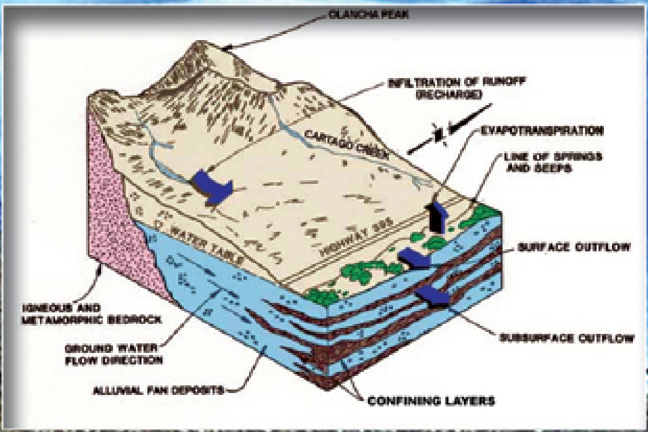
April 2003

Confining Layer Characteristics Cooperative Study:

Final Report



MEMORANDUM

MWH

To:	LADWP/ICWD	**Date:**	April 10, 2003
From:	MWH	**Reference:**	1341515.030204
Subject:	Final Report		

This Final Report has been prepared in fulfillment of the deliverable for Task Order 3.2.4 (Prepare Final Report) of Agreement 47026 between the City of Los Angeles Department of Water and Power (LADWP) and MWH.

Section X of the Inyo/LA Water Agreement (1991) recognizes the need for cooperative studies related to the effects of groundwater pumping on the environment of the Owens Valley. As such, a cooperative study on the "Characterization of Confining Layer Hydraulic Conductivity and Storage Properties in Owens Valley, Inyo County, California," hereby referred to as the "Confining Layer Characteristics Cooperative Study," was approved by the Inyo/Los Angeles Standing Committee on March 23, 2000.

The confining unit is Hydrogeologic Unit 2, as defined by Hollett, et al (1991). Hydrogeologic Unit 2 is a confining bed consisting of either one continuous clay bed or a series of lenticular clay beds thick enough to store groundwater that could be released from storage during periods of stressed conditions in the aquifer systems. This unit retards the upward and downward flow of groundwater between Hydrogeologic Unit 1 (unconfined part of the aquifer system) and Hydrogeologic Unit 3 (confined aquifer). The thickness, lateral continuity, vertical hydraulic conductivity, and hydraulic head differential across the confining unit control the quantity of groundwater that flows through it. In the Owens Valley, a number of clay beds lying in close proximity to one another over a large area typify the configuration of this unit (Hollett, et al, 1991).

The Confining Layer Characteristics Cooperative Study is a two-phased study consisting of four tasks as summarized in **Table 1**. This phased approach was conceived as one that would allow for early analysis of existing data with progressive low- to high-intensity field projects, if deemed necessary by the Cooperative Study Team. Phase I has been completed, and this Final Report represents the culmination of work conducted under Task 2.

Table 1
Summary of the Confining Layer Characteristics Cooperative Study

Phase	Task	Description of Task	Division of Responsibility		
			ICWD	LADWP	MWH
I	1	Sensitivity Analysis of the Coupled Aquifer Model of Denis and Motz (1998)	Performed sensitivity analysis	Reviewed sensitivity analysis	None
	2	Analysis of Available Aquifer Test Data	Review/ Comment	Review/ Comment	Identify aquifer tests, methods, and software; Perform aquifer test analysis; Development of GIS layers
II	3	Measurement of Vertical Groundwater Velocity from Temperature Profiles in Wells and Calculation of Vertical Hydraulic Conductivities using Head Measurements	To Be Determined	To Be Determined	To Be Determined
	4	Conduct New Drilling and Aquifer Tests to Determine the Characteristics of the Confining layer	To Be Determined	To Be Determined	To Be Determined

Task 1, "Sensitivity Analysis of the Coupled Aquifer Model of Denis and Motz (1998)" was conducted by Randy Jackson of the Inyo County Water Department (ICWD) and Saeed Jorat of LADWP. The analysis was documented in the Inyo County Water Department Report 2000-2 (Jackson and Jorat, 2000). The purpose of the sensitivity analysis was to quantify the uncertainty in the calibrated analytical model's predicted shallow unconfined aquifer drawdown caused by the uncertainty in the estimates of confining layer and other parameters. Results of the analysis indicated that drawdown in the shallow unconfined aquifer was most sensitive to aquitard vertical hydraulic conductivity.

LADWP and ICWD jointly implemented Task 2 of this Cooperative Study with assistance from MWH. Implementation of this task included three Cooperative Study Team meetings as summarized in **Table 2**.

Table 2
Summary of Cooperative Study Team Meetings

Meeting Date	Participants		
	ICWD	LADWP	MWH
April 15, 2002	Randy Jackson	Saeed Jorat Bob Prendergast	Karen Miller Tom McCarthy Victor Harris
July 19, 2002	Randy Jackson	Saeed Jorat	Karen Miller Victor Harris David Ebersold
February 24, 2003	Randy Jackson Chris Howard	Saeed Jorat	Karen Miller Victor Harris David Ebersold Tom McCarthy Kirsta Armor

Task 2, "Analysis of Available Aquifer Test Data" began with an ICWD/LADWP/MWH scoping meeting conducted on April 15, 2002 in Bishop. At this meeting, the purpose of the Cooperative Study was reviewed, and consensus among the project team was reached on the following study objectives:

- To develop an isopach map and a geographic information system (GIS) layer of the confining unit in the Owens Valley,
- To characterize the properties of the confining unit,
- To aid in the development of future deep-well operational testing, and
- To improve procedures to manage groundwater pumping from the deep aquifer.

In order to meet the study objectives, the following deliverables were developed and are included in this Final Report:

- *Technical Memorandum on the Identification of Methods and Tools for Characterization of the Confining Layer* (July 24, 2002). The purpose of this Technical Memorandum was to identify aquifer test analysis methods, aquifer test analysis software, and existing pump tests to utilize in the study.

- *Technical Memorandum on the Technical Review and Evaluation of the 1992 Deep Test Hole Study* (October 24, 2002). The purpose of this Technical Memorandum was to review the 1992 Deep Test Hole study and to make recommendations regarding the implementation of similar studies in the future.

- *Technical Memorandum on Aquifer Test Analysis* (December 4, 2002). The purpose of this Technical Memorandum was to analyze the selected pump tests using the recommended software and analysis methods in order to determine the vertical hydraulic conductivity of the confining unit at specific locations. Comments on this Technical Memorandum were received at a Cooperative Study Team Meeting on February 24, 2003. As such, this Final Report contains the revised version of the Technical Memorandum on Aquifer Test Analysis.

- *GIS Layers for the Confining Unit in the Owens Valley*. The purpose of the GIS layer maps was to develop a visual representation across the Owens Valley illustrating the areal extent of low permeability units. Comments on this Technical Memorandum were received at a Cooperative Study Team Meeting on February 24, 2003. As such, this Final Report contains the revised GIS layer maps.

In addition, a reference notebook of pump test analysis methods was assembled and distributed to the Cooperative Study Team members.

Implementation of Phase I of the Cooperative Study was very successful in meeting the objectives defined in the Cooperative Study proposal. The Cooperative Study Team has determined that additional work to be performed under Phase II of the Confining Layer Characteristics Cooperative Study is needed to meet the objectives of the overall study. The objectives of additional Phase II work would be to:

- Improve GIS layer maps developed in Phase I,
- Improve characterization of the confining unit,
- Aid in the development of future deep-well operational testing, and
- Improve procedures to manage groundwater pumping from the deep aquifer.

Specifically, an operational plan for short-term pump testing at specific locations followed by implementation is envisioned.

Technical Memorandum on the Identification of Methods and Tools for Characterization of the Confining Layer

TECHNICAL MEMORANDUM

MWH

To:	LADWP	**Date:**	July 24, 2002
From:	MWH	**Reference:**	1341515.030202

Subject: Identification of Methods and Tools for Characterization of the Confining Layer

INTRODUCTION

This Technical Memorandum has been prepared in fulfillment of the deliverable for Task Orders 3.2.1 (Initial Data Review and Participation in Inyo/LA Scoping Meeting) and 3.2.2 (Provide Recommendations on Analytical Strategy) of Agreement 47026 between the City of Los Angeles Department of Water and Power (LADWP) and Montgomery Watson Harza (MWH).

BACKGROUND AND STUDY OBJECTIVES

Section X of the Inyo/LA Water Agreement (1991) recognizes the need for cooperative studies related to the effects of groundwater pumping on the environment of the Owens Valley. As such, a cooperative study on the "Characterization of Confining Layer Hydraulic Conductivity and Storage Properties in Owens Valley, Inyo County, California," hereby referred to as the "Confining Layer Characteristics Cooperative Study," was approved by the Inyo/Los Angeles Standing Committee on March 23, 2000.

The confining unit is Hydrogeologic Unit 2, as defined by Hollett, et al (1991). Hydrogeologic Unit 2 is a confining bed consisting of either one continuous clay bed or a series of lenticular clay beds thick enough to store groundwater that could be released from storage during periods of stressed conditions in the aquifer systems. This unit retards the upward and downward flow of groundwater between Hydrogeologic Unit 1 (unconfined part of the aquifer system) and Hydrogeologic Unit 3 (confined aquifer). The thickness, lateral continuity, vertical hydraulic conductivity, and the hydraulic head differential across the confining unit control the quantity of groundwater that flows across it. In the Owens Valley, a number of clay beds lying in close proximity to one another over a large area typify the configuration of this unit (Hollett, et al, 1991).

LADWP and the Inyo County Water Department (ICWD) are jointly implementing this cooperative study with assistance from MWH. The study is a two-phased program consisting of four tasks as summarized in **Table 1**. This phased approach allows for early analysis of existing data with progressive low- to high-intensity field projects, if deemed necessary by the Cooperative Study team. Currently, Phase I is under implementation, whereas the decision to implement Phase II will depend on the outcome of Phase I.

Table 1
Summary of the Confining Layer Characteristics Cooperative Study

Phase	Task	Description of Task	Division of Responsibility		
			ICWD	LADWP	MWH
I	1	Sensitivity Analysis of the Coupled Aquifer Model of Denis and Motz (1998)	Perform sensitivity analysis	Perform/Review sensitivity analysis	Review paper on sensitivity analysis
	2	Analysis of Available Aquifer Test Data	Review/ Comment	Review/ Comment	Identify aquifer tests, methods, software, and GIS development
II	3	Measurement of Vertical Groundwater Velocity from Temperature Profiles in Wells and Calculation of Vertical Hydraulic Conductivities using Head Measurements	Joint effort	Joint effort	TBD
	4	Conduct New Drilling and Aquifer Tests to Determine the Characteristics of the Confining layer	TBD	TBD	TBD

Task 1, "Sensitivity Analysis of the Coupled Aquifer Model of Denis and Motz (1998)" was conducted by Randy Jackson of ICWD and Saeed Jorat of LADWP. The analysis was documented in the Inyo County Water Department Report 2000-2 (Jackson and Jorat, 2000). The purpose of the sensitivity analysis was to quantify the uncertainty in the calibrated analytical model's predicted shallow unconfined aquifer drawdown caused by the uncertainty in the estimates of confining layer and other parameters. Results of the analysis indicated that drawdown in the shallow unconfined aquifer was most sensitive to aquitard vertical hydraulic conductivity.

Task 2, "Analyses of Available Aquifer Test Data" began with an ICWD/LADWP/MWH scoping meeting conducted on April 17, 2002 in Bishop. At this meeting, the purpose of the Cooperative Study was reviewed, and consensus among the project team was reached on the following study objectives:

- To develop an isopach map and a geographic information system (GIS) layer of the confining unit in the Owens Valley,
- To characterize the properties of the confining unit,
- To aid in the development of future deep-well operational testing, and
- To improve procedures to manage groundwater pumping from the deep aquifer.

In addition, the following deliverables were identified for Task 2 of the Cooperative Study:

- GIS layer of the confining unit (effective thickness, location, and characteristics),
- Isopach map of the confining unit occurrence in the Owens Valley, and
- Vertical conductance values for the confining unit at discrete locations based on the analysis of existing aquifer test data.

APPROACH

As part of the initial work on the Cooperative Study's Task 2, the following approach was identified, and the results of these subtasks are presented in this Technical Memorandum:

- Review work conducted by LADWP and separate work by ICWD on mapping and defining the extent of the confining layer,
- Perform a literature review of aquifer test analysis methods and analytical software for use in the study,
- Conduct an initial review of the available aquifer test data to determine the most appropriate data sets for quantitative analysis,
- Develop recommendations on pump tests, methods, software, and future GIS work related to the confining unit, and
- Coordinate with Dr. Shlomo P. Neuman, a world-renowned expert in the field of well hydraulics and aquifer test analysis, for technical review of recommendations developed.

ORGANIZATION OF THIS TECHNICAL MEMORANDUM

The results of this work are presented below and organized into the following sections:

- Previous Work by LADWP and ICWD
  - Confining Layer Characterization by LADWP
  - Confining Layer Characterization by ICWD
  - Comparison of the LADWP and ICWD Previous Work
- Literature Review Process
  - Evaluation of Aquifer Test Analysis Software Packages
  - Evaluation of Aquifer Test Analysis Methods
  - Evaluation of Existing Pump Test Data
- Recommendations
  - Recommended Integration of Previous Work into GIS
  - Recommended Aquifer Test Analysis Methods
  - Recommended Aquifer Test Analysis Software Packages
  - Recommended Existing Pump Test Data for Analysis
- References

PREVIOUS WORK BY LADWP AND ICWD

Both LADWP and ICWD have undertaken efforts to characterize the regional extent and character of the confining layer. A summary of this previous work is presented below.

Confining Layer Characterization by LADWP

In an effort to gain a preliminary understanding of both the thickness and the areal extent of the confining layer, LADWP compiled a spreadsheet that details zones of low permeability for over 300 wells throughout the Owens Valley. The summary spreadsheet was constructed by reviewing available well logs in the Owens Valley and extracting the following information:

- Well Number,
- Wellfield/Area,
- Depth and Perforated Intervals,
- Low Permeability Zones (depth below ground surface and description of each zone),
- Depth to Water (February 1990),
- Water Surface Elevation (February 1990), and
- Nominal and Long-term Pumping Capacity.

The data contained in LADWP's spreadsheet are summarized by geographical area in **Table 2**. The percent of reviewed well logs that contain low permeability zones was computed by MWH for the whole Owens Valley. This analysis indicates that 89 percent of available well logs in the Owens Valley suggest the presence of a low permeability zone. However, overall characteristics of individual wellfields may be different because the evaluation was limited to the available data.

Table 2
Summary of Previous Work by LADWP

Wellfield/Area	Total Number of Wells	Number of Wells with Well Logs Available	Well Logs Exhibiting a Low Permeability Zone
Bairs-Georges	15	15	15 (100%)
Big Pine	44	37	25 (68%)
Bishop	45	41	41 (100%)
Chalfant	6	1	0 (0%)
Independence-Oak	46	41	38 (93%)
Laws	43	34	28 (82%)
Lone Pine	9	5	5 (100%)
Symmes-Shepherd	37	32	31 (97%)
Taboose-Aberdeen	30	22	18 (82%)
Thibaut-Sawmill	27	23	23 (100%)
TOTAL	**302**	**251**	**224 (89%)**

Confining Layer Characterization by ICWD

A similar confining layer table was prepared by the ICWD in the summer of 1999. These data consist of confining layer information from zero to 200 feet below ground surface. The fields of record for these data are as follows:

- Well Number,
- UTM East Coordinates,
- UTM North Coordinates,
- Maximum Clay Layer Thickness,
- Top Depth of Upper Clay Layer,
- Bottom Depth of Lowest Clay Layer, and
- Cumulative Clay Thickness.

Each well log that indicated the presence of a confining layer in the Owens Valley was reviewed, and the suspected confining layers were highlighted. Each layer was then input into a table, and the upper and lower extents of the confining layers were noted along with the cumulative confining layer thickness.

After completion of the data table, ICWD used Surfer® plotting software to prepare the following maps, which were also reviewed by MWH:

- Contour Map of Maximum Confining Layer Thickness,
- Post Map of Maximum Confining Layer Thickness,
- Contour Map of Maximum Cumulative Confining Layer Thickness, and
- Map of Maximum Cumulative Confining Layer Thickness.

Comparison of LADWP and ICWD Previous Work

The LADWP and ICWD data sets are very similar with the primary difference being that the deepest extent of the ICWD data is 200 feet below ground surface whereas the LADWP data includes the total depth of the well. When comparing the top 200 feet of the LADWP data with the ICWD data, little difference is observed between the two data sets. In effect, the ICWD data set is a subset of the more comprehensive LADWP data set. The Cooperative Study team agreed on July 19, 2002 to begin creation of the GIS layer using only the LADWP data set.

