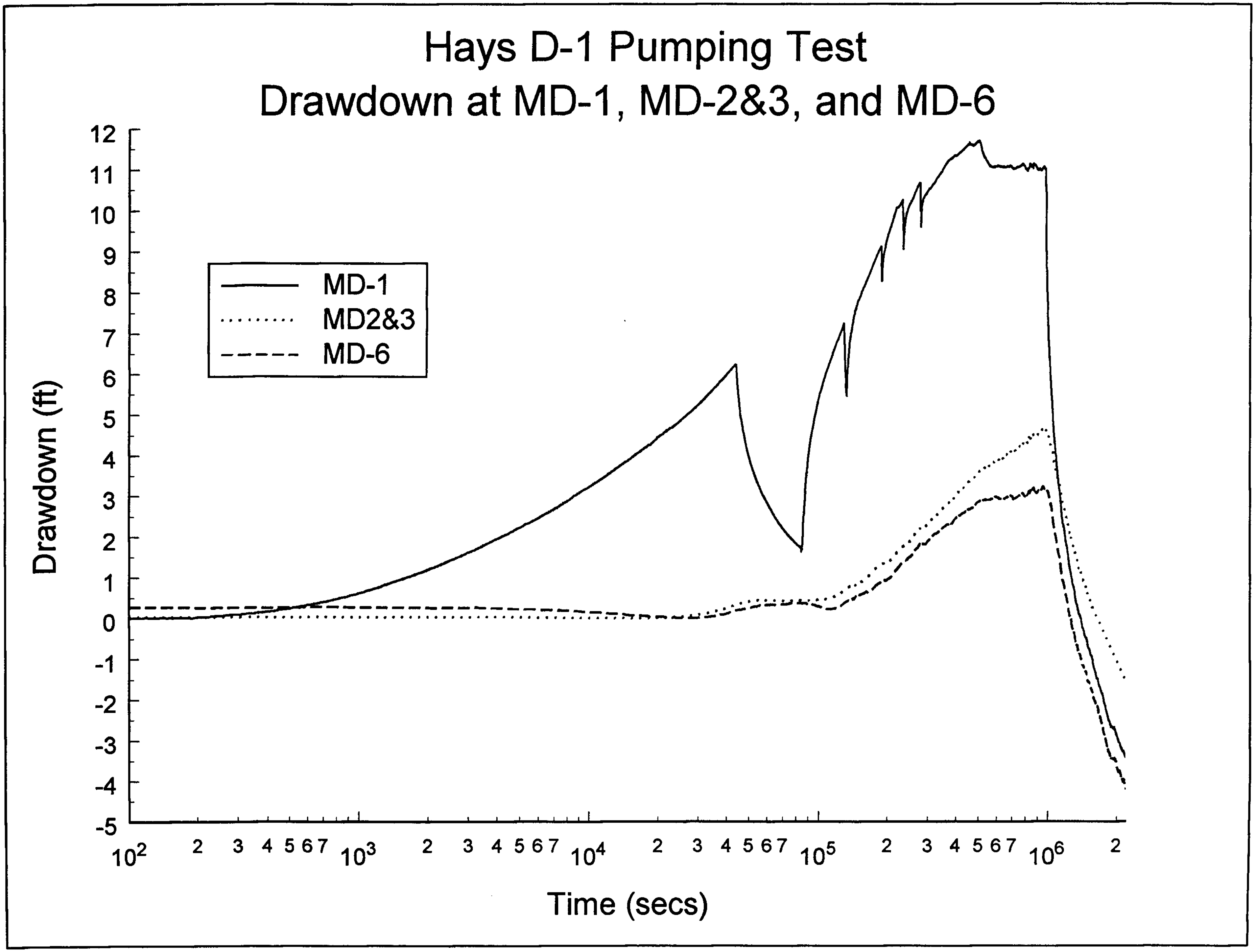

Hays D-1 Pumping Test
Drawdown at MD-1, MD-2&3, and MD-6
MD-1
MD2&3
MD-6
Drawdown (ft)
Time (secs)
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
10^2
2
3
4
5
6
7
10^3
10^4
10^5
10^6

Common Problems

- Nearby Pumping Wells
  - examples
    - GEMS - Douglas County
    - Hays Dakota Well Field
  - options
    - measure and incorporate
    - analyze unaffected intervals
    - schedule carefully



8/13/99 Pumping Test #1 Q = 22.2 gpm
Pumping Interval (2') Centered 65.2' Below TOC
Direct Push Screen 65.0-65.3' Below TOC
7-1 - Screen = 35'
DP 7-1 - Screen = 0.33'
Slope for K=381 ft/d
Drawdown (ft)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0.0
8
10^0
2
3
4
5
6
7
8
10^1
2
3
4
5
6
7
8
10^2
2
3
4
5
6
7
8
10^3
2