LITERATURE REVIEW PROCESS

For the literature review component of the study, MWH conducted reviews on the following three topics:

- Aquifer test analysis methods,
- Aquifer test analysis software packages, and

- Existing pump test data for wells in the Owens Valley.

Evaluation of Aquifer Test Analysis Software Packages

A comprehensive search was conducted for software packages that can be used for aquifer test analysis. Fourteen potential packages were identified during this search. **Table 3** presents the cost of each package along with the analytical methods utilized.

Evaluation of Aquifer Test Analysis Methods

More than twenty aquifer test analysis methods were reviewed to determine their potential for use in this study. Analysis methods were evaluated with respect to the following categories; **Table 4** presents a summary of this evaluation:

- Aquifer type (confined, leaky, unconfined, fractured),
- Aquifer test type (pump test, step test, slug test, etc.),
- Type of flow (transient or steady-state),
- Data needed to perform the analysis (i.e. drawdown vs. time data, discharge rate, etc.),
- Calculated values yielded by the analysis (i.e. transmissivity, storativity, etc.), and
- Available software packages for analysis with each method.

Additionally, as part of the literature review of aquifer test analytical methods, the original journal references for each of the pump tests researched were compiled into a reference notebook, entitled "Confining Layer Characteristics Cooperative Study: Pump Test Analysis Methods." Notebooks were provided to the Cooperative Study team members.

Table 3
Summary of Aquifer Test Analysis Software Packages

Software Title:	Cost:	Method(s) Used:
ADEPT	Stand-alone version: **$425** (includes limited version of Mathcad) ADEPT alone: **$350** (requires Mathcad 6.0 or higher)	**Includes**: Cooper-Jacob Distance Drawdown Analysis, Cooper-Jacob Time-Drawdown Analysis, Estimation of Drawdown at Specified Radius, Estimation of Drawdown at Specified Time, Theis Drawdown Analysis, Thiem Drawdown Analysis, Birsoy-Summers Step-Test Analysis, De Glee's Method for Steady-State Flow, Hantush's Inflection Point Method, Fully Penetrating Well in a Leaky Aquifer, Partially Penetrating Well in a Leaky Aquifer, Neuman's Method for Unconfined Flow
AQTESOLV for Windows	Standard version: **$500** Professional version: **$750** Modeling Pro version #1: **$1000** (includes TWODAN) Modeling Pro version #2: **$1000** (includes ModelCad for Windows)	**Standard Version Includes**: Theis Method (1935), Cooper-Jacob Method (1946), Papadopulos-Cooper Method (1967), Theis residual drawdown method (1935), Bouwer-Rice Method (1976), Cooper-Bredehoeft-Papadopulos Method (1967), Hvorslev Method (1951), Birsoy-Summers Method (1980), Neuman Method (1974), Moench Method (1993, 1996), Hantush-Jacob Method (1955), Hantush Method (1960), Moench Method (1984) **Professional Version Includes:** All standard version methods, Theis step test Method (1935), Hantush wedge-shaped aquifer Method (1962), Murdoch interceptor trench Method (1994), Hyder KGS Model (1994), Quick Neuman Method, Streltsova Method (1974), Moench Method (1997), Moench Method (1985), Neuman-Witherspoon Method (1969)
Aquifer Test Toolbox	**$225**	**Includes**: Theis and Jacob Confined Aquifer Methods, Walton and Hantush Inflection Leaky Aquifer Methods, Stallman Single Boundary Method, Theis Regression and Curve Fit Methods, Hvorslev and Bouwer and Rice Methods, Hantush-Biershenk Step Drawdown Method, Birsoy-Summers Variable Discharge Method, WAFER Falling Head Tests
AquiferTest for Windows	**$590**	**Includes**: Theis Method (Confined), Cooper-Jacob Method (Time-Drawdown, Confined), Cooper-Jacob Method (Distance-Drawdown, Confined), Cooper-Jacob Method (Time-Distance-Drawdown), Hantush and Jacob Method (Leaky-Confined), Neuman Method (Unconfined), Moench Method (Unconfined, Partially Penetrating Well), Moench Method (Fracture Flow)
Aquifer^{win32}	Slug Test Price: **$340** (slug test analyses) Standard Version: **$540** (slug test & pumping test analyses) Professional version: **$740** (slug test, pumping test, step test, derivative analysis, pump test sim.) Modeling Version: **$995** (Professional Version plus WinFlow)	**Includes**: Thiem Method (Distance-Drawdown, 1906), Cooper and Jacob Method (Straight Line Method, 1946), Theis Method (Unconfined, 1935), Theis Method (Recovery, 1946), Hantush Method (Partially Penetrating Well/Non-leaky aquifer, 1961), Papadopulos and Cooper Method (1967), Hantush Method (Leaky Aquifer, 1960), Hantush and Jacob Method (Fully Penetrating Well/Leaky Aquifer, 1955), Hantush Method (Partially Penetrating Well/Leaky Aquifer, 1964), Neuman Method (1972), Neuman Method (1974), Moench Method (1984)

Table 3 (continued)
Summary of Aquifer Test Analysis Software Packages

Software Title:	Cost:	Method(s) Used:
AQUIPACK	**$200**	**Includes**: Hydraulic conductivity and transmissivity estimation (steady-state and non steady-state pumping tests) Methods not specified.
AQUIX-4S	**$695**	**Includes**: Theis Method (1935), Hantush Method (1960), Hantush Method (1964), Neuman Method (1975), Cooper et al Method (1967)
Infinite Extent	Infinite Extent alone: **$350** w/ StepMaster and Super Slug: **$695**	**Includes**: Theis Method (Confined Aquifer), Walton Method (Leaky Aquifer), Hantush Method (Leaky Aquifer), Neuman Method (Unconfined Aquifer), Hantush's Method for Partial Penetration (Modification of Theis Method), Specific Capacity Method, Theis Method (Confined Aquifer, by slope-matching), Hantush Method (Leaky Aquifer/Steady-State, by slope-matching), Theim Method (Confined and Unconfined Aquifer/Steady-State), Distance-Drawdown Method
MODPUMP	**$250**	**Utilizes:** MODFLOW ("A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model" developed by McDonald and Harbaugh, USGS, 1984
PUMPTEST	**$125**	**Includes**: Theis Method, Jacob Method, Walton Method, Hantush Method, Neuman Method, Hvorslev Method, Cooper Bredehoeft Method, Bouwer & Rice Method
StepMaster	**$250**	**Includes**: Hantush-Bierschenk Method, Eden-Hazel Method, Birsoy-Summers Method
Super Slug	**$250**	**Includes**: Bouwer and Rice Method (Automatic), Bouwer and Rice Method (Graphical), Cooper Method, Bredehoeft Method, Papadopulos Type Curve Method, Hvorslev Method (Automatic), Hvorslev Method (Graphical), Ferris and Knowles Method (Automatic)
TSSLEAK	**$50**	**Utilizes**: Hantush-Jacob Method
WELLTEST	**$195**	**Includes**: Jacob straight-line method

Table 4
Summary of Aquifer Test Analysis Methods

	Aquifer Type			Test Type					Flow		Data Needed									Calculated Values											Software Packages														
Method:	Confined	Leaky	Unconfined	Pumping	Recovery	Single-Well	Step	Slug	Steady State	Transient	Discharge Rate(s)	Times corresponding to each discharge rate	Distance from pumped well to piezometer(s)	Drawdown vs Time data for the Pumped Well	Drawdown vs Time data for at least one piezometer	Drawdown vs Distance data for multiple piezometers	Aquitard thickness	Aquifer thickness (initial saturated thickness)	Other (see notes below)	Aquifer Transmissivity[a] (KD or T)	Aquifer Storativity[b] (S)	Elastic Storativity[b] (S_A)	Specific Yield[c] (S_Y)	Aquifer Hydraulic Conductivity[d] (K)	Aquitard Hydraulic Resistance[e] (c)	Leakage Factor[f] (L)	Aquitard vertical hydraulic conductivity[d] (K')	Aquitard storage coefficient[g] (S')	Other (see notes below)	Confining Layer Properties Calculated? (Yes/No)	ADEPT	AQTESOLV PRO	Aquifer Test Toolbox	AquiferTest for Windows	Aquiferwin32	AQUIPACK	AQUIX-4S	Denis and Motz Software	Infinite Extent	MODPUMP	PUMPTEST	StepMaster	Super Slug	TSSLEAK	WELLTEST
Birsoy-Summers Step Test (1980)	✓						✓			✓	✓	✓	✓		✓					✓	✓									No	✓	✓	✓									✓			
Bouwer-Rice (1976)	✓		✓					✓	✓									✓	1					✓						No		✓	✓								✓		✓		
Cooper-Bred.-Papa (1967)	✓							✓		✓				✓					2	✓	✓									No		✓					✓				✓		✓		
Cooper and Jacob (1946)	✓			✓						✓	✓		✓		✓	(✓)				✓	✓									No	✓	✓	✓	✓	✓						✓				✓
De Glee (1930, 51)		✓		✓					✓		✓					✓				✓					✓	✓				Yes	✓														
Denis and Motz (1998)		✓		✓						✓	✓		✓		✓		✓			✓	✓						✓	✓		Yes								✓							
Eden-Hazel (1973)	✓						✓			✓	✓	✓		✓						✓									3	No												✓			
Hantush Biershenk Step (1964)	✓	✓	✓				✓			✓	✓	✓		✓															4	No			✓									✓			
Hantush Curve Fit (1960)		✓		✓						✓	✓		✓		✓		✓			✓	✓								5	Yes		✓			✓		✓		✓		✓				
Hantush Inflection (1956)		✓		✓						✓	✓		✓		✓				6	✓	✓				✓	✓				Yes	✓		✓						✓		✓				
Hantush-Jacob (1955)		✓		✓						✓	✓		✓		✓	(✓)				✓					✓	✓				Yes		✓		✓	✓									✓	
Hantush Wedge (1962)	✓			✓						✓	✓		✓		✓				7	✓	✓									No		✓													
Neuman (1974)			✓	✓						✓	✓		✓		✓			✓	8	✓		✓	✓	✓						No		✓													
Neuman Curve Fit (1972, 1975)			✓	✓						✓	✓		✓		✓			✓		✓		✓	✓	✓						No	✓	✓		✓	✓		✓		✓		✓				
Neuman-Witherspoon (1969)		✓		✓						✓	✓		✓		✓		✓			✓	✓						✓	✓		Yes		✓													
Papadopulos-Cooper (1967)	✓				✓	✓				✓	✓			✓						✓										No		✓			✓										
Streltsova (1974)			✓	✓						✓	✓		✓		✓			✓		✓		✓	✓	✓						No		✓													
Theis (1935)	✓			✓						✓	✓		✓		✓					✓	✓									No	✓	✓	✓	✓	✓		✓		✓		✓				
Theis Recovery (1935)	✓				✓					✓	✓								9	✓										No		✓													
Theis Step (1935)	✓						✓			✓	✓		✓		✓	(✓)				✓	✓									No		✓													
Thiem (1906)	✓			✓					✓		✓		✓		✓					✓										No	✓				✓				✓						
Theim-Dupuit (1906)			✓	✓					✓		✓		✓		✓			✓		✓										No	✓				✓				✓						
Walton (1962)		✓		✓						✓	✓		✓		✓					✓	✓				✓	✓				Yes			✓						✓		✓				

Notes:

1: This method also requires: observed head vs time, length of the well screen, horizontal distance from the well center to the aquifer, the depth of well below the water table, the radius of the unscreened part of the well where head is rising.
2: This method also requires: the diameter of the well casing and the diameter of the screened interval or open borehole and the instantaneous drawdown in the unpumped well.
3: This method also yields: C (the nonlinear well-loss coefficient).
4: This method yields: B (linear aquifer-loss coefficient + linear well-loss coefficient) and C (nonlinear well-loss coefficient).
5: This method also yields: the value of K'S' (aquitard hydraulic conductivity * aquitard storativity).
6: There is a version of this method that must be performed using drawdown vs time data for multiple piezometers.
7: This method also requires: the angle between the flow direction and a line connecting the pumped well and the piezometer.
8: This method also requires: the vertical distance between the bottom of perforations in the pumping well and the initial position of the water table.
9: This method also requires residual drawdown vs t/t' data. (Note: t/t' = the time since the start of pumping divided by the time since the cessation of pumping)

Definitions:

a: The rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer.
b: The volume of water released from storage per unit surface area of the aquifer per unit decline in the component of hydraulic head normal to that surface.
c: The volume of water than an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline of the watertable.
d: The volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles of the direction of flow.
e: Characterizes the resistance of an aquitard to vertical flow, either upward or downward.
f: Also known as characteristic length, is a measure for the spatial distribution of the leakage through an aquitard into a leaky aquifer and vice versa.
g: The volume of water released from storage, or taken into storage, per unit of aquitard storage per unit change in head.

Evaluation of Existing Pump Test Data

MWH was provided with pump test data packets for 41 wells located within the Owens Valley. **Table 5** is a comprehensive summary of these data packets. The table contains the following information:

- Location and date of the pump test,
- Depth and screened intervals of the pumped well,
- Depth and screened intervals of any monitoring wells (where available),
- Description of aquifer relationships,
- Description of any substantial confining units noted on the well log,
- Type and duration of the pump test,
- Calculated transmissivity,
- Calculated storativity,
- Calculated permeability,
- Well efficiency, and
- Notes on the nature of confinement as found in the data packets.

For selected data packets, drawdown versus time plots were created for the data collected from the pumping well only. The purpose of these plots was to identify the shape of the drawdown curve and determine if “leaky” aquifer conditions exist. The presence of a “leaky” aquifer system is evidenced by a flattening of the drawdown vs. time curve relative to a Theis curve when plotted on a log-log scale. The criteria for determining whether or not to create a drawdown vs. time plot for each of the data packets were as follows:

- Is the pump test data included in the data packet?
- Does the well log for the pumping well indicate the presence of a confining unit?
- Is the pumping well screened below the potential confining unit?

For each pump test data packet for which the answer to the above three questions is “Yes,” a drawdown vs. time plot was plotted on log-log scale. **Table 6** presents a summary of the selection process. Drawdown vs. time plots for the 12 selected wells are included in **Appendix A**.

Pump test data packets provided by ICWD were summarized in **Table 5**, but were not further evaluated because these data come from wells in the southern portion of Owens Valley, which was identified as a lower priority for study by the cooperative study team.

Table 5
Summary of Existing Pumping Test Data

Packet Title (Date)	Date of Test	Well Field	Tested Well[1] (depth in feet) [screened zones]	Observation Wells[1] (depth in feet)	Description of Aquifer Relationships	Substantial Confining Layers	Types of Tests Performed (including duration)	Calculated Transmissivity[2] (gpd/ft)	Calculated Storativity (-)	Calculated Permeability (gpd/ft^2)	Well Efficiency	Notes on Nature of Confinement
"USGS/LA/Inyo-Owens Valley Groundwater Investigation Deep Well Aquifer Test - Big Pine West of Owens River Site" (February, 1985)	September, 1984	Big Pine	**USGSV014GA (324) [275-315]**	USGS V014GC (41) [21-41] USGS V014GB **(166) [137-155]**	USGS V014GA is deep V014GB is intermediate V014GC is shallow	Clay from 177 to 185 ft, 196 to 250 ft, 335 to 380 ft	1: Deep Well test (Test was started 3 times. Test durations are as follows: 12 hours, 2.5 days, 3.5 days.)	36,000 (Modified Theis method)	N/A	900	89% for Q = 190 gpm	*Pumping did not produce any detectable effect on the shallow water table or intermediate zone.
"Report on the Deep Well Aquifer Test at the Big Pine East of the Owens River Site" (November, 1985)	June, 1985	Big Pine	**USGS V016GA (390) [330-390]**	**USGS V016GB (48) [28-48]** **USGS V014GA (315) [275-315]** **USGS V014GB (166) [137-155]** **USGS V014GC (41) [21-41]**	USGS V016GA and USGS V014GA are deep USGS V016GB and USGS V014GC are shallow USGS V014GB is intermediate	Tight clay from 182 to 250 ft	1: Short term test at Half-Q = 259 gpm (2.5 hours) 2: Long term test at Max-Q = 507 gpm (10 days)	45,000 (Modified Theis method)	N/A	1150	N/A	*Ten days of pumping did not appear to affect the shallow water table.
"Report on the Deep Well Aquifer Test at the Fish-Springs-Tinemaha Site" (December, 1985)	July, 1985	Fish Springs - Tinemaha Site	**USGS V017GA (360) [300-340]**	**USGS V017GB (144) [123-144]** **USGS V017GC (48) [28-48]** **V260 (115) [66-87, 103-115]** V224 (322) [96-114] W219 AQ (225) [85-144] V017N (181) [72-87, 160-164.5]	V017GA is deep V017GC is shallow V017GB, V260, and V017N are intermediate V224 and W219 AQ are deep	Tight clay from 162 to 255 ft	1: Short-term test (3 hr, 10 min) 2: Long-term test (12 d, 20 hr)	6,000 (Modified Theis method)	N/A	150 (based on 40 ft perf'd casing) 70 (based on est. aquifer thickness of 85 ft)	N/A	*Pumping from the deep aquifer produced no drawdown effect in the shallow zone and a slight response in the intermediate zone.
"Report on Well W374 AQ Aquifer Test - Big Pine Well Field" (August, 1986)	May, 1986	Big Pine	**W374 AQ (450) [260-440]**	**USGS V014GA (315) [275-315]** **USGS V014GB (166) [137-155]** **USGS V014GC (41) [21-41]** **W375 EM (450) [260-440]**	W374 AQ is deep V014GC is shallow V014GB is intermediate V014GA and W375 EM are deep	Clay (and some sand) from 190 to 252 ft	1: Step-drawdown test with 3 steps (6 hours) 2: Constant Rate Aquifer test (22 hr, 45 min)	77,000 (Modified Theis method)	2.70E-04	430	77% for Q = 6 cfs (2693 gpm)	*Pumping did not produce and significant effect on the shallow or intermediate zones.
"Report on Well W375 EM Aquifer Test - Big Pine Well Field" (August, 1986)	May, 1986	Big Pine	**W375 EM (450) [260-440]**	USGS V014GA (315) [275-315] USGS V014GB (166) [137-155] USGS V014GC (41) [21-41] **W374 AQ (450) [260-440]**	W375 EM is deep V014GC is shallow V014GB is intermediate V014GA and W374 AQ are deep	Clay from 180 to 245 ft	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (22 hours)	73,000 (Modified Theis method)	2.70E-04	420	83.5% for Q = 6 cfs (2693 gpm)	*Pumping did not produce any significant effect on the shallow or intermediate zones.
"Well W376 EM Aquifer Test - Laws Well Field" (October, 1992)	September/ October, 1986	Laws	**W376 EM (560) [50-200] [400-550]**	T624 (550) [500-540] **W377 EM (560) [50-200, 400-550]**	W376 EM is deep T624 and W377 EM are deep	Conglomerate clay from 380 to 400 ft	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (17.3 hours)	100,000-150,000 (Modified Theis and Hantush methods)	1.00E-03	N/A	74% for Q = 3500 gpm	*Well W376 EM is believed to penetrate a semi-confined aquifer.
"Well W377 EM Aquifer Test - Laws Well Field' (November, 1992)	October, 1986	Laws	**W377 EM (560) [50-200] [400-550]**	**W376 EM (56) [50-200, 400-550]** T624 (550) [500-540] T625 (550) [500-540]	W377 EM is deep W376 EM, T624, and T625 are deep	Clay and gravel from 265 to 310 ft	1: Step-drawdown test with 4 steps (6 hours) 2: Constant Rate Aquifer test (20 hours)	40,000-70,000 (Modified Theis and Hantush methods)	2.00E-03	N/A	44% for Q = 2400 gpm	*Well W377 EM is believed to penetrate a semi-confined aquifer.
"Well W379 EM Aquifer Test - Big Pine Well Field" (October, 1992)	August, 1986	Big Pine	**W379 EM (410) [200-400]**	T627 (360) [300-350] **W378 EM (410) [200-400]**	W379 EM is deep T627 and W378 EM are deep	Clay from 100 to 200 ft (Big Pine X-Sections)	1: Step-drawdown test with 4 Steps (6 hours) 2: Constant Rate Aquifer test (20 hours)	80,000-90,000 (Modified Theis, Hantush, Modified Hantush methods)	1.00E-03	N/A	Close to 100% for Q = 3060 gpm	*Well W379 EM is believed to penetrate a semi-confined aquifer.

Table 5 (continued)
Summary of Existing Pumping Test Data

Packet Title (Date)	Date of Test	Well Field	Tested Well[1] (depth in feet) [screened zones]	Observation Wells[1] (depth in feet)	Description of Aquifer Relationships	Substantial Confining Layers	Types of Tests Performed (including duration)	Calculated Transmissivity[2] (gpd/ft)	Calculated Storativity (-)	Calculated Permeability (gpd/ft^2)	Well Efficiency	Notes on Nature of Confinement
"Well W380 EM Aquifer Test - Thibaut/Sawmill Well Field" (October, 1992)	September, 1986	Thibaut-Sawmill	**W380 EM (700) [250-690]**	T628 (700) [300-320] T629 (?) [?] T630 (700) [300-320] T631 (?) [?]	W380 EM is deep T628 and T630 are deep No data is available for T629 or T631	No obvious confining unit	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (15 hours)	40,000-45,000 (Modified Theis, Hantush, Modified Hantush methods)	3.00E-04	N/A	70% for Q = 1550 gpm	*Well W380 EM is believed to penetrate a confined aquifer.
"Well W381 EM Aquifer Test - Thibaut/Sawmill Well Field" (December, 1992)	September, 1986	Thibaut-Sawmill	**W381 EM (690) [250-690]**	T630 (700) [300-320]	W381 EM is deep T630 is deep	Clay from 130 to 150 ft	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (17 hours)	40,000-50,000 (Modified Theis and Hantush methods)	6.00E-05	N/A	44% for Q = 1440 gpm	*Well W381 EM is believed to penetrate a confined aquifer.
"Well W382 EM Test - Thibaut-Sawmill Field" (March, 1993)	December, 1986	Thibaut-Sawmill	**W382 EM (625) [275-615]**	T729 (700) [300-320]	W382 EM is deep T729 is deep	Sporadic clay & gravel from 110 to 635 ft	1: Step-drawdown test with 2 steps (3 hours) 2: Constant Rate Aquifer test (20 hours)	8,000-11,000 (Modified Theis method)	3.00E-03	N/A	N/A	*Well W382 EM is believed to penetrate a semi-confined aquifer.
"Well W383 EM Aquifer Test - Independence-Oak Well Field" (October, 1992)	October, 1986	Independence-Oak	**W383 EM (575) [264-565]**	T632 (420) [370-410]	W383 EM is deep T632 is deep	Sporadic clay & gravel from 60 to 160 ft	1: Step-drawdown test with 3 Steps (4.5 Hours) 2: Constant Rate Aquifer test (22 hours)	40,000-60,000 (Modified Theis and Hantush methods)	7.00E-04	N/A	54% for Q = 2240 gpm	*Well W383 EM is believed to penetrate a confined aquifer.
"E/M Well W384 EM Aquifer Test - Independence-Oak Well Field" (February, 1993)	September, 1986	Independence-Oak	**W384 EM (650) [300-640]**	T633 (550) [500-540]	W384 EM is deep T633 is deep	Cemented from 250 to 340 ft	1: Step-drawdown test with 3 Steps (4.5 Hours) 2: Constant Rate Aquifer test (22 hours)	35,000-40,000 (Modified Theis method)	2.00E-04	N/A	62% for Q = 949 gpm	*Well W384 EM is believed to penetrate a confined aquifer.
"Well W385 EM Test - Laws Field" (March, 1993)	March, 1987	Laws	**W385 EM (560) [50-200] [220-550]**	T732 (560) [500-540]	W385 EM is deep T732 is deep	No obvious confining unit	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (22 hours)	160,000-200,000 (Modified Theis method)	5.00E-04	N/A	85% for Q = 4190 gpm	*Well W385 EM is believed to penetrate a confined aquifer.
"Well W386 EM Test - Laws Field" (May, 1993)	March/ April, 1987	Laws	**W386 EM (560) [50-200] [220-550]**	**W385 EM (560) [50-200, 220-550]** T704 (35) [25-35] T733 (?)	W386 EM is deep T704 is shallow W385 EM and T733 are deep	Sand w/ clay lenses from 180 to 200 ft	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifertest (22 hours)	130,000-150,000 (Modified Theis and Hantush methods)	1.00E-03	N/A	Close to 100% for Q = 4030 gpm	*Pumping produced markedly less effect on the shallow zone than on the deep zone.
"Well W387 EM Test - Laws Field" (May, 1993)	April, 1987	Laws	**W387 EM (540) [200-240] [240-260] [260-530]**	T734 (370) [300-350]	W387 EM is deep T734 is deep	Sporadic clay from 110 to 220 ft	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (22 hours)	50,000-80,000 (Modified Theis, Hantush, Modified Hantush methods)	3.00E-03	N/A	79% for Q = 3610 gpm	*Well W387 EM is believed to penetrate a semi-confined aquifer.
"Well W388 EM Test - Laws Field" (July, 1993)	April/May, 1987	Laws	**W388 EM (540) [200-240] [240-260] [260-530]**	T735 (510) [440-490] **T701 (31) [21-31]**	W388 EM is deep T701 is shallow T735 is deep	Sporadic clay & silt lenses from 80 to 560 ft	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (19 hours)	80,000-100,000 (Modified Theis and Hantush methods)	5.00E-03	N/A	78% for Q = 3375 gpm	*No drawdown seen in shallow well T701. Well W388 EM believed to penetrate a semi-confined aquifer.

Table 5 (continued)
Summary of Existing Pumping Test Data

Packet Title (Date)	Date of Test	Well Field	Tested Well[1] (depth in feet) [screened zones]	Observation Wells[1] (depth in feet)	Description of Aquifer Relationships	Substantial Confining Layers	Types of Tests Performed (including duration)	Calculated Transmissivity[2] (gpd/ft)	Calculated Storativity (-)	Calculated Permeability (gpd/ft[2])	Well Efficiency	Notes on Nature of Confinement
"Well W389 EM Test - Big Pine Field" (September, 1993)	April, 1987	Big Pine	**W389 EM (410) [200-400]**	T736 (370) [300-350]	W389 EM is deep T736 is deep	Clay from 100 to 200 ft (Big Pine X-Sections)	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (21 hours)	80,000-100,000 (Modified Theis method)	1.00E-03	N/A	Close to 100% for Q = 3130 gpm	*Well W389 EM is believed to penetrate a semi-confined aquifer.
"Well W390 EM Test - Lone Pine Field" (March, 1993)	March, 1987	Lone Pine	**W390 EM (510) [120-500]**	T737 (360) [300-340]	W390 EM is deep T737 is deep	Sporadic clay from 120 to 520 ft	1: Step-drawdown test with 3 steps (6 hours) 2: Constant Rate Aquifer test (20 hours)	50,000-55,000 (Modified Theis method)	2.00E-02	N/A	79% for Q = 3000 gpm	*Well W390 EM is believed to penetrate an unconfined aquifer.
"Well W391 AQ Aquifer Test" (April, 1989)	December, 1988	Independence-Oak	**W391 AQ (700) [150-280] [300-680]**	T769 (702) [520-580] **T023 (336) [?]** T554 (21) [?]	W391 AQ is deep T554 is shallow T769 and T023 are deep	Silt, clay with sand from 100 to 140 ft	1: Step-drawdown test with 2 steps (5 hr, 45 min) 2: Constant Rate Aquifer test (20 hours)	50,000-60,000 (Modified Theis method)	8.00E-04 to 1.70E-03	110	67-68% for Q = 1984 & 2406 gpm	*Pumping of deep well produced no measurable response from shallow aquifer.
"Well W392 AQ Aquifer Test - Symmes-Shepherd Well Field" (May, 1989)	November, 1988	Symmes-Shepherd	**W392 AQ (600) [150-270] [290-580]**	T778 (460) [440-460] T779 (680) [660-680] T780 (440) [400-440] T781 (520) [510-520]	W392 AQ is deep T778, T779, T780, and T781 are deep	Sand w/ silty clay from 152 to 168 ft	1: Step-drawdown test with 4 steps (6 hours) 2: Constant Rate Aquifer test (17.5 hours)	100,000-110,000 (Modified Theis, Hantush, Modified Hantush methods)	2.00E-04 to 2.00E-3	245	Close to 100% for Q = 3000 gpm	*Well W392 AQ is believed to penetrate a confined aquifer.
"Well W393 AQ Aquifer Test - Symmes-Shepherd Well Field" (December, 1991)	December, 1988	Symmes-Shepherd	**W393 AQ (600) [150-280] [300-580]**	T779 (680) [660-680] T780 (440) [400-440] **V066 (370) [50-343]**	W393 AQ is deep T779, T780, and V066 are deep	No obvious confining unit	1: Step-drawdown test with 3 steps (6 hours)	140,000-160,000 (Modified Theis, Hantush, Modified Hantush methods)	8.60E-04	N/A	70-80% for Q = 1090 gpm	*Well W393 AQ is believed to penetrate a confined aquifer.
"Well W394 AQ Aquifer Test - Symmes-Shepherd Well Field" (February, 1993)	January, 1989	Symmes-Shepherd	**W394 AQ (590) [150-280] [300-570]**	T781 (520) [510-520] **V067 (312) [55-88, 126-165, 244-312]**	W394 AQ is deep T781 and V067 are deep	No obvious confining unit	1: Step-drawdown test with 3 steps (6 hours)	130,000-150,000 (Modified Theis, Hantush, Modified Hantush methods)	4.50E-03	N/A	Close to 100% for Q = 2527 gpm	*Well W394 AQ is believed to penetrate a semi-confined aquifer.
"Well W395 AQ Aquifer Test - Symmes/Shepherd Well Field" (September, 1992)	January, 1989	Symmes-Shepherd	**W395 AQ (600) [150-280] [300-580]**	T782 (540) [500-540] **W394 AQ (590) [150-280, 300-570]**	W395 AQ is deep T782 and W394 AQ are deep	Sticky clay with fine sand from 88 to 188 ft	1: Step-drawdown test with 3 steps (6 hours) 2: Constant Rate Aquifer test (96 hours)	220,000-300,000 (Modified Theis, Hantush, Modified Hantush methods)	3.00E-04	N/A	82% for Q = 3050 gpm	*Well W395 AQ is believed to penetrate a confined aquifer.
"Well W396 AQ Aquifer Test - Symmes/Shepherd Well Field" (February, 1993)	December, 1988	Symmes-Shepherd	**W396 AQ (700) [150-280] [300-680]**	T783 (700) [505-545] **W074 AQ (375) [65-360]**	W396 AQ is deep T783 and W074 AQ are deep	No obvious confining unit	1: Step-drawdown test with 3 steps (6 hours)	100,000-110,000 (Modified Theis, Hantush, Modified Hantush methods)	6.00E-04	N/A	Close to 100% for Q = 1000 gpm	*Well W396 AQ is believed to penetrate a confined aquifer.
"Well W398 AQ Aquifer Test - Laws Well Field" (October, 1991)	April, 1991	Laws	**W398 AQ (560) [200-240] [260-350]**	**V246 (399) [40-348] W247 AQ (494) [28-470] V271 (113) [91-111]**	W398 AQ is deep V271 is intermediate V246 and W247 AQ are deep	Fine to medium sand w/ clay from 74 to 183 ft	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (20 hours)	120,000 (Modified Theis and Hantush methods)	2.00E-03	N/A	75% for Q = 3000 gpm	*Well W398 AQ is believed to penetrate a semi-confined aquifer.