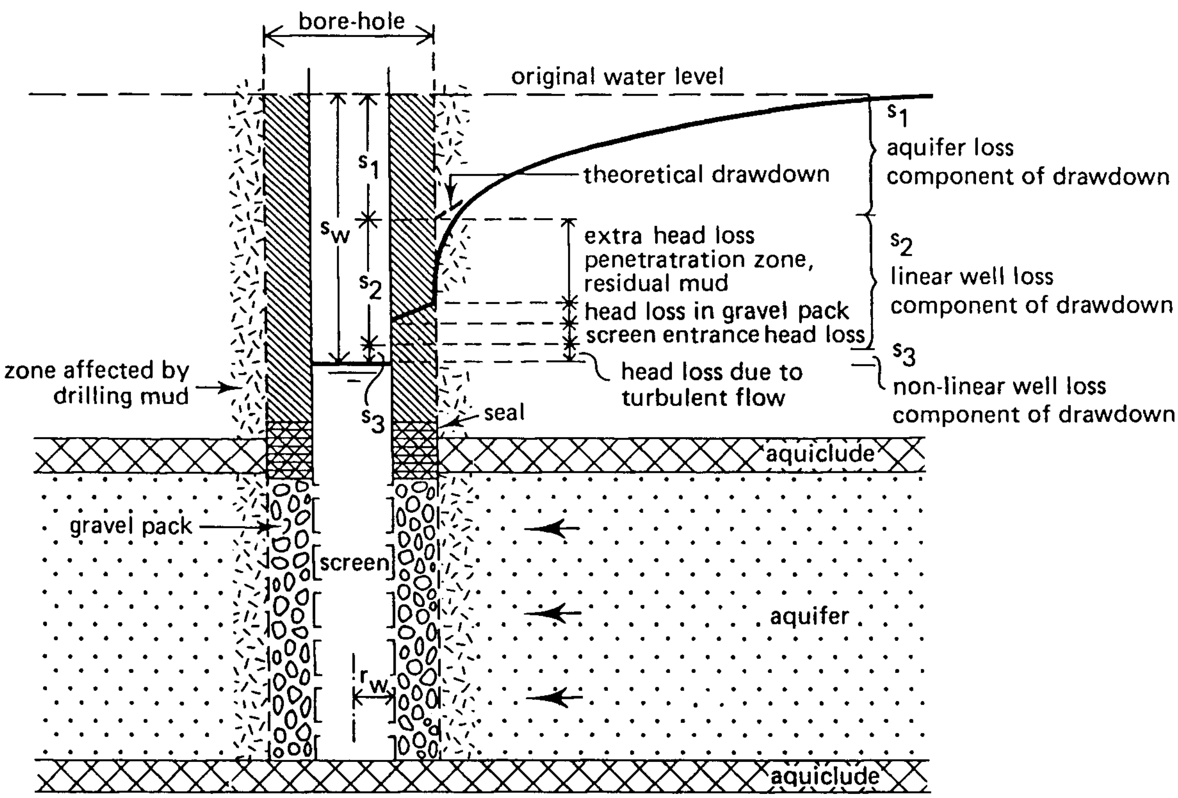


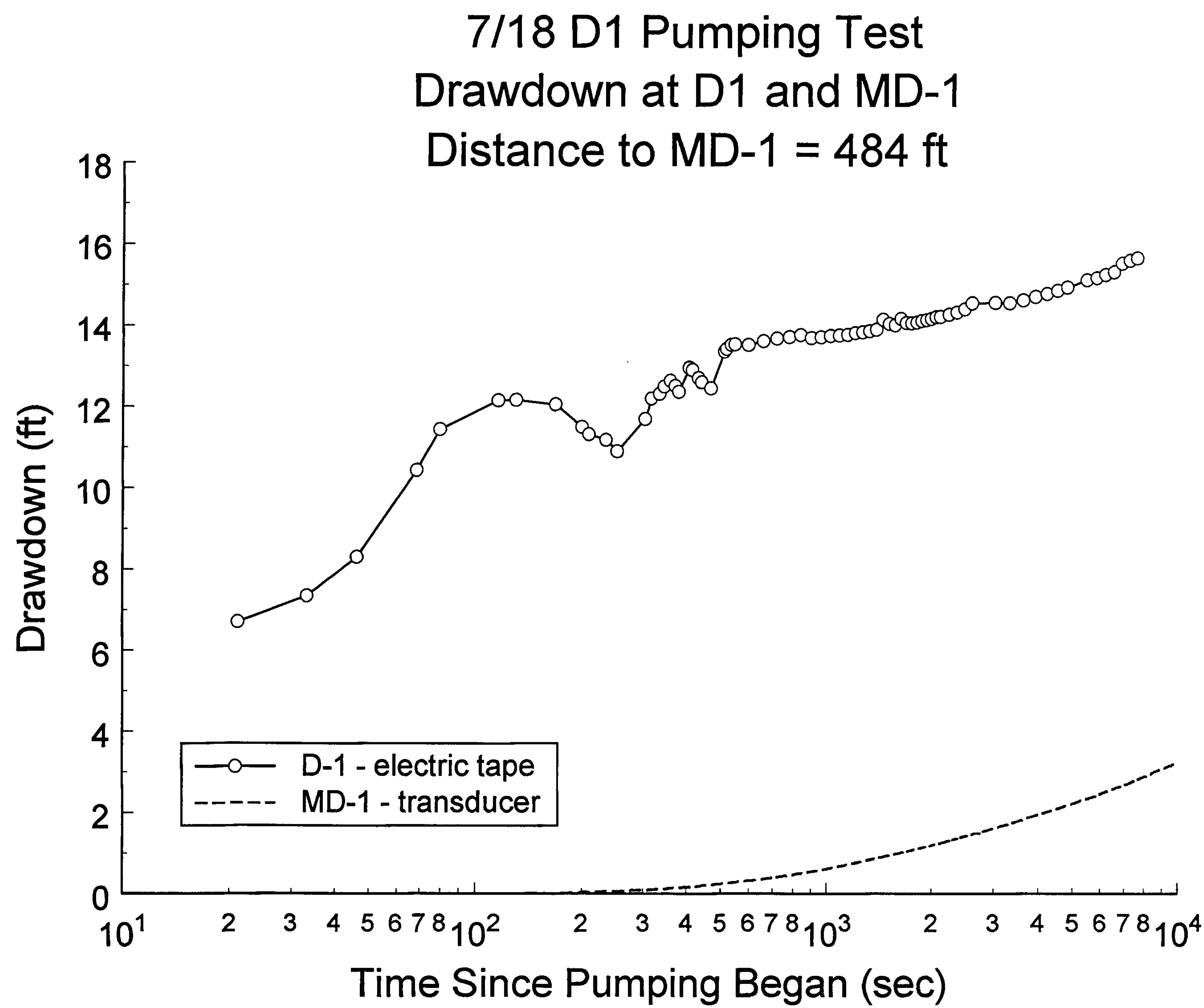
Hays D-1 Pumping Test
Drawdown at MD-1, MD-2&3, and MD-6
MD-1
MD2&3
MD-6
Drawdown (ft)
Time (secs)
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
10^2
10^3
10^4
10^5
10^6