Table 5 (continued)
Summary of Existing Pumping Test Data

Packet Title (Date)	Date of Test	Well Field	Tested Well[1] (depth in feet) [screened zones]	Observation Wells[1] (depth in feet)	Description of Aquifer Relationships	Substantial Confining Layers	Types of Tests Performed (including duration)	Calculated Transmissivity[2] (gpd/ft)	Calculated Storativity (-)	Calculated Permeability (gpd/ft^2)	Well Efficiency	Notes on Nature of Confinement
"Well W399 AQ Aquifer Test - Laws Well Field" (September, 1991)	May, 1991	Laws	**W399 AQ (610) [200-240] [260-600]**	**V242 (490) [40-260]**	W399 AQ is deep V242 is deep	Silty clay with cobbles from 260 to 385 ft	1: Step-drawdown test with 4 steps (6 hours) 2: Constant Rate Aquifer test (21.5 hours)	110,000-150,000 (Modified Theis and Hantush methods)	3.00E-03	N/A	N/A	*Well W399 AQ is believed to penetrate a confined aquifer.
"Well W400 AQ Aquifer Test - Independence/Oak" (February, 1992)	July, 1991	Independence-Oak	**W400 AQ (700) [170-250] [270-690]**	T813 (700) [190-230, 310-350, 450-480] **W077 AQ (330) [65-100, 110-305]**	W400 AQ is deep T813 and W077 AQ are deep	No obvious confining unit	1: Step-drawdown test with 4 steps (5.5 hours) 2: Constant Rate Aquifer test (21.5 hours)	90,000-140,000 (Modified Theis and Hantush methods)	1.40E-03	N/A	77% for Q = 3000 gpm	*Well W400 AQ is believed to penetrate a semi-confined aquifer.
"Well W401 AQ Aquifer Test - Independence Well Field" (September, 1992)	August, 1991	Independence-Oak	**W401 AQ (610) [170-220] [240-600]**	T814 (460) [250-310, 390-440]	W401 AQ is deep T814 is deep	No obvious confining unit	1: Step-drawdown test with 5 steps (5 hours) 2: Constant Rate Aquifer test (24 hours)	150,000-190,000 (Modified Theis and Hantush methods)	6.00E-04	N/A	90% for Q = 3100 gpm	*Well W401 AQ is believed to penetrate a confined aquifer.
"Well W402 EM Aquifer Test - Symmes/Shepherd" (September, 1992)	July, 1991	Symmes-Shepherd	**W402 EM (580) [180-280] [300-570]**	T815 (560) [490-560]	W402 EM is deep T815 is deep	No obvious confining unit	1: Step-drawdown test with 3 steps (4.5 hours) 2: Constant Rate Aquifer test (22.5 hours)	45,000-55,000 (Modified Theis and Hantush methods)	2.50E-04	N/A	Close to 100% for Q = 2800 gpm	*Well W402 EM is believed to penetrate a confined aquifer.
"Well W403 AQ Aquifer Test - Bair-Georges Well Field" (September, 1992)	June, 1991	Bairs-Georges	**W403 AQ (560) [250-550]**	**V095 (375) [50-365, not continuous]**	W403 AQ is deep V095 AQ is deep	No obvious confining unit	1: Step-drawdown test with 4 steps (6 hours) 2: Constant Rate Aquifer test (23 hours)	2,000-3,000 (Modified Theis and Hantush methods)	2.63E-02	N/A	N/A	*Well W403 AQ is believed to penetrate a confined aquifer.
"Well W406 AQ Aquifer Test" (June, 1998)	March, 1998	On the Bishop Cone	**W406 AQ (650) [60-160] [180-240] [260-420] [430-610] [620-640]**	V235 (200) **W371 AQ (252) [80-146, 155-226]**	W406 AQ is deep W371 AQ is intermediate	Clay from 390 to 400 ft	1: Step-drawdown test with 4 steps (5 hr, 50 min) 2: Constant Rate Aquifer test (23 hours)	55,000-75,000 (Modified Theis method)	1.90E-03 to 1.41E-02	N/A	79% for Q = 10 cfs (4489 gpm)	*No information available
"Well W407 AQ Aquifer Test" (June, 1998)	February, 1998	On the Bishop Cone	**W407 AQ (650) [60-270] [290-640]**	**V137 (632) [30-611, not cont.] W408 AQ (650) [60-240, 260-640]** T387 (?) T389 (?)	W407 AQ is deep V137 and W408 AQ are deep	Clay from 370 to 410 ft	1: Step-drawdown test with 4 steps (6 hours) 2: Constant Rate Aquifer test (23 hours)	40,000-55,000 (Modified Theis method)	2.90E-03 to 4.8E-03	N/A	66% for Q = 10 cfs (4489 gpm)	*No information available
"Well W408 AQ Aquifer Test" (June, 1998)	February, 1998	On the Bishop Cone	**W408 AQ (650) [60-240] [260-640]**	**138 (584) [30-515, not cont.] V137 (632) [30-611, not cont.]** T387 (?)	W408 AQ is deep 138 and V137 are deep	Clay from 320 to 330 ft, 440 to 450 ft	1: Step-drawdown test with 4 steps (6 hours) 2: Constant Rate Aquifer test (23 hours)	30,000-50,000 (Modified Theis method)	3.90E-03 to 1.86E-02	N/A	72% for Q = 10 cfs (4489 gpm)	*No information available
Data received from Inyo County. Note that wells do not conform to the USGS or the LADWP well numbering systems												
"Monitoring Well Installation and Aquifer Testing Cottonwood Springs Site" (June, 1993)	April, 1993	N/A (Cottonwood Springs)	PW-1 (~460)	P-1, P-2, P-3, P-4, MW-1, MW-2S, MW-2D, PPG,	PPG, P-1, P-2, P-3, P-4, and MW-2S are shallow PW-1, MW-1, and MW-2D are deep	Sporadic clay from approx. 275 to 460 ft	1: Constant Rate Aquifer test (330 hr) 2: Recovery test (192 hr)	386,000-387,000	9.00E-04 to 1.30E-03	N/A	N/A	Deep wells are assumed to be semi-confined.
Revised Draft EIR for the Anheuser-Busch Companies (etc.) (July, 1993)	May, 1989	N/A (Cabin Bar Ranch)	PW-1 (753)	5 local surface water locations 16 shallow piezometers 19 off-site wells	Depths ranging from 50 to 198 ft	Clay stringers at various depths	1: Constant Rate Aquifer test (338 hr)	25,200-28,600	7.1E-04 to 2.1E-03	N/A	N/A	Response was observed in the shallow piezometers

Table 5 (continued)
Summary of Existing Pumping Test Data

Packet Title (Date)	**Date of Test**	**Well Field**	**Tested Well[1] (depth in feet) [screened zones]**	**Observation Wells[1] (depth in feet)**	**Description of Aquifer Relationships**	**Substantial Confining Layers**	**Types of Tests Performed (including duration)**	**Calculated Transmissivity[2] (gpd/ft)**	**Calculated Storativity (-)**	**Calculated Permeability (gpd/ft²)**	**Well Efficiency**	**Notes on Nature of Confinement**
Keeler Community Services District New Domestic Well Aquifer Test (May, 1984)	May, 1984	N/A (West of town of Keeler)	**PW (123) [51-109]**	OW (200, backfilled to 125?) [60-70, 80-120, 160-200]	PW and OW are both intermediate depths	Clay stringers noted at various depths	1: Constant Rate Aquifer test (24 hr)	260,000-330,000 (PW) 340,000-370,000 (OW)	1.9E-04 to 5.6E-04 (OW)	N/A	N/A	*No information available
Report on the Hydrology Study for the Owens Lake, CA Soda Ash Project (February, 1991)	November, 1990	N/A (Cottonwood Springs)	**PW-1 (460) [200-430]**	P1 (6.8) [0.5-3.8] P2 (6.8) [0.5-3.8] P3 (8.1) [1.4-4.7] P4 (7.7) [1.2-4.5] **MW-1 (650) [200-400]**	P1, P2, P3, and P4, are shallow PW-1 and MW-1 are deep	Fine sand to very fine sand from 340 to 360 ft	1: Constant Rate Aquifer test (164 hr)	360,000-560,000	N/A	N/A	N/A	No response in the shallow water table.
Report on Aquifer Test on Swansea Alluvial Fan for Inyo Marble Project Inyo County, California (November, 1984)	September, 1984	N/A (Swansea Alluvial Fan)	Test Well #1 (535) [255-275] [300-320] [340-400] [410-430]	Test Well #2 (272)	Test Well #1 and Test Well #2 are deep	Sporadic "clayey strata" observed during well drilling	2: Constant Rate Aquifer test (66 hr)	198,000	N/A	N/A	N/A	*No information available
Olancha Water Development Project Appendix A - Hunter #1 Aquifer Test (October, 1998)	March, 1998	N/A (Olancha, CA)	**Hunter #1 (600) [90-500]**	MW-2 PVC, MW-2 abandoned, MW-2 domestic, MW-3, MW-4, MW-5, MW-6, MW-7 **BW #1**, **BW #2**, BW #3, BW #4, BW #5, and BW #6	Hunter #1 is deep 1 well is shallow 8 wells are intermediate 5 wells are deep	Clay from 120 to 140 ft, 240 to 310 ft, 360 to 420 ft, Layers from 450 to 600	1: Step-drawdown test with four steps 2: Constant Rate Aquifer test (72 hr)	23,000-38,000	1E-04 to 1E-03	N/A	N/A	The data suggest confined conditions at this well.
Olancha Water Development Project Appendix A - Butter-worth #4 Aquifer Test (October, 1998)	April, 1998	N/A (Olancha, CA)	Butterworth #4 (145) [30-145]	Sand Ranch #1, MW-2 PVC, MW-2 abandoned, MW-2 domestic, MW-3, MW-4, MW-5, MW-6, **BW #1**, **BW #2**, BW #3, BW #5, BW #6, 86-1, 86-4, 86-6, and 309	Butterworth #4 is intermediate 3 wells are shallow 9 wells are intermediate 5 wells are deep	No information available	1: Step-drawdown test with three steps 2: Constant Rate Aquifer test (48 hr)	100,000-150,000	1E-03 to 1.5E-01	N/A	N/A	The data suggest unconfined conditions with recharge to the aquifer by gravity drainage.

1 Bold well numbers represent wells for which boring log data is available

2 The transmissivities that were calculated using the Hantush Method and/or the Modified Hantush Method utilized the Graphical Well Analysis Package (GWAP)

Table 6
Criteria for Creating Log-Log Plots

Well Number	Pump Test Data Attached?	Possible Confining Unit Documented?	Pumping Well Screened Below Confining Unit?	Drawdown vs. Time Plot Created?
USGS Well VO14GA	✓	✓	✓	✓
USGS Well V016GA	✓	✓	✓	✓
USGS Well V017GA	✓	✓	✓	✓
W374 AQ		✓	✓	
W375 EM		✓	✓	
W376 EM	✓	✓		
W377 EM	✓	✓		
W379 AQ	✓	✓	✓	✓
W380 EM				
W381 EM	✓	✓	✓	✓
W382 EM	✓	✓	✓	✓
W383 EM	✓	✓	✓	✓
W384 EM	✓	✓	✓	✓
W385 EM	✓			
W386 EM	✓	✓		
W387 EM	✓	✓	✓	✓
W388 EM	✓	✓		
W389 EM	✓	✓	✓	✓
W390 EM	✓	✓		
W391 AQ		✓	✓	
W392 AQ		✓		
W393 AQ				
W394 AQ	✓			
W395 AQ	✓	✓	✓	✓
W396 AQ	✓			
W398 AQ	✓	✓	✓	✓
W399 AQ	✓	✓		
W400 AQ	✓			
W401 AQ	✓			
W402 EM	✓			
W403 AQ	✓			
W406 AQ	✓	✓		
W407 AQ	✓	✓		
W408 AQ	✓	✓		

RECOMMENDATIONS

Based on both the evaluation of previous work performed to characterize the confining layer and the research conducted during the cooperative study literature review process, MWH has formulated recommendations pertaining to four areas, as described below.

- Integration of confining layer thickness data compiled during previous work by LADWP into GIS,
- Aquifer test analysis methods to be utilized to calculate confining layer properties from the existing pump test data,
- Aquifer test analysis software packages to be utilized to perform the recommended analysis.
- Existing pump test data sets to be analyzed with the recommended software packages.

Recommended Integration of Previous Work into GIS

The confining layer data sets assembled independently by LADWP and ICWD should be incorporated into the LADWP GIS as individual coverages. A decision was made at the July 19, 2002 cooperative study team meeting to use only the LADWP data because the ICWD dataset is a subset of the more comprehensive LADWP dataset. Prior to incorporation of the LADWP data set into the GIS, steps need to be taken to ensure quality of data and ease of conversion.

Unfortunately, processing errors and inaccuracies are often inherently part of data recording. These data must be validated prior to their incorporation into a GIS, from which decisions may be made and management alternatives might be established. The validation procedure would be two-fold:

- Random review and confirmation of 25 percent of the well logs, and
- Check of arithmetic formulas.

If however, significant error is noted in the 25 percent quality assurance/quality control (QA/QC) check, then the QA/QC process should be re-evaluated by the cooperative study team.

The incorporation of this data set can be completed by linkage of the well number as a key identifier to the existing well database. Prior to database linking, the well numbers for each existing confining layer data set must be converted to the existing AS400 designated numbering system that includes a letter prefix and, at times, a letter suffix (e.g. T812).

Once this data set is incorporated into the GIS, data querying and export to other software for development of isopach maps can be easily accomplished.

Recommended Aquifer Test Analysis Methods

After review of the potential pump test analysis methods, MWH identified four methods that demonstrate the greatest potential for yielding vertical hydraulic conductivity and storage coefficient values for the confining layer.

Upon examination of **Table 4**, it is evident that information about the confining layer can only be obtained with seven of the 23 analytical methods presented. After consultation with Dr. Shlomo P. Neuman, this list was reduced to three methods:

- Hantush-Jacob Method, "Classic Leaky Aquifer Solution" (1955),
- Hantush Method, "Modified Leaky Aquifer Solution" (1960), and
- Neuman-Witherspoon Method, "Two Aquifer, One Aquitard Solution" (1969)

In addition, as was discussed at the scoping meeting in April 2002 and clarified at the July 19, 2002 Cooperative Study team meeting, the Denis and Motz (1998) model will be used to perform a cross check/simulation of the results. It is anticipated that this work will be conducted by ICWD because the software is readily available, and additional analysis of the confining layer properties will serve to refine the estimates generated by the three methods listed above. We recommend that this analysis be conducted by ICWD because they are most familiar with the model and have immediate access to the software.

The Hantush-Jacob Method (1955), known as the "Classic Leaky Aquifer Solution," can be used to find the aquitard vertical hydraulic conductivity for leaky aquifer systems. This analysis is performed by matching the Hantush-Jacob (1955) solution to drawdown data that is collected during a pumping test. This solution is valid for unsteady flow conditions. However, the Hantush-Jacob Method (1955) does not account for storage in the confining layer or for drawdown in the unpumped aquifer.

The second method recommended for analysis is the Hantush Method (1960), known as the "Modified Leaky Aquifer Solution." Similar to the above solution, this method can be used to find the aquitard vertical hydraulic conductivity for leaky aquifer systems. This analysis is performed by matching the Hantush (1960) solution to drawdown data that is collected during a pump test. As with the Hantush-Jacob Method (1955), this solution is valid for unsteady flow conditions, and it neglects the effects of drawdown in the unpumped aquifer. However, this solution does take into account storage in the confining layer.

The Neuman-Witherspoon Method (1969), known as the "Two Aquifer, One Aquitard Solution," is the third method recommended for analysis. This method can be used to find not only the vertical hydraulic conductivity but also the storage coefficient of the aquitard for leaky aquifer systems. This analysis is performed by matching the Neuman-Witherspoon (1969) solution to drawdown data that is collected during a pump test. This solution is valid for unsteady flow conditions. Unlike the other two methods presented, the Neuman-Witherspoon (1969) solution accounts for drawdown in the unpumped (unconfined) aquifer. That is, the Neuman-Witherspoon (1969) solution does not assume a constant head boundary condition, which can lead to significant errors when estimating the hydraulic properties of the confined aquifer.

The Denis and Motz Method (1998) is the final method recommended for cross check and simulation of the results. This solution can also be used to find both the vertical hydraulic conductivity and the storage coefficient of the aquitard for leaky aquifer systems. Unlike the previous three analysis methods, this analysis is performed not by curve matching, but rather with an analytical model. This solution can be used for both steady and unsteady flow conditions. Like the Neuman-Witherspoon (1969) solution, this method accounts for drawdown in the unpumped (unconfined) aquifer. Additionally, the Denis and Motz method accounts for a reduction in evapotranspiration (ET) due to the decline in the shallow water table.

Characteristics of the four recommended aquifer test analysis methods are summarized below in **Table 7**.

Table 7
Summary of Recommended Aquifer Test Analysis Methods

Solution Characteristics	**Hantush-Jacob Method (1955)**	**Hantush Method (1960)**	**Neuman-Witherspoon Method (1969)**	**Denis and Motz Method (1998)**
Common Name	"Classic Leaky Aquifer Solution"	"Modified Leaky Aquifer Solution"	"Two Aquifer, One Aquitard Solution"	"Denis and Motz Method"
Confining Layer Properties Calculated	Vertical Hydraulic Conductivity	Vertical Hydraulic Conductivity	Vertical Hydraulic Conductivity and Storage Coefficient	Vertical Hydraulic Conductivity and Storage Coefficient
Type of Flow	Unsteady	Unsteady	Unsteady	Steady or Unsteady
Accounts for Confining Layer Storage?	No	Yes	Yes	Yes
Accounts for Drawdown in the Unpumped Aquifer?	No	No	Yes	Yes
Accounts for ET Reduction?	No	No	No	Yes

Recommended Aquifer Test Analysis Software Packages

MWH recommends that aquifer test analysis using the Hantush-Jacob (1955) solution, the Hantush (1960) solution, and the Neuman-Witherspoon (1969) solution be performed with AQTESOLV for Windows, Pro Version. This software package is the only package available that can perform analyses using all three of the recommended aquifer test analysis methods. The cost of this software is approximately $750.

It is also recommended that the software described by Denis and Motz (1998) already obtained by LADWP and ICWD be used in order to perform analyses using this solution.