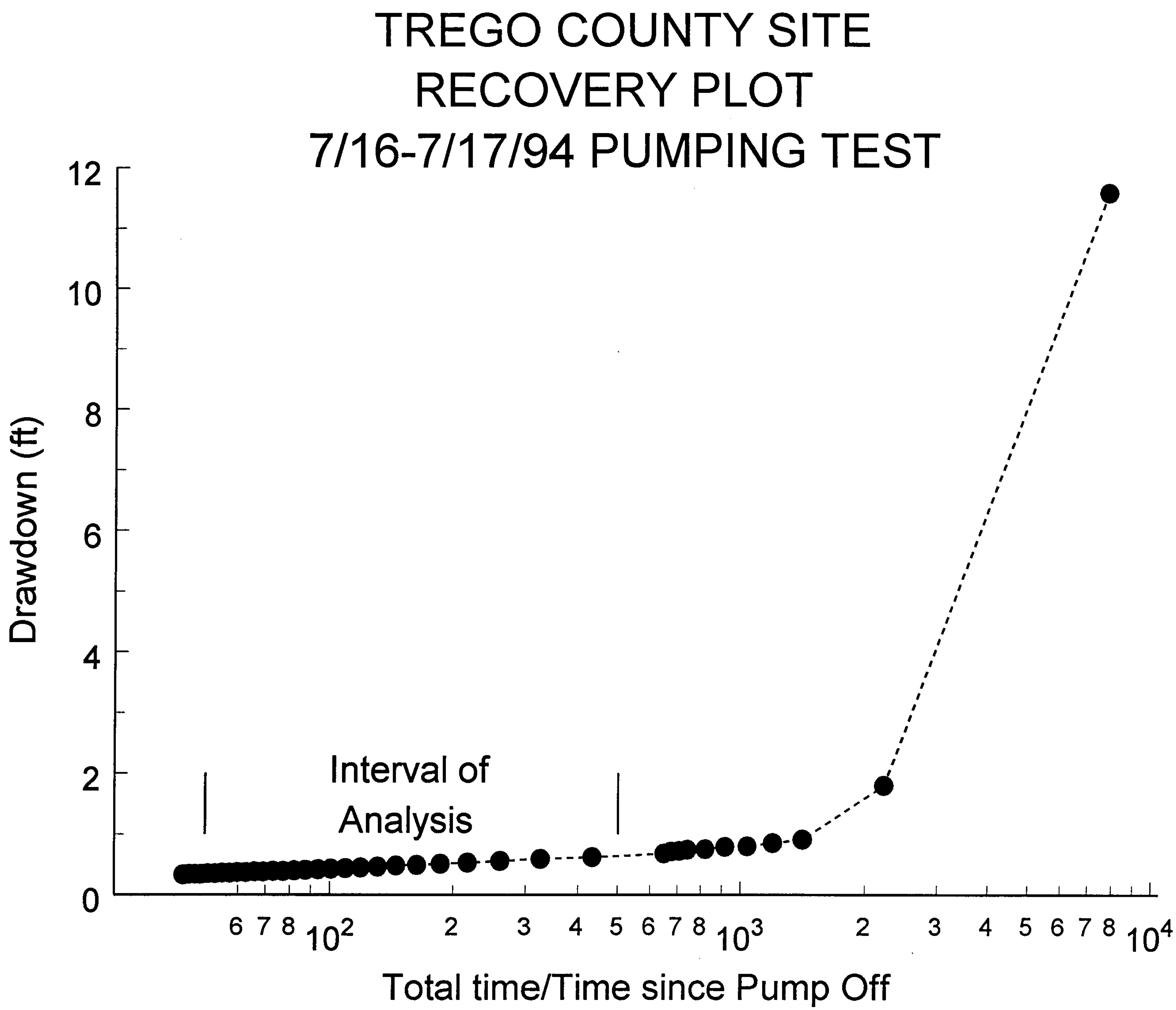
Common Problems

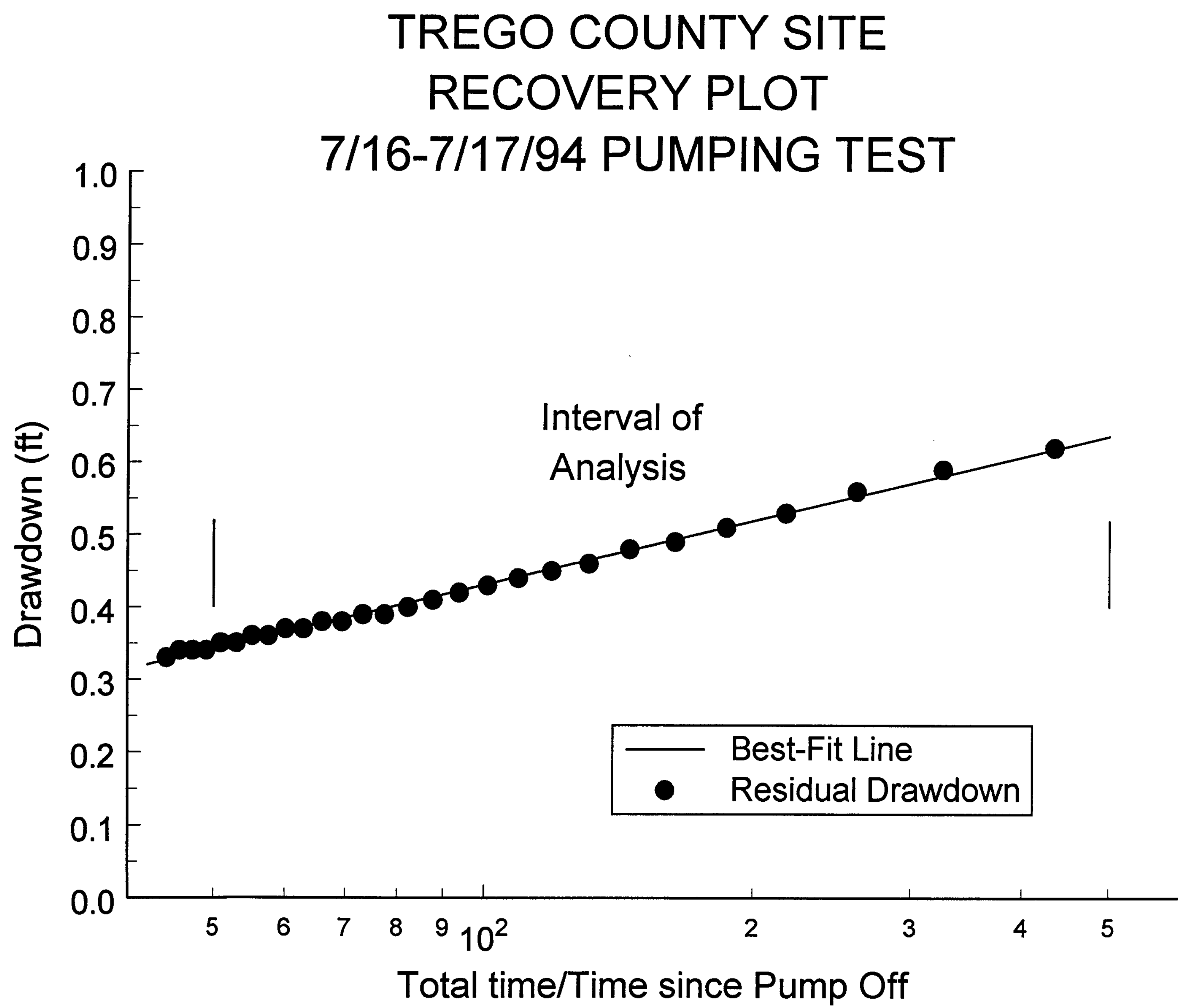
- Drawdown at the Pumping Well
  - examples
    - Hays Dakota Well Field
    - Trego County
  - options
    - use Cooper-Jacob method to remove well losses
    - use recovery data

SCHEMATIC OF VARIOUS HEAD LOSSES IN A PUMPED WELL (FROM KRUSEMAN AND DE RIDDER (1990))



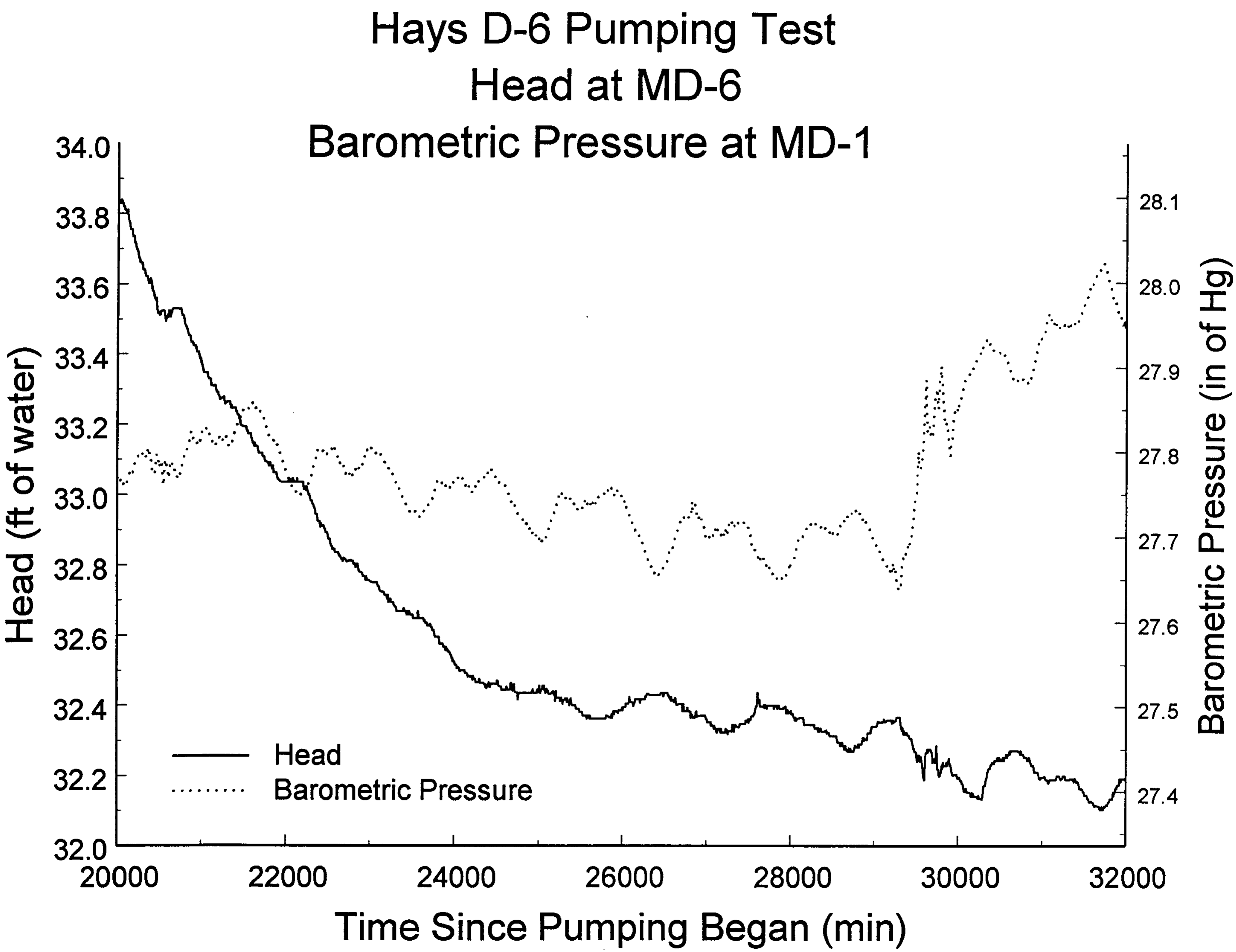

7/18 D1 Pumping Test
Drawdown at D1 and MD-1
Distance to MD-1 = 484 ft
Drawdown (ft)
18
16
14
12
10
8
6
4
2
0
D-1 - electric tape
MD-1 - transducer
10^1
2
3
4
5
6
7
8
10^2
2
3
4
5
6
7
8
10^3
2
3
4
5
6
7
8
10^4
Time Since Pumping Began (sec)