Recommended Existing Pump Test Data for Analysis

As described above under "Recommended Aquifer Test Analysis Methods", the presence of a "leaky" aquifer system is evidenced by a flattening of the drawdown vs. time curve relative to a Theis curve when plotted on a log-log scale. In order to choose pump test data for further analysis, drawdown vs. time plots were created for selected pumping wells, as described earlier in this Technical Memorandum. Based on the shapes of these curves, the following pumping tests are recommended by MWH for further analysis:

- USGS Well V014GA,
- USGS Well V016GA,
- LADWP Well W379 AQ,
- LADWP Well W383 EM,
- LADWP Well W384 EM,
- LADWP Well W387 EM,
- LADWP Well W389 EM,
- LADWP Well W395 AQ, and
- LADWP Well W398 AQ.

USGS Well V017GA was discarded for further analysis because of the irregular shape of the drawdown vs. time curve. Wells W381 EM and W382 EM were discarded because of multiple changes in flow rate during the "constant rate" test.

It is important to note that a significant amount of uncertainty is expected in the analysis of some existing pump test data due to both the lack of adequate early time data and the short duration of most of the pump tests (less than 24 hours). However, it is the opinion of MWH that enough data exists to attempt to analyze the data using the analytical methods described above.

SUMMARY OF RECOMMENDATIONS

MWH makes the following recommendations for future work on Task 2 of the Confining Layer Characteristics Cooperative Study.

- Integrate previous work on confining layer characterization by LADWP into GIS.
- Purchase AQTESOLV for Windows, Pro Version for analysis of aquifer test data.
- Utilize the software AQTESOLV for Windows, Pro Version to analyze the selected data sets using the following methods:
  - Hantush-Jacob (1955),
  - Hantush (1960), and
  - Neuman-Witherspoon (1969).
- Utilize the Denis and Motz software to cross check and simulate the results from the AQTESOLV analysis. (ICWD)
- The following tests are recommended for analysis:
  - USGS Well V014GA,
  - USGS Well V016GA,
  - LADWP Well W379 AQ,
  - LADWP Well W383 EM,
  - LADWP Well W384 EM,
  - LADWP Well W387 EM,
  - LADWP Well W389 EM,
  - LADWP Well W395 AQ, and
  - LADWP Well W398 AQ.

To summarize, MWH recommends moving forward with the analysis of the proposed aquifer test data as well as development of the confining unit GIS layer. Simultaneously, the Cooperative Study team will evaluate wells for future pump testing in data collection related to the characterization of the confining layer.

REFERENCES

Denis, R. E. and Motz, L. H., 1998, Drawdowns in Coupled Aquifers with Confining Unit Storage and ET Reduction, Journal of Ground Water, Vol. 36, No. 2, 201-207.

Hantush, M. S., 1960, Modification of the Theory of Leaky Aquifers, Journal of Geophysical Research, Vol. 65, No. 11, 3713-3725.

Hantush, M. S. and Jacob, C. E., 1955, Non-Steady Radial Flow in an Infinite Leaky Aquifer, Transactions, American Geophysical Union, Vol. 36, No. 1, 95-100.

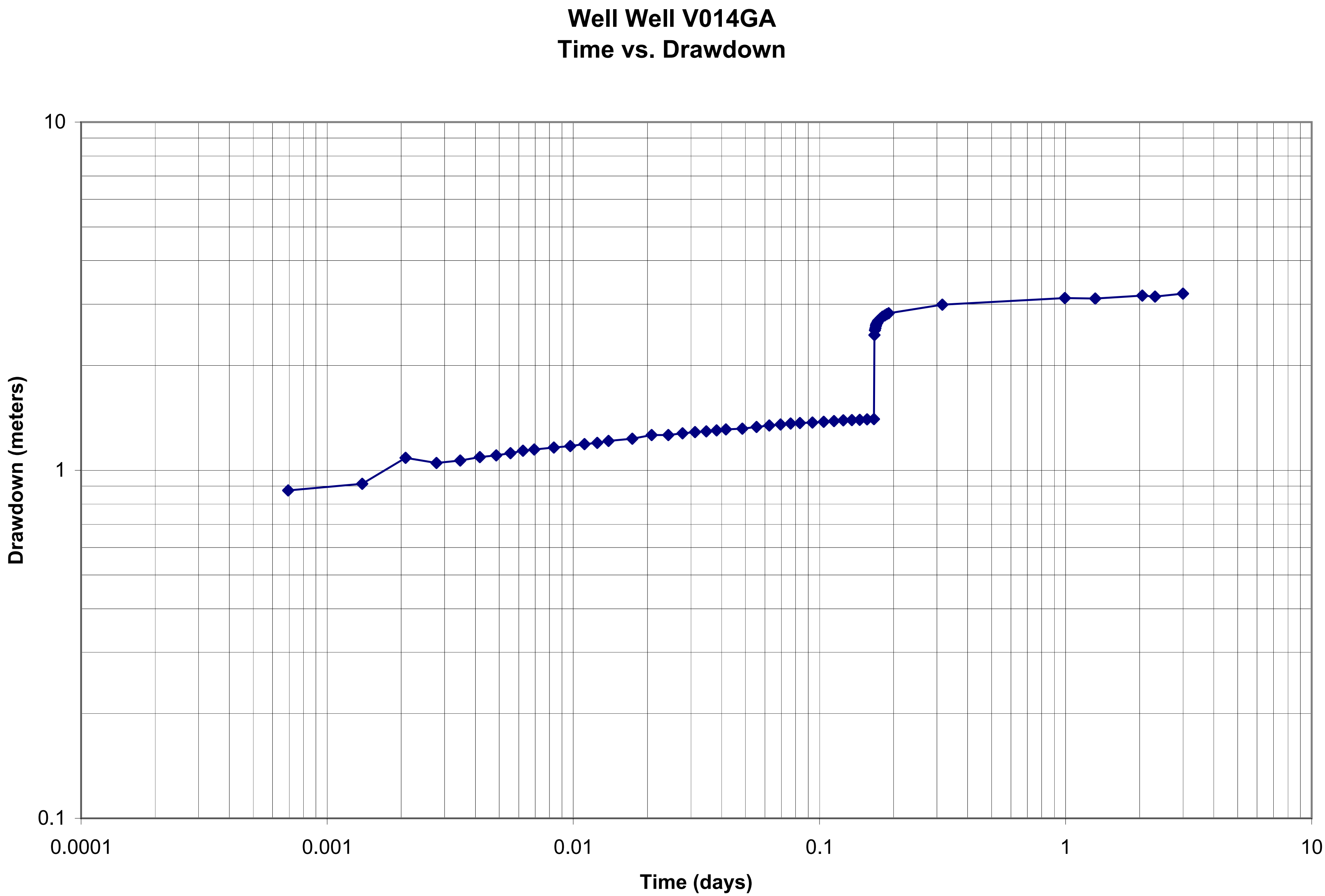
Hollett, K.J., Danskin, W.R., McCaffrey, W.F., Walti, C.L., 1991, Geology and Water Resources of Owens Valley, California, USGS Water-Supply Paper 2370-B, 77 p.

Inyo/LA Water Agreement, 1991, Agreement Between the County of Inyo and the City of Los Angeles and Its Department of Water and Power on a Long Term Groundwater Management Plan for Owens Valley and Inyo County, City of Los Angeles LADWP/ICWD, 33 p.

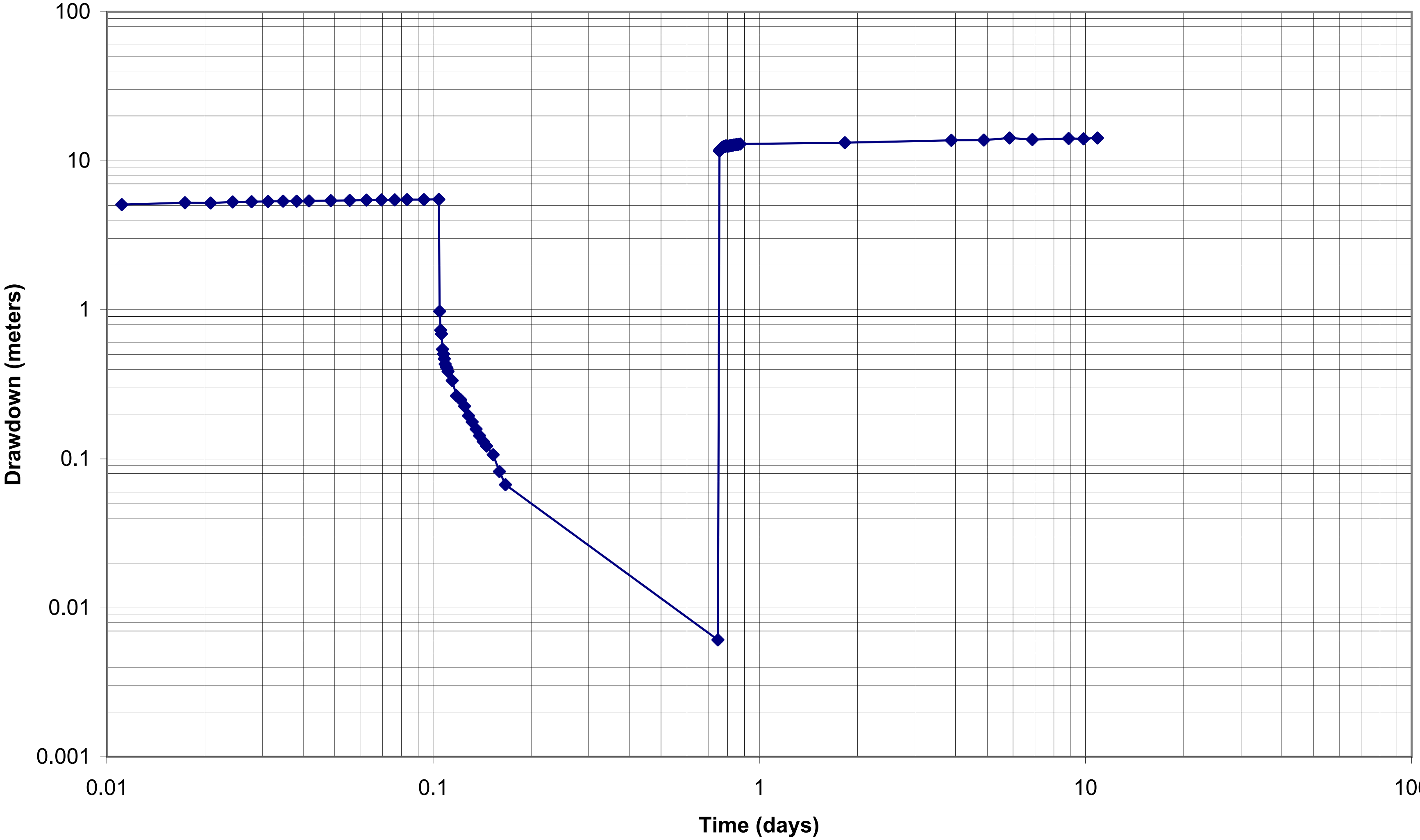
Jackson, R., and Jorat, S., 2000, Sensitivity Analysis of the Coupled Aquifer Model of Denis and Motz, Inyo County Water Department Report 2000-2, 18 p.

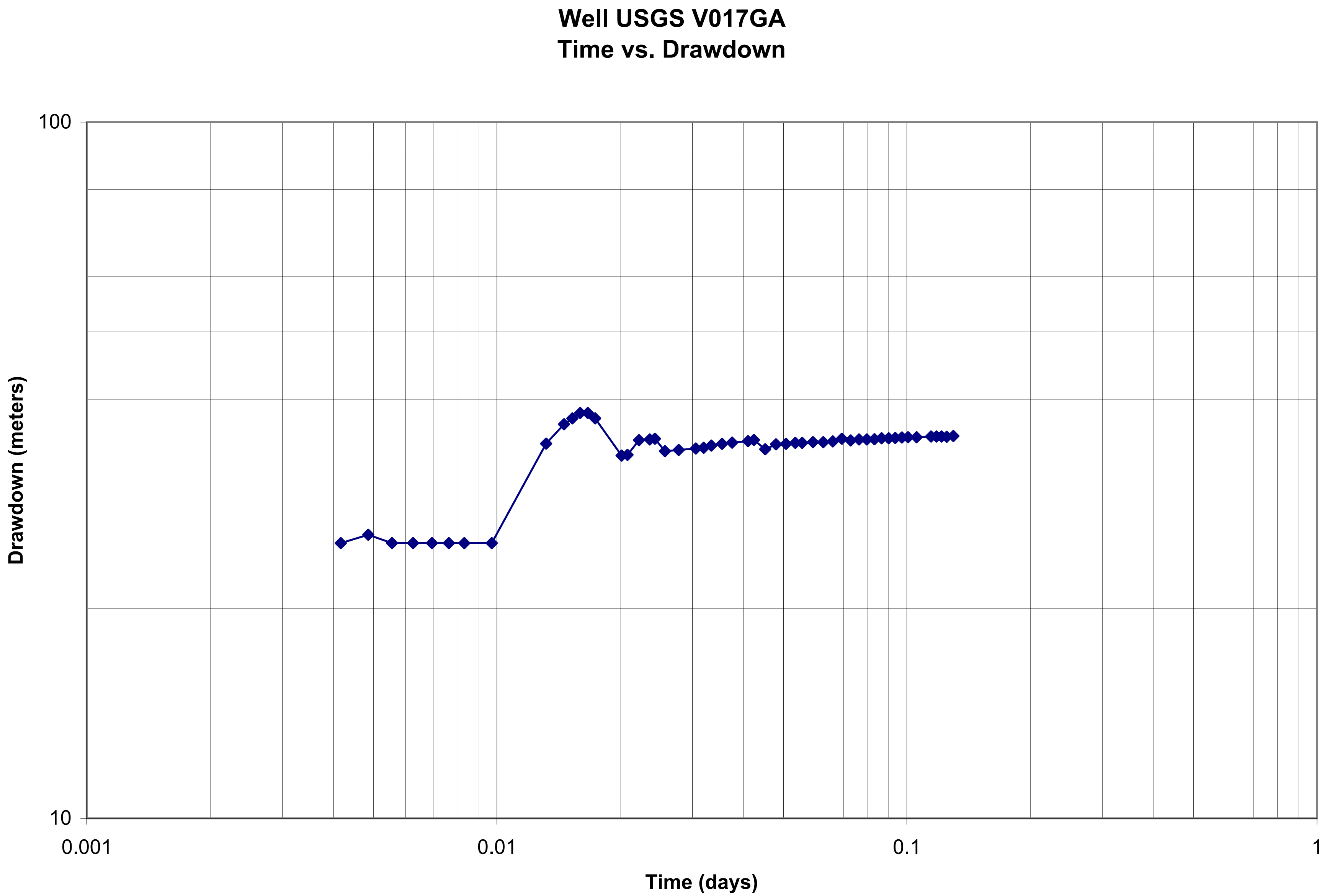
Neuman, S. P. and Witherspoon, P. A., 1969, Theory of Flow in a Confined Two Aquifer System, Water Resources Research, Vol. 5, No. 4, 803-816.