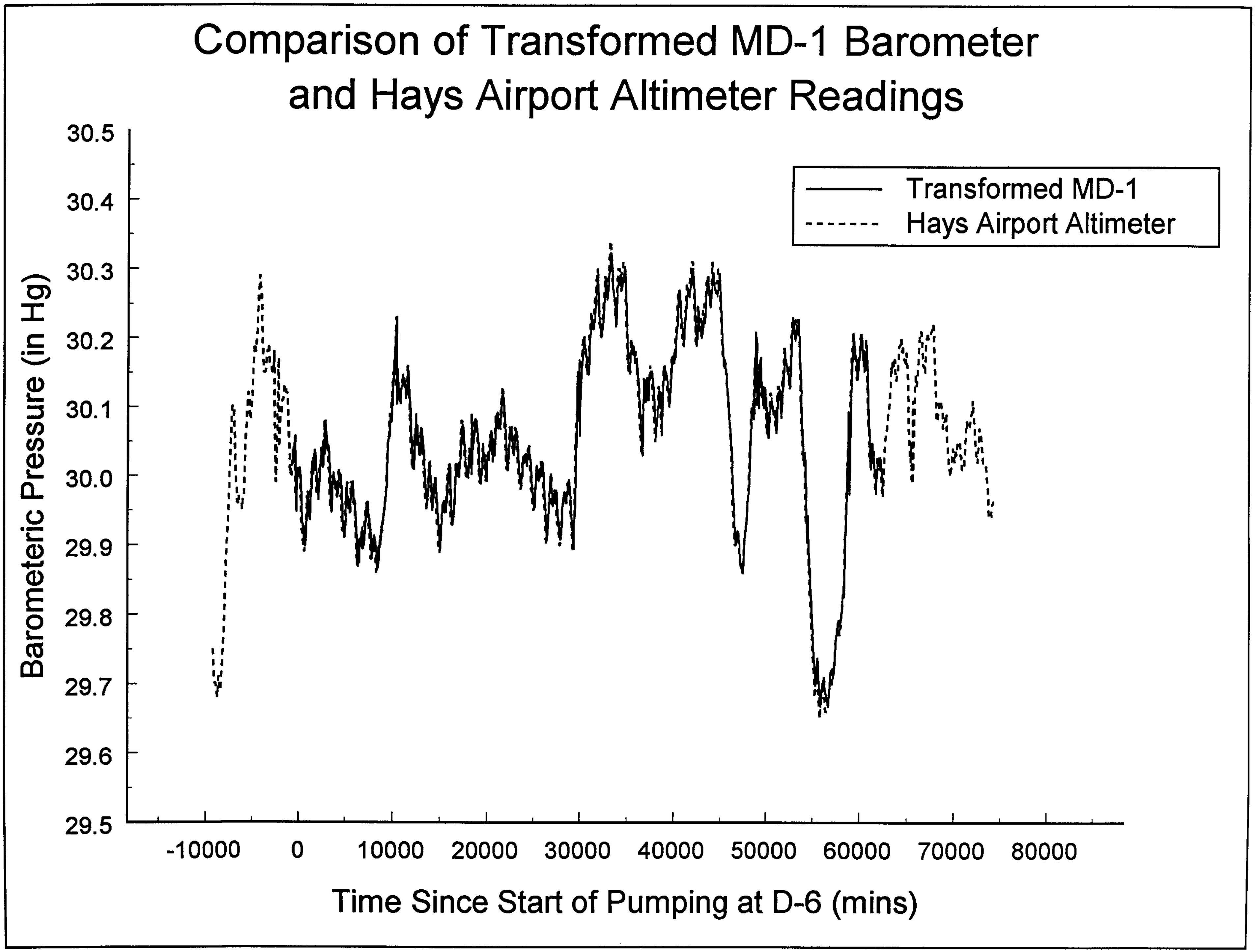

TREGO COUNTY SITE
RECOVERY PLOT
7/16-7/17/94 PUMPING TEST
Drawdown (ft)
0
2
4
6
8
10
12
Interval of
Analysis
6 7 8 10^2 2 3 4 5 6 7 8 10^3 2 3 4 5 6 7 8 10^4
Total time/Time since Pump Off


TREGO COUNTY SITE
RECOVERY PLOT
7/16-7/17/94 PUMPING TEST
Drawdown (ft)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Interval of
Analysis
Best-Fit Line
Residual Drawdown
5
6
7
8
9
10^2
2
3
4
5
Total time/Time since Pump Off

Common Problems

- Barometric Pressure Fluctuations
  - example
    - Hays Dakota Well Field
  - options
    - measure and incorporate
    - place observation well close to the pumping well
      - improve signal to noise ratio


Hays D-6 Pumping Test
Head at MD-6
Barometric Pressure at MD-1
Head (ft of water)
34.0
33.8
33.6
33.4
33.2
33.0
32.8
32.6
32.4
32.2
32.0
Barometric Pressure (in of Hg)
28.1
28.0
27.9
27.8
27.7
27.6
27.5
27.4
20000
22000
24000
26000
28000
30000
32000
Time Since Pumping Began (min)
Head
Barometric Pressure


Comparison of Transformed MD-1 Barometer and Hays Airport Altimeter Readings
Transformed MD-1
Hays Airport Altimeter
Barometeric Pressure (in Hg)
30.5
30.4
30.3
30.2
30.1
30.0
29.9
29.8
29.7
29.6
29.5
-10000
0
10000
20000
30000
40000
50000
60000
70000
80000
Time Since Start of Pumping at D-6 (mins)

Some New Directions

- Direct Push Methods
  - rapid installation of temporary observation wells
  - reduce nonuniqueness
  - improves stratigraphic control
- Stream-Aquifer Interactions
  - pumping tests in the vicinity of partially penetrating streams
    - streams of finite width and shallow penetration
    - stream depletion estimates based on more realistic conditions than Jenkins model

Kansas Geological Survey, Open File Report 99-40

Hydrostratigraphic Characterization of Unconsolidated Alluvial Deposits with Direct-Push Sensor Technology

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KGS Open-File Report 99-40
Prepared for presentation at
The Geological Society of America
1999 Annual Meeting in Denver, Colorado
October 27, 1999

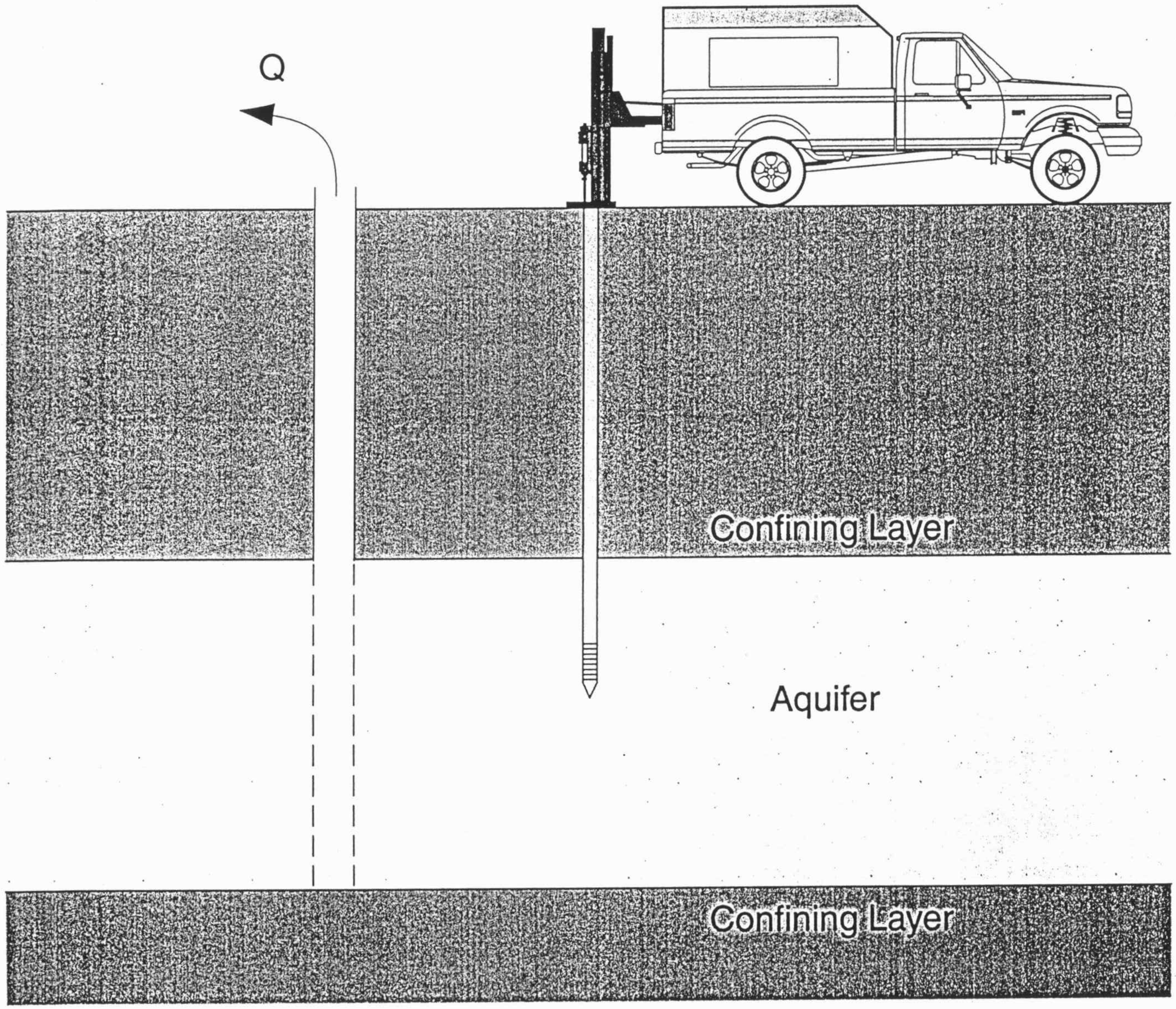
Abstract

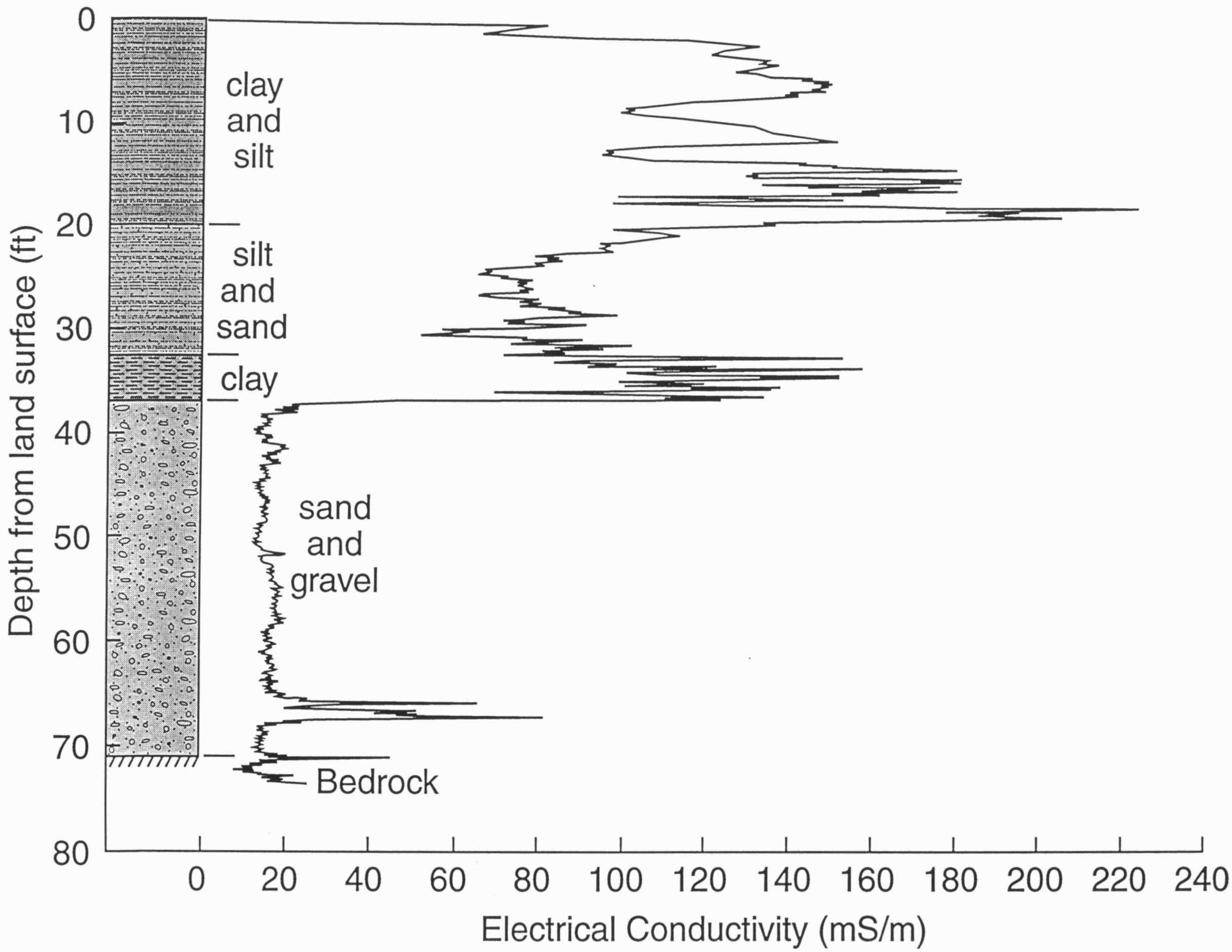
The incorporation of down-hole sensors into direct-push equipment provides a novel method for the rapid and detailed hydrostratigraphic characterization of unconsolidated deposits. The potential of this technology was assessed through two field investigations in unconsolidated alluvial deposits (60-70 ft thick) using downhole electrical conductivity and cone penetrometer sensors. At both sites, these sensors served as excellent tools for the lateral and vertical delineation of hydrostratigraphic units. Electrical conductivity surveys at a lateral spacing of less than 2 to more than 200 feet graphically demonstrated the spatial variability inherent in alluvial deposits. Core samples, hydraulic tests, water-level data, and well-bore geophysics corroborated the information provided by the direct-push sensors. The results of these investigations indicate that this technology can provide detailed information about the hydrostratigraphic framework of unconsolidated deposits in a rapid and cost efficient manner without generation of cuttings or the need for a pre-existing borehole or well.

Introduction

In the last decade, direct-push (DP) technology has become a viable alternative to conventional drilling methods for sampling soils, sediments and ground water in unconsolidated formations. This technology has been particularly widely used for a range of activities in support of environmental site investigations. The DP technology utilized in this study employs high-frequency (~ 30 Hz) percussion hammers and hydraulic slide systems, mounted on conventional pick-up trucks, vans or specialized track machines, to rapidly advance pipes into the subsurface. Advantages of DP technology over conventional drilling methods include (Thornton et al., 1997):

- smaller less-expensive systems with greater mobility


Q
Confining Layer
Aquifer
Confining Layer



Depth from land surface (ft)
0
10
20
30
40
50
60
70
80
clay
and
silt
silt
and
sand
clay
sand
and
gravel
Bedrock
0
20
40
60
80
100
120
140
160
180
200
220
240
Electrical Conductivity (mS/m)

Welcome!

Ths web site has been created in support of the Kansas Geological Survey's Stream-Aquifer Interactions Project. For information on this project, please contact Jim Butler or Ming-Shu Tsou, project investigators.