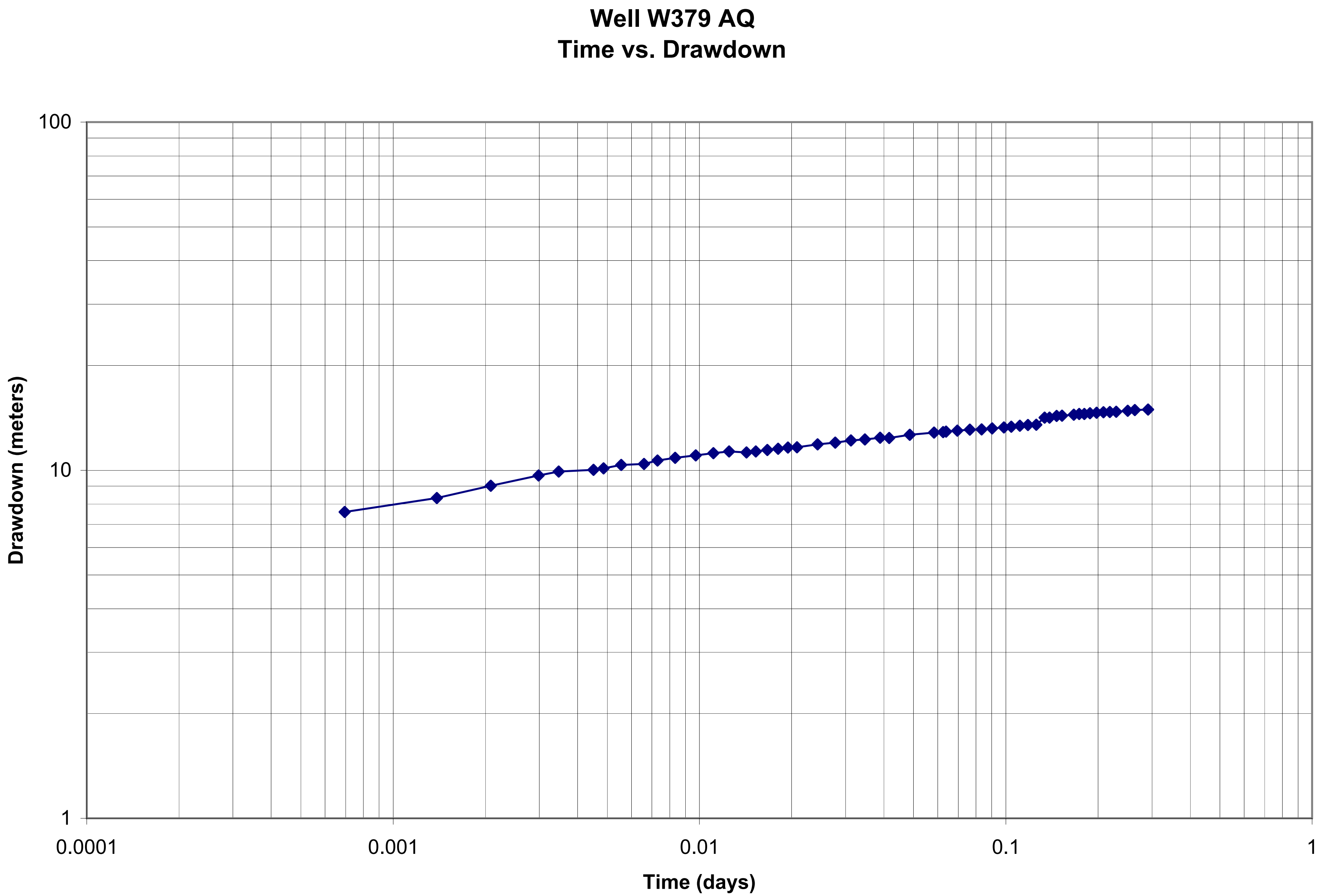
Appendix A
Log-Log Plots for Selected Pump Test Data


Well Well V014GA
Time vs. Drawdown
Drawdown (meters)
10
1
0.1
0.0001
0.001
0.01
0.1
1
10
Time (days)

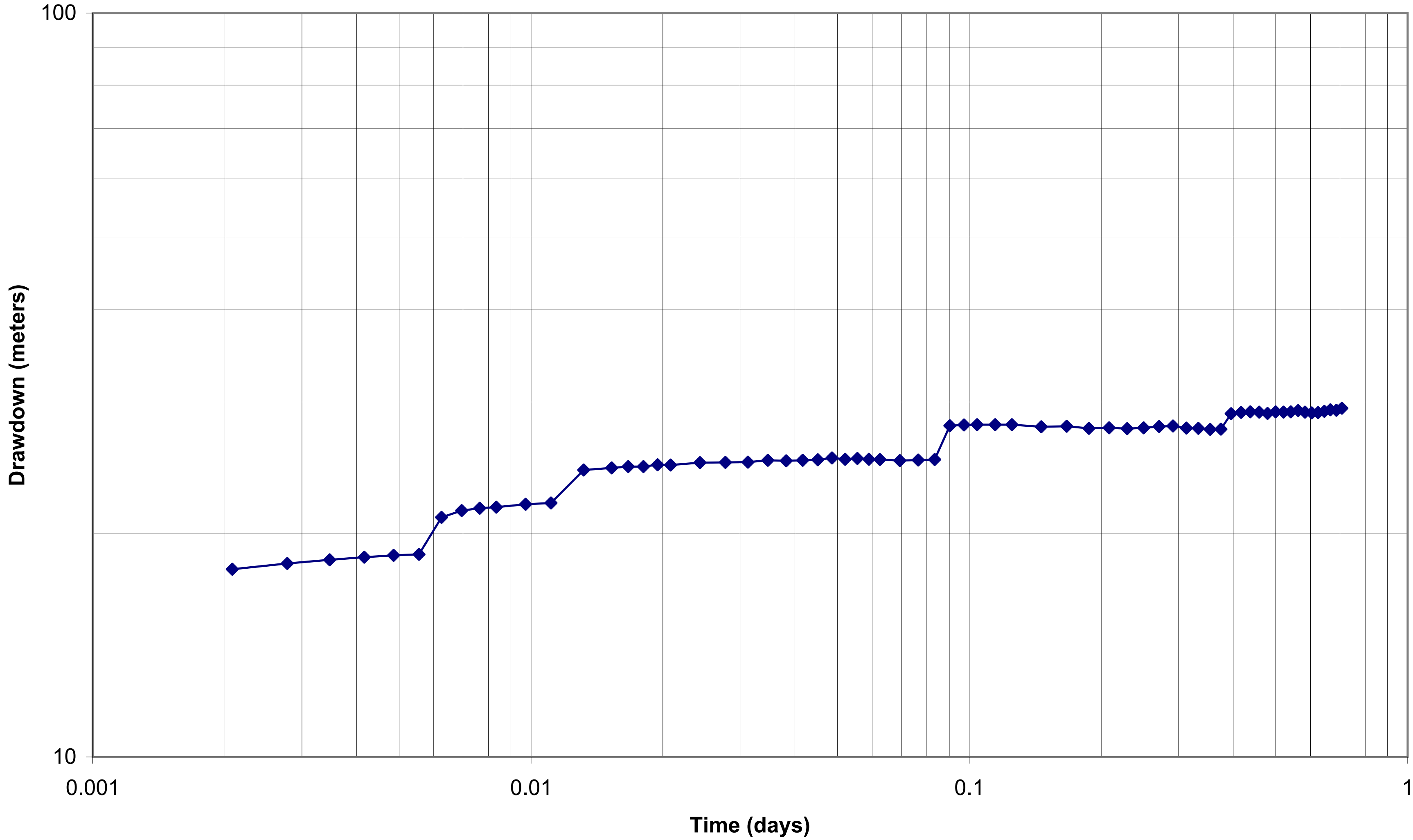
Well USGS V016GA
Time vs. Drawdown

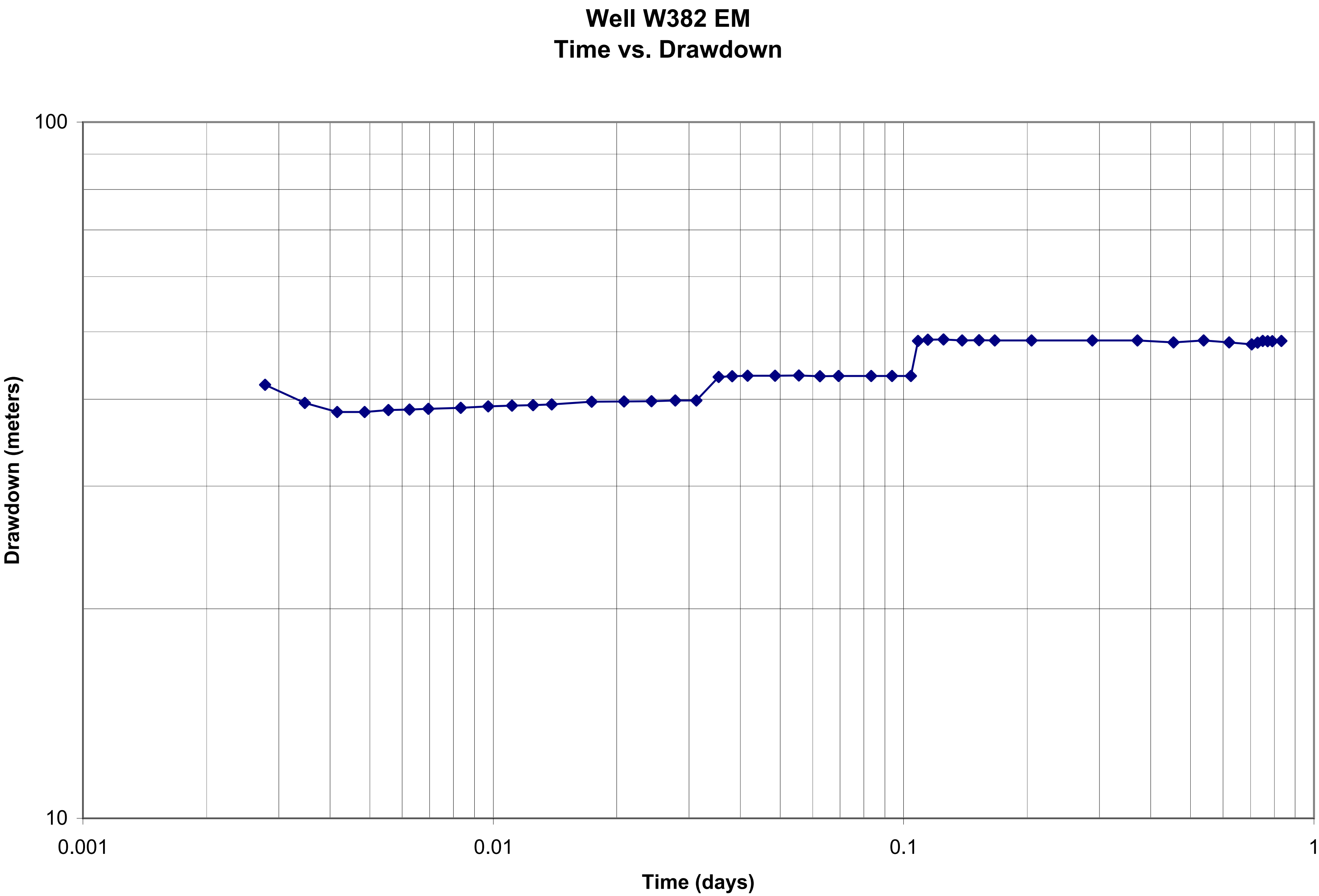



Well USGS V017GA
Time vs. Drawdown
100
10
Drawdown (meters)
0.001
0.01
0.1
1
Time (days)

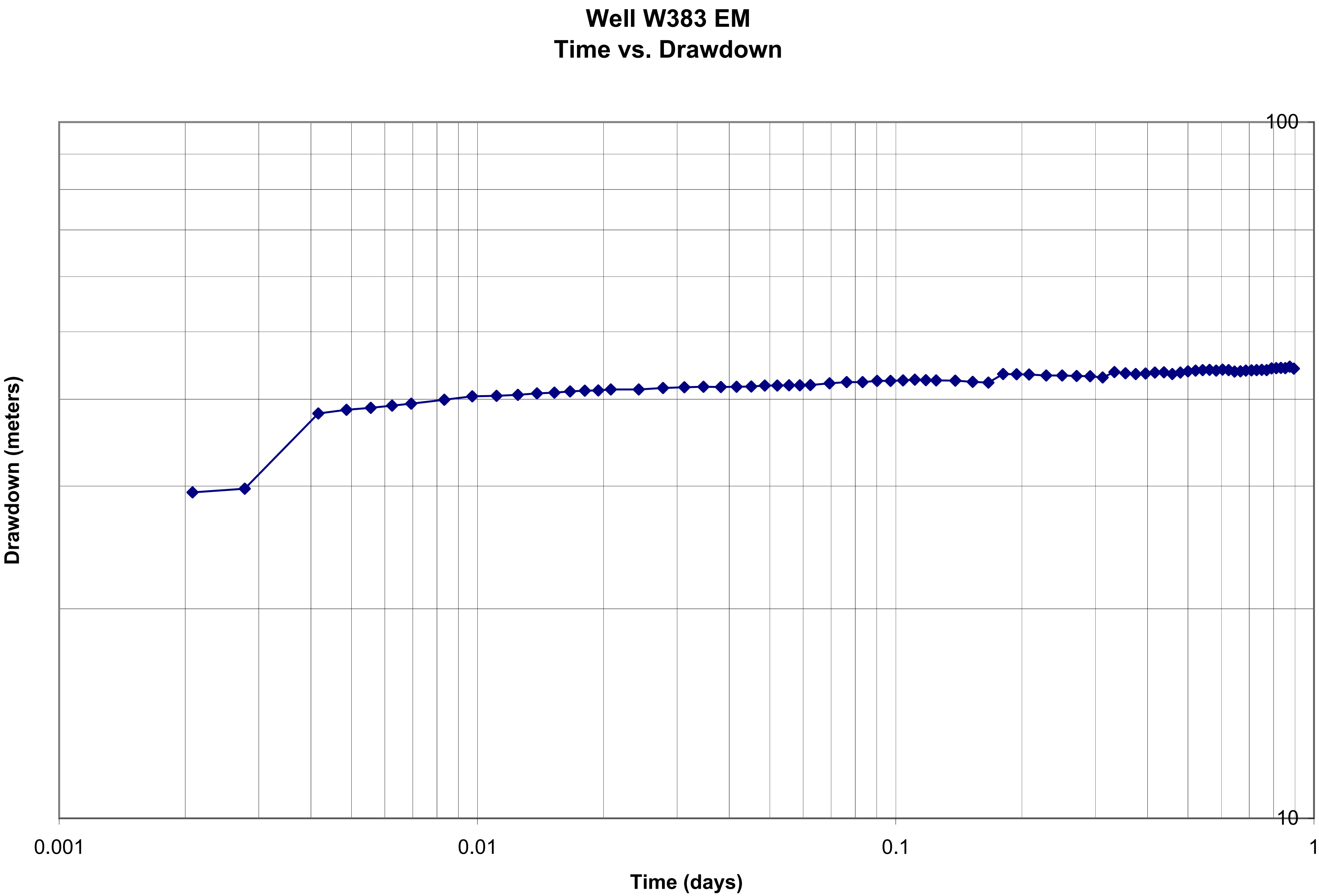

Well W379 AQ
Time vs. Drawdown
Drawdown (meters)
100
10
1
0.0001
0.001
0.01
0.1
1
Time (days)