Background Reports

Evaluation of Stream Depletion Considering Finite Stream Width, Shallow Penetration, and Properties of Streambed Sediments by Vitaly A. Zlotnik, Huihua Huang, and James J. Butler, Jr.

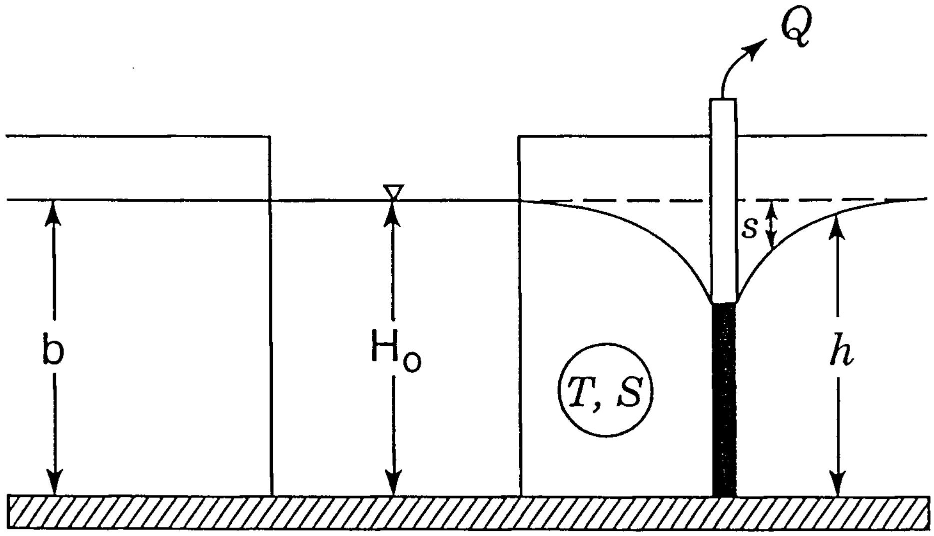
Mathematical Derivation of Drawdown and Stream Depletion Produced by Pumping in the Vicinity of a Finite-Width Stream of Shallow Penetration by James J. Butler, Jr., and Ming-Shu Tsou

Computer Software

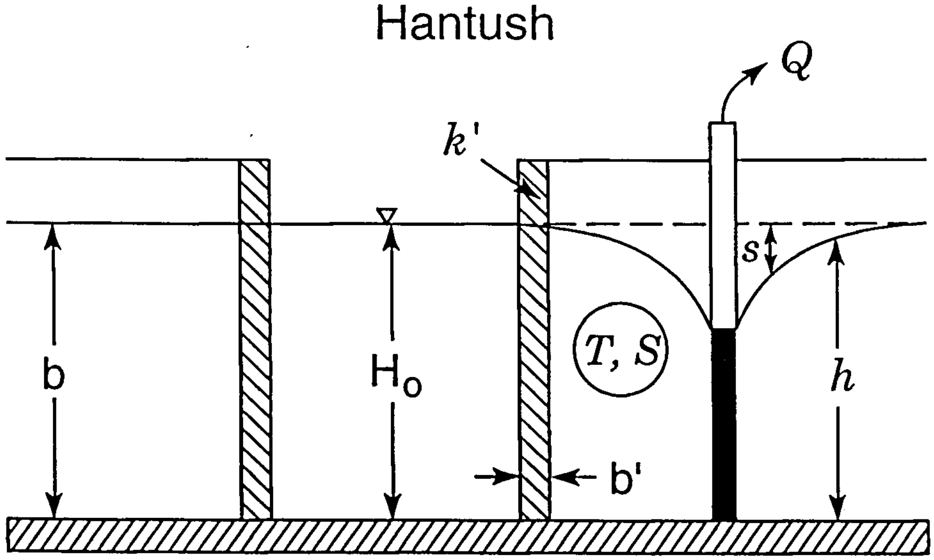
The StrpStrm model for calculation of pumping-induced drawdown and stream depletion--An executable program to download and sample data.

Kansas Geological Survey, Stream-Aqufer Interactions Project
Placed online Feb. 2000
Comments to webadmin@kgs.ukans.edu
The URL is HTTP://www.kgs.ukans.edu/StreamAq/index.html

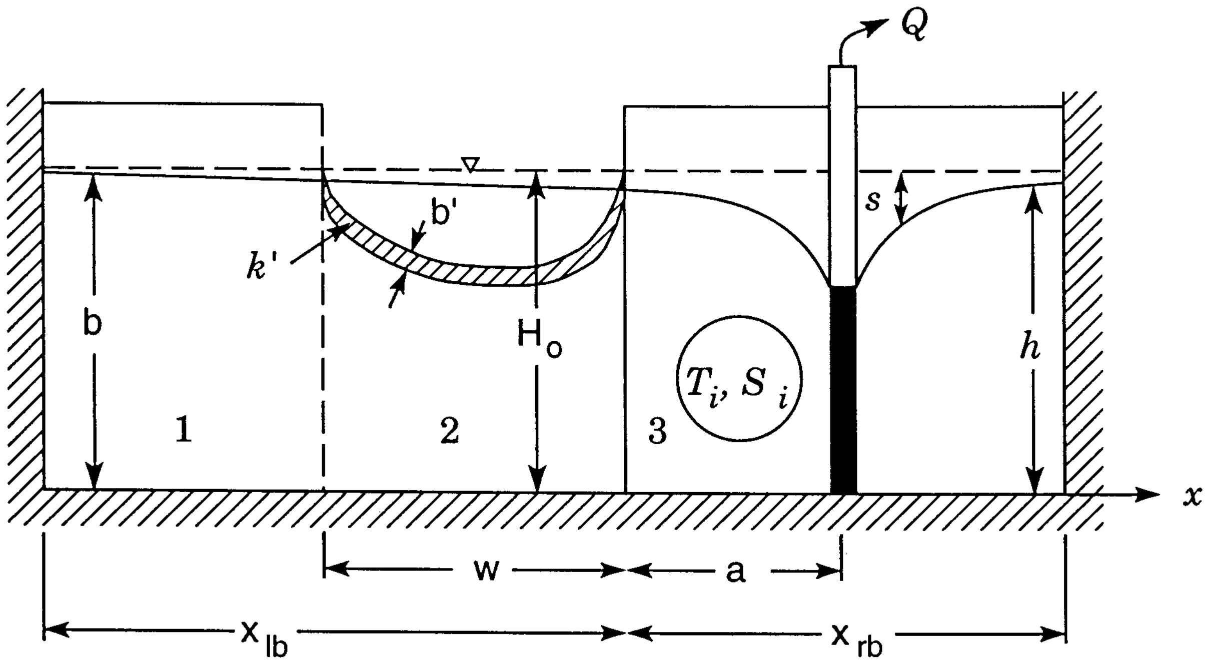
Glover - Balmer



Hantush



Most Kansas Streams



Conclusions

- Pumping Tests
  - advantages
    - large-scale T and S estimates
      - insensitive to conditions in well
    - hydraulic boundaries
      - moderate-term response of system to pumping
  - disadvantages
    - costly and involved
      - power generation
      - water disposal
      - nearby disturbances
    - low-K units
      - slug tests preferred

AQUIFER HYDRAULICS
A Comprehensive Guide to Hydrogeologic Data Analysis

Vedat Batu, Ph.D., P.E.