Well W381 EM
Time vs. Drawdown

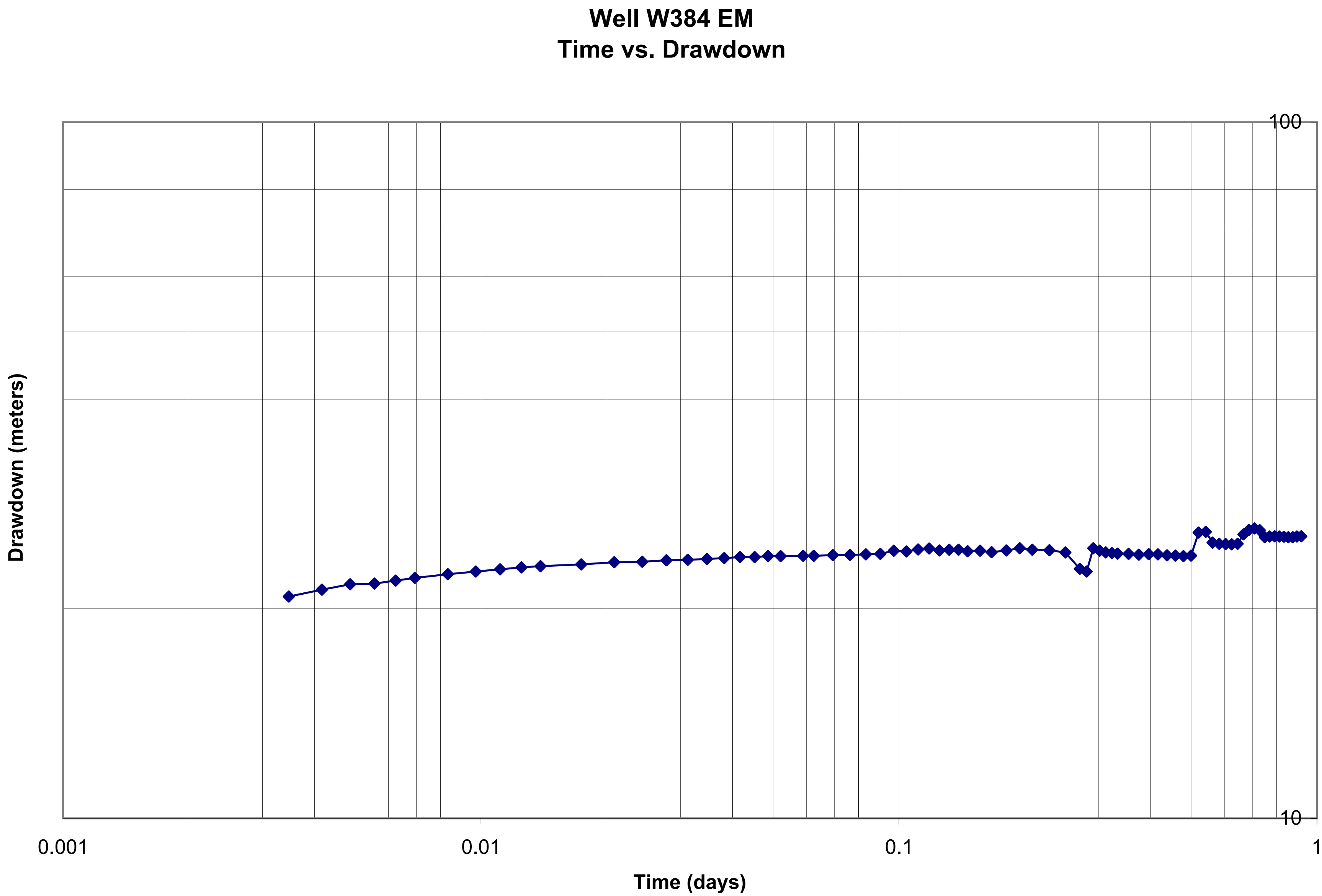




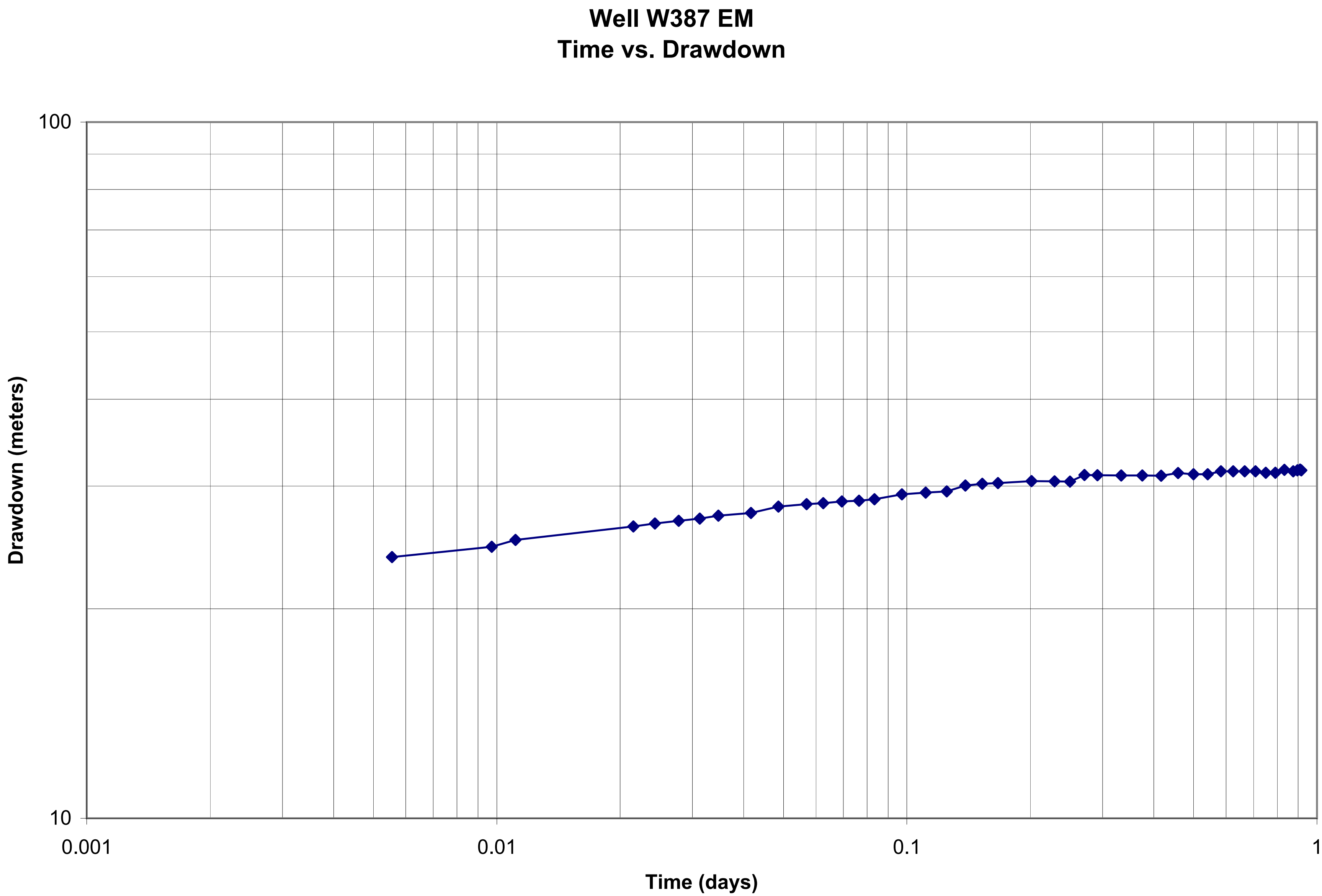
Well W382 EM
Time vs. Drawdown
100
10
Drawdown (meters)
0.001
0.01
0.1
1
Time (days)



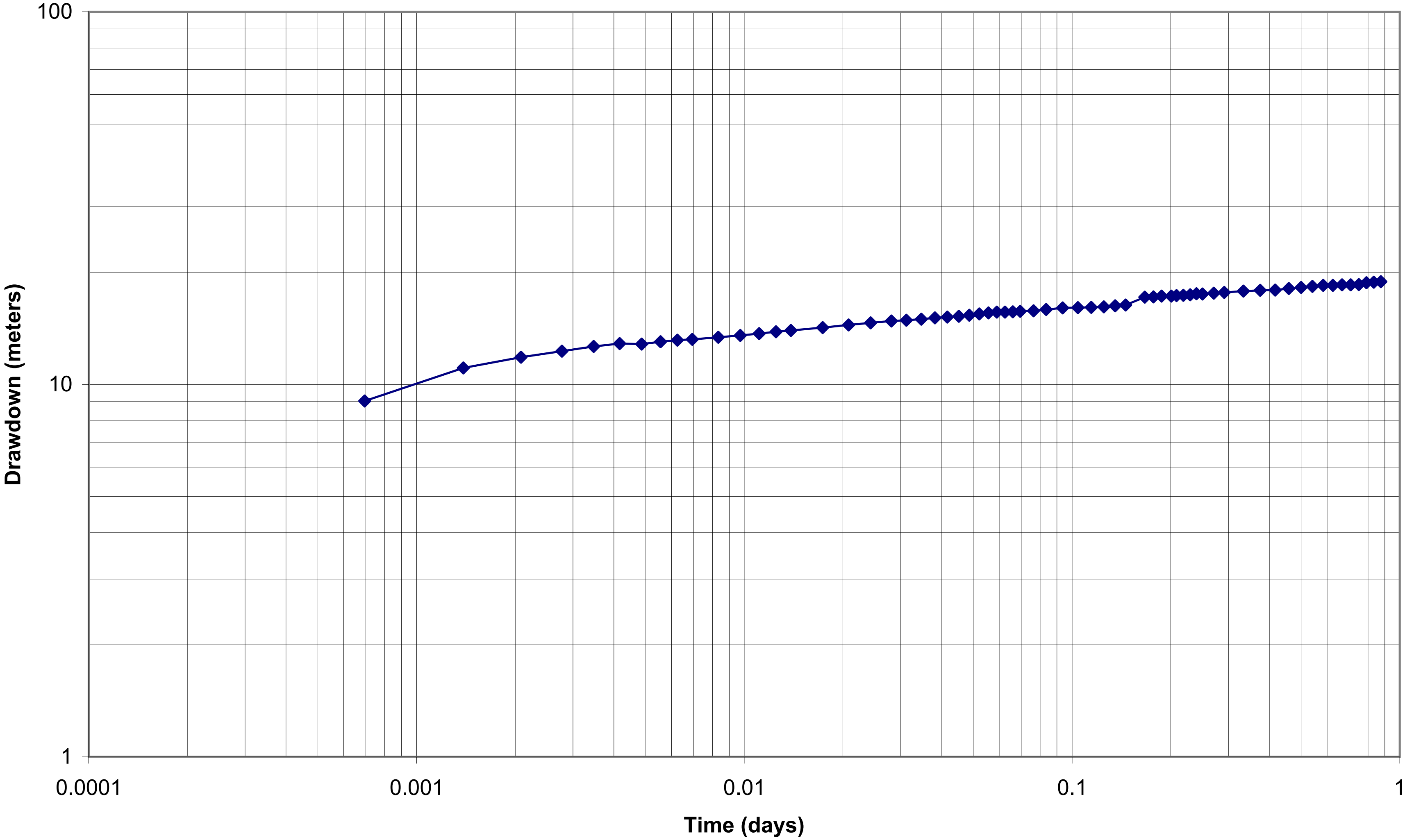
Well W383 EM
Time vs. Drawdown
Drawdown (meters)
100
10
0.001
0.01
0.1
1
Time (days)

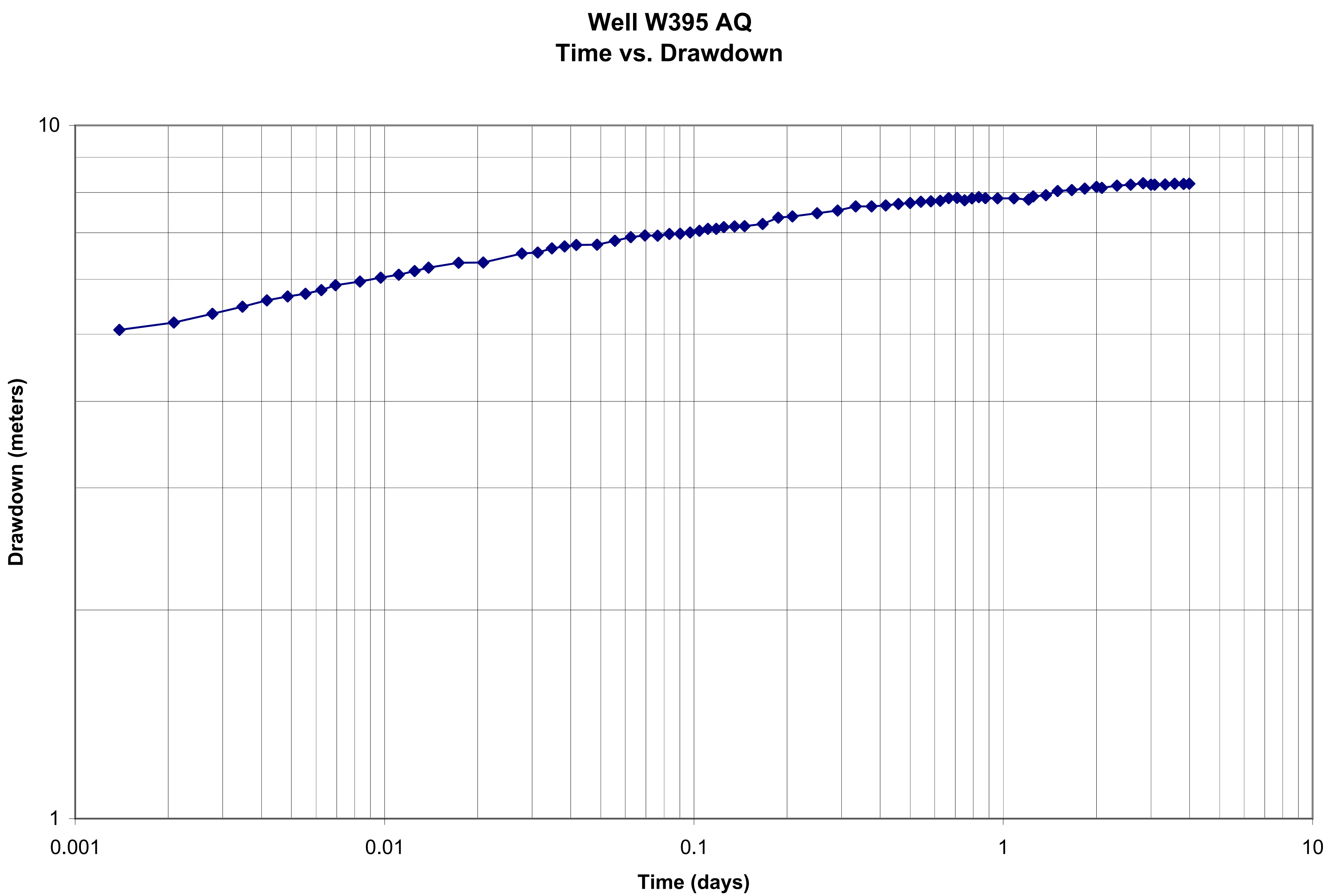


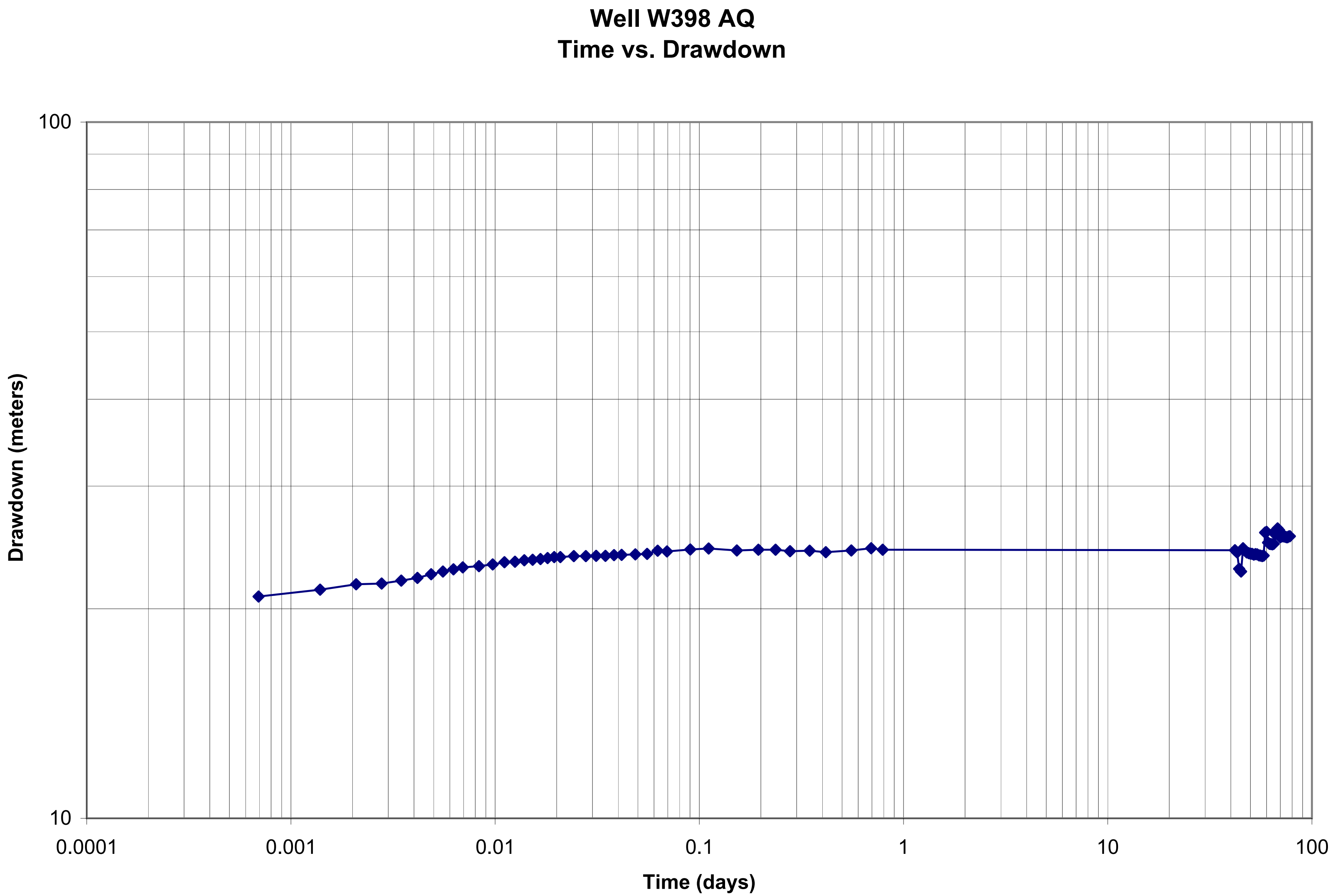
Well W384 EM
Time vs. Drawdown
Drawdown (meters)
100
10
0.001
0.01
0.1
1
Time (days)


Well W387 EM
Time vs. Drawdown
100
10
Drawdown (meters)
0.001
0.01
0.1
1
Time (days)

Well W389 EM
Time vs. Drawdown




Well W395 AQ
Time vs. Drawdown
Drawdown (meters)
10
1
0.001
0.01
0.1
1
10
Time (days)



Well W398 AQ
Time vs. Drawdown
100
10
Drawdown (meters)
0.0001
0.001
0.01
0.1
1
10
100
Time (days)

Technical Memorandum on the Technical Review and Evaluation of the 1992 Deep Test Hole Study

TECHNICAL MEMORANDUM

MWH

To:	Inyo/LA Cooperative Study Team	**Date:**	October 24, 2002
From:	Victor Harris MWH	**Reference:**	1341515.030203
Subject:	Technical Review and Evaluation of the 1992 Deep Test Hole Study		

INTRODUCTION

On August 1, 2002, the Los Angeles Department of Water and Power (LADWP) authorized Montgomery Watson Harza (MWH) to continue the Confining Layer Characteristics Cooperative Study with Task 3.2.3, entitled "*Compile, Analyze, and Review Existing Data Sets.*" Subtask 3.2.3.4 of this task is entitled "*Technical Review and Evaluation of the 1992 Deep Test Hole Study, Performed by the Inyo/Los Angeles Technical Group.*" The scope of this subtask is as follows:

> *"MWH shall complete a technical review of the 1992 Deep Test Hole Study in the Taboose-Aberdeen Wellfield. This review shall provide an evaluation of the study, a recommendation on whether or not to expand these types of studies, and a recommendation of what type of information can be gathered from the 1992 study conducted."*

The purpose of this technical memorandum, which represents the deliverable for Subtask 3.2.3.4, is to summarize the results of MWH's evaluation of the1992 Deep Test Hole Study as described in the scope of work.