To Dr. Jim Butler
Colleague and friend
February 13, 1998

A Wiley-Interscience Publication
JOHN WILEY & SONS, INC.
New York / Chichester / Weinheim / Brisbane / Singapore / Toronto

The Role of Pumping Tests in Site Characterization: Some Theoretical Considerations

by James J. Butler, Jr.[a]

Abstract

Pumping tests are the primary means of estimating the large-scale storage and transmissive properties of an aquifer for site-characterization investigations. Most analyses of pumping-induced drawdown are performed using either the Theis log-log curve-matching procedure or the approximate Cooper-Jacob semilog method. These two procedures provide dissimilar estimates in nonuniform aquifers due to their emphasis on properties in different portions of a unit. The log-log curve-matching approach heavily weights the properties of local material, while the semilog procedure emphasizes the properties of material within the front of the cone of depression. The different emphasis of the two procedures results in log-log parameters being more appropriate for estimating pumping-well drawdown, while semilog parameters are better for estimating well yield. The magnitude of the difference between parameters estimated by the two approaches is a function of the degree of aquifer nonuniformity and the distance between the observation and pumping wells. The further the observation well is from the pumping well, the smaller the difference between the parameters. The difference between parameters estimated by slug tests and those estimated by pumping tests, on the other hand, will increase with this distance. Due to their emphasis on near-well materials, slug-test parameters may be of use in estimating pumping-well drawdown when employed in a patchy aquifer model. In general, predictions of aquifer behavior can be improved by more careful application of the conventional techniques used in pumping-test analyses.

Introduction

The pumping test has traditionally been one of the primary field methods used by hydrogeologists to improve their understanding of conditions in the subsurface. This technique can provide several types of information to the hydrogeologist, such as conditions within, and in the immediate vicinity of, the pumping well (e.g., step-drawdown tests; Lennox, 1966), the large-scale flow behavior in the system (e.g., the nature of the vertical and lateral boundaries), and estimates of the transmissive and storage properties of the aquifer (Walton, 1970; Kruseman and DeRidder, 1970). This article addresses the role of pumping tests in providing estimates of subsurface flow properties for site-characterization investigations. Such parameter estimates can aid in assessing the effectiveness of various proposed remediation schemes as well as in predicting the gross movement of a contaminant plume. The focus of this article is on the hydraulic behavior of confined aquifers, although the conclusions are certainly not limited to such systems.

There are a number of techniques that can be used to analyze pumping-induced drawdown in confined aquifers. These include the log-log curve-matching approach first proposed by Theis in the late 1930s (Jacob, 1940), the semilog straight-line approach of Cooper and Jacob (1946), and the closely associated recovery analysis of Theis (1935), the pressure-derivative techniques primarily employed in petroleum engineering (Tiab and Kumar, 1980; Bourdet *et al.*, 1983), and various numerical models. Pressure-derivative techniques, which involve use of the temporal derivative of drawdown as the plotted quantity, have not been employed frequently in hydrogeological applications due to their sensitivity to noisy data. The use of numerical models is unjustified for many pumping-test applications because limited drawdown data make it difficult to move beyond the detail and accuracy of techniques based on analytical solutions. For most applications, the log-log curve-matching approach (henceforth designated the log-log approach) and the semilog straight-line method (henceforth designated the semilog approach) are the preferred methods for analysis of pumping-test drawdown. This discussion

[a] Kansas Geological Survey, The University of Kansas, 1930 Constant Ave., Lawrence, Kansas 66046.

Received January 1989, revised September 1989, accepted October 1989.

Discussion open until November 1, 1990.

Analysis and Evaluation of Pumping Test Data

Second Edition (Completely Revised)

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Senior hydrogeologist, International Institute for Land Reclamation and Improvement, Wageningen
and
Professor in Hydrogeology, Free University, Amsterdam

With assistance from
J.M. Verweij
Freelance hydrogeologist

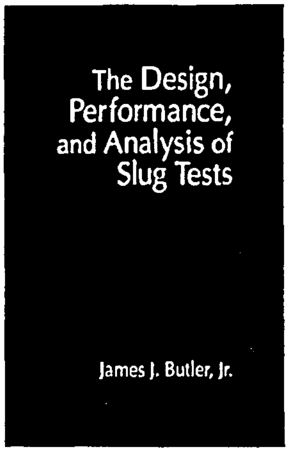
Publication 47

International Institute for Land Reclamation and Improvement,
P.O.Box 45, 6700 AA Wageningen, The Netherlands, 1990

L1230 FL

New!

"Excellent...a significant milestone in slug test technology and, for that matter, groundwater hydrology."
—Herman Bouwer, USDA Water Conservation Laboratory



The Design, Performance, and Analysis of Slug Tests

James J. Butler, Jr.
Kansas Geological Survey, University of Kansas, Lawrence

Available for 30-Day Examination

Addresses practical problems involved in using slug test data

Lewis Publishers

The slug test is currently the most common method for the *in situ* estimation of hydraulic conductivity at sites of suspected groundwater contamination. However, inappropriate procedures in one or more phases of a slug test can introduce considerable error into the resulting parameter estimates. This book remedies this problem by answering virtually every question regarding the design, performance, and analysis of slug tests. This is the first book to provide detailed information on the practical aspects of the methodology of slug tests.

All major analysis methods are described in **The Design, Performance, and Analysis of Slug Tests.** Each analysis method is outlined in a step-by-step manner and illustrated with a field example. The major practical issues related to the field application of each technique are also discussed. This book will help the reader get more reliable parameter estimates from slug tests and increase the utility of slug test data.

Features

- Flow charts make it easy to select analysis methods most appropriate for particular applications
- Methods are illustrated using field examples, demonstrating how the reader should use each method to analyze field data
- Major results are summarized in each chapter in the form of practical guidelines that allow readers to easily grasp the key points of that chapter
- Mathematical models underlying all major techniques are presented, providing a thorough understanding of the analysis methods
- Step-by-step descriptions of analysis methods help readers apply and understand techniques

Contents

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Contents continued on reverse side