EVALUATION OF THE STUDY

The 1992 Deep Test Hole study is documented in a 5-page report, which contains an appendix with detailed lithologic logs and relative zone-specific water production by depth for six test holes drilled in the Spring of 1988 to depths ranging from 535 to 855 feet. Also included are two Plates, which contain maps of the borehole locations and five detailed geologic cross sections. The report is well written and presents a relatively complete summary of drilling results, combined with cross sections and geologic correlation.

One of the unique aspects of this study was the use of the reverse-circulation dual tube method of drilling the six test holes. In this method, the drill stem (typically small diameter) contains a "pipe within a pipe." Water is forced down the annular space between the two pipes, and cuttings and water are returned through the small-diameter center pipe. This method was selected because of its associated benefits, listed below:

- The reverse-circulation dual tube method can be cheaper and faster than conventional rotary drilling,
- Cuttings are returned in water (vs. mud), meaning that description of the cuttings is easier and more accurate,
- Cuttings are returned rapidly with little mixing, meaning that the depth provenance of the cuttings is known with relatively high accuracy, and
- The method allows for relative evaluation of water-producing characteristics or "water make" by suspending drilling and airlifting at discrete depths.

The 1992 Deep Test Hole study does not contain data on head conditions or gradients in various aquifers, nor does it contain information on dynamic changes of water levels, such as those that would result from a pumping test. However, the presentation of drilling information is detailed and professional. The care and detail used in lithologic logging and cross-section construction is exemplary.

Prior to this study, the deepest drilling data available were to depths of approximately 350 feet, whereas the six test holes described in the 1992 Deep Test Hole Study were completed to depths of between 535 to 855 feet. Thus, the work identified and described previously unknown alluvial and volcanic aquifers at depth. The drilling results revealed the following general stratigraphy in the vicinity of the test holes (from shallowest to deepest):

- A surface alluvial layer varying in thickness from approximately 20 to 200 feet,
- An upper basalt layer varying in thickness from approximately 75 to 100 feet (this is the aquifer tapped by many existing production wells, and is an extension of a basalt outcrop to the west of the well field),
- An alluvial layer consisting of sand and gravel with thin (but relatively continuous) clay layers, with a thickness of approximately 250 to 500 feet, and
- A deeper basalt layer with a thickness greater than 430 feet.

In general, all of these layers dip to the east at a shallow angle (one to five degrees). Potentially productive strata were found in all of the three lower zones, and the deeper basalt was found to be particularly productive based on airlifting tests.

IMPLEMENTATION OF SIMILAR STUDIES

Depending on the specific intent and funds available for future studies, there are several means in which similar studies could be expanded, as described in the following sections.

Improvement of the Drilling Method and Casing Installation

Although the reverse-circulation dual tube method for exploratory drilling has several benefits, (described above), it does have pitfalls, which include:

- The apparent inability to document head conditions during drilling, (they are not documented in the report). Head measurements at discrete intervals provide valuable information on vertical hydraulic gradients. Because the amount of water produced during airlifting is a function of depth to water and submergence of the drill stem, the lack of this data means that the "water make" information is subject to some uncertainty. It should be noted that head measurements during mud rotary drilling are not possible either.
- The potential inability to conduct geophysical logs, (except gamma logs, which are of limited value in the Owens Valley), because the hole is not held open by the weight of drilling mud once the drill stem is removed. Geophysical logs provide important quantitative information on changes in stratigraphy that are easily correlatable from well to well. The combination of detailed lithologic logs (as provided in the report) with high-quality geophysical logs would be especially valuable.
- The potential inability to install a casing and annular seal. Given the cost of mobilization and use of a drill rig, the installation of PVC casing is relatively inexpensive and provides for long-term collection of water level data. If a small-diameter piezometer is installed with a proper annual seal, valuable information on vertical gradients and time-series data on groundwater head can be collected.

An ideal solution would be to combine the benefits of reverse-circulation dual tube drilling with the ability to measure head, conduct geophysical logging, and install casing. Although this would require further consultation and planning with drilling contractors, a potential solution would be to withdraw the drill stem (after reaching the total depth) while simultaneously injecting mud, followed by geophysical logging after the drill stem is removed. After geophysical logging, a small diameter casing with a pre-constructed filter pack and annular seal could be inserted. Similar methods are sometimes used in hollow-stem auger drilling. The resultant piezometric information afforded by installation of casing could be very valuable in determining confining characteristics and the hydraulic interaction of volcanic and sedimentary deposits.

Geologic Interpretation

As previously noted, the report contains detailed lithologic logs and cross sections. The presentation of basic (un-interpreted) data is excellent. However, correlation of stratigraphic zones are made by straight-line interpolations of materials in adjacent test holes, without regard to the probable depositional environment, timing, and nature of volcanism and/or tectonism.

Geologic interpretation could be improved by superimposing the map of drilling locations and cross sections on a detailed geologic map that includes fault locations and relative fault throw. In this manner, the structural geology of the area could be incorporated into the cross section interpretation. In addition, the incorporation of other historical literature in the regional area would allow for interpretation of a depositional model in the context of known historical geologic events. For example, the U.S. Geological Survey has developed a regional depositional model of the area (Danskin, 1998), and several age-dating studies have been conducted on the nature and timing of volcanic events in the valley. These actions would shed light on the three-dimensional extent of lacustrine, alluvial, and volcanic deposits that exert a large influence on groundwater flow in the well field.

Incorporation of Piezometric Data

The report does not contain piezometric information such as groundwater contours and hydrographs. These data (especially if available for varying depths) are critical to the understanding of groundwater flow. For example, it is always advantageous to show groundwater levels on geologic cross sections, and provide groundwater contours based on both existing wells and test holes constructed during the study. This work was probably not within the scope of the 1992 Deep Test Hole study, but should be included in future work regarding the nature of confining units.

Aquifer Testing

The objective of the 1992 Deep Test Hole study was to *"determine if alternate well sites could be located and developed with minimal or no surface impact because of depth and separation of aquifers".* The report was successful in meeting this objective. Two potential deeper zones of production were identified: a relatively thick and probably anisotropic alluvial layer, and a thick deep basalt layer.

Future studies on the impacts of pumping from the deeper alluvial or basalt formations will require pumping from one or both of these zones, and carefully documenting the impact to the shallow zone and the radial influence of drawdown in nearby monitoring wells. Such an aquifer test should be modeled after the techniques identified for testing of the confining layer at Well W380EM and Well W381EM, described in "Task 1.3.4 Deep Well Operational Testing, Draft Operational Plan", (July 2002).

Further Exploration of the Deeper Basalt Aquifer

The drilling report documents the fact that the lower basalt layer is a major feature in the central portion of the Owens Valley, and suggests that the basalt flow may have traveled for over 15 miles or so from the north. This basalt flow may have influenced the subsequent deposition of lacustrine deposits. Because this basalt appears to have high transmissivity, it may provide an effective hydraulic connection to wellfields to the north. These hydrologic concepts should be tested by more complete geologic evaluation, combined with exploratory drilling data to determine the areal extent of the deeper basalt aquifer. These exploratory holes could then be cased and serve as observation wells for future production well testing from either the deep alluvial or basalt layers.

Groundwater Modeling

The concluding section of the report poses an interesting question: *"Would it be better to drill and complete a production well in the deeper alluvium or in the deeper basalt?"* One of the ways to shed light on this question would be to create a groundwater model that contains two highly permeable basalt layers separated by an anisotropic alluvial layer. Modeling simulations could then be used to evaluate the comparative effects of pumping from either layer.

SUMMARY OF FINDINGS

One of the most outstanding characteristics of the report is the inclusion of very detailed and professional lithologic logs, and the construction of detailed, scaled geologic sections that display the three-dimensional characteristics of the penetrated formations. This detailed basic data will remain extremely valuable in all future investigations of the area, including groundwater modeling. The documentation of deeper alluvial and basaltic aquifers is an important contribution to the understanding of the hydrogeology of the area.

The documentation of relative "water make" affords estimation of the hydraulic conductivity of the various hydrostratigraphic layers, which will also be beneficial in future exploration and modeling efforts. In general, the report provides a sound basis for future geologic interpretation, well siting, and modeling.

SUMMARY OF RECOMMENDATIONS

A summary of recommendations for the implementation of future studies is provided below:

- In future drilling operations, consult with a drilling contractor to identify a drilling method that combines the benefits of reverse-circulation dual tube drilling with the ability to measure head, perform geophysical logging, and install casing.
- In creating cross sections, incorporate information from existing regional geologic maps and historical literature.
- In future studies, incorporate the generation of piezometric information such as groundwater contours and hydrographs.
- Conduct aquifer tests to determine any shallow zone impacts due to the pumping of the deeper alluvial and basalt formations.
- Conduct a more complete geologic evaluation of the lower basalt layer.
- Utilize groundwater modeling to compare the relative effects of pumping the deeper alluvial layer versus the deeper basalt layer.

REFERENCES

Los Angeles Department of Water and Power, May 1992. *Deep Test Hole Study.* Report to the Inyo/Los Angeles Standing Committee from the Inyo/Los Angeles Technical Group.

Montgomery Watson Harza and Inyo/Los Angeles Cooperative Study Team, July 2002. *Task 1.3.4 Deep Well Operational Testing, Draft Operational Plan.*

Danskin, Wesley R., 1998. *Evaluation of the Hydrologic System and Selected Water-Management Alternatives in the Owens Valley, California.* U.S. Geological Survey Water-Supply Paper 2370. 175 pp.

Technical Memorandum on Aquifer Test Analysis

TECHNICAL MEMORANDUM

MWH

To: Inyo/LA Cooperative Study Team **Date:** April 10, 2003

From: MWH **Reference:** 1341515.030203

Subject: Confining Layer Characteristics Cooperative Study - Aquifer Test Analysis
FINAL

INTRODUCTION

On August 1, 2002, the Los Angeles Department of Water and Power (LADWP) authorized Montgomery Watson Harza (MWH) to continue the Confining Layer Characteristics Cooperative Study with Task 3.2.3, entitled "*Compile, Analyze, and Review Existing Data Sets.*" Subtask 3.2.3.1 of this task is entitled "*Aquifer Test Analysis.*" The scope of this subtask is as follows:

> *"MWH shall analyze the existing data sets selected in the July 24, 2002 'Identification of Methods and Tools for Characterization of the Confining Layer' Technical Memorandum. LADWP will loan a copy of AQTESOLV for MS Windows software to MWH for analysis. MWH shall utilize the following analysis methods to analyze the nine selected pump test data sets.*
>
> - *Hantush-Jacob Method, 'Classic Leaky Aquifer Solution'*
> - *Hantush Method, 'Modified Leaky Aquifer Solution'*
> - *Neuman-Witherspoon Method, 'Two Aquifer, One Confining Unit Solution'*
>
> *Application of three different methods is expected to produce variable values for hydraulic conductivity. As such, MWH shall evaluate the results of this analysis to determine a representative hydraulic conductivity for each given data set. In addition, MWH shall evaluate the results of this analysis with the goal of optimizing and refining future pump testing and associated data collection efforts in the Valley."*

The purpose of this technical memorandum, which represents the deliverable for Subtask 3.2.3.1, is to summarize the results of MWH's analysis of the selected aquifer test data sets as described in the scope of work.

The technical memorandum is organized into the following sections:

- **Background** – presents a brief description of each of the three methods used to perform the aquifer test analysis.

- **Aquifer Test Analysis Strategy –** presents the general guidelines and assumptions that were utilized to conduct the aquifer test analysis.
- **Aquifer Test Analysis Results –** presents the results of the aquifer test analysis for each pumping well. The wells are organized by wellfield beginning at the northernmost wellfield and continuing south. The nine wells that were analyzed are listed in **Table 1**.
- **Summary of Findings –** presents a summary of aquifer and confining layer parameters estimated during the aquifer test analysis.
- **Recommendations for Future Aquifer Testing –** presents a bulleted list of recommendations to be considered during implementation of future aquifer testing.

Table 1
Summary of Aquifer Tests Evaluated by Wellfield

Laws	Big Pine	Independence-Oak	Symmes-Shepherd
W387 EM W398 AQ	V014GA V016GA W379 EM W389 EM	W383 EM W384 EM	W395 AQ

BACKGROUND

As described in more detail in the *Technical Memorandum on the Identification of Methods and Tools for Characterization of the Confining Layer* (MWH, 2002), the following three pump test analysis methods were selected for aquifer test analysis: Hantush-Jacob (1955), Hantush (1960), and Neuman-Witherspoon (1969). A brief description of each of these methods is provided below.

Hantush-Jacob Method (1955)

The Hantush-Jacob Method (1955), from this point on referred to as the Hantush-Jacob Method, is a leaky aquifer analysis method that can be used to yield confined aquifer transmissivity and storativity and confining unit vertical hydraulic conductivity. Analysis is performed by fitting observed displacement vs. time data to a mathematically defined curve. The Hantush-Jacob solution assumes no storage in the confining unit. Originally, the Hantush-Jacob Method did not account for partially penetrating wells; however, the software program utilized during this analysis has modified the solution such that analysis of partially penetrating wells was possible.

Hantush Method (1960)

The Hantush Method (1960), from this point on referred to as the Hantush Method, is a leaky aquifer analysis method that can be used to yield confined aquifer transmissivity and storativity, and the product of confining unit vertical hydraulic conductivity and storativity. Similar to the Hantush-Jacob Method, analysis is performed by fitting observed displacement vs. time data to a mathematically defined curve. This solution has also been modified to account for partially penetrating wells. Unlike the Hantush-Jacob Method, the Hantush Method does account for storage in the confining unit.

Neuman-Witherspoon Method (1969)

The Neuman-Witherspoon Method (1969), from this point on referred to as the Neuman-Witherspoon Method, is a leaky aquifer analysis method that yields the transmissivity and storativity of the confined aquifer, the vertical hydraulic conductivity and storativity of the confining unit, and the transmissivity and storativity of the unconfined aquifer. Similar to the other two methods described above, analysis is performed by fitting observed displacement vs. time data to a mathematically defined curve. This method accounts for storage in the confining unit and partially penetrating wells. However, unlike the two other methods presented above, this method also accounts for drawdown in the unpumped aquifer. [Note: This method is not to be confused with the Neuman-Witherspoon "ratio" method (1972). In order to perform the "ratio" method, observations of drawdown for wells screened throughout the confining unit must be available. No such measurements were available for any of the existing pump tests available for analysis.]

AQUIFER TEST ANALYSIS STRATEGY

In order for the results of the aquifer test analyses to be both consistent and reproducible, an analysis strategy was created to:

1. Identify data subsets to be analyzed,
2. Make assumptions for data input, and
3. Determine curve matching techniques.

The analysis strategy is outlined below:

1. Identify data subsets to be analyzed:
    - It is difficult to estimate the "distance from the center of pumping" for observation measurements obtained at the pumping well, and at small distances, the analytical solutions are quite sensitive to the distance chosen. As a result, observation well data were selected for analysis over pumping well data wherever possible. However, if adequate drawdown vs. time data were not available for an observation well, pumping well data were analyzed.
    - Observation well data were only used for wells that were screened in the same zone as the pumping well. If no observation wells screened in the same aquifer as the pumped well were utilized, data from the pumping well were selected for analysis.
    - Data collected less than 10 minutes into the aquifer test were not analyzed. This is because the "early"-time data is often suspect because the well is emptying the casing. Thus, the water that is withdrawn from the well casing is not from the aquifer, and less drawdown may be observed than would be predicted by theory. In addition, drawdown measurements were obtained manually. Therefore, from a practical standpoint, the

personnel on the site may have been rushed to take measurements as the water level fell quickly, perhaps resulting in inaccurate measurements.

- The Hantush Method can only be used to analyze early-time data; however, "early-time" is dependent on several aquifer and aquitard parameters that are unknown. For this reason, a qualitative determination was made for each data set as to which data points would be analyzed with the Hantush Method. For the purposes of this analysis, any measurements obtained after an observable change in inflection of the drawdown vs. time curve were discarded from the analysis.

2. Make assumptions for data input:
   - Aquifer Data
     - The saturated thickness of the confined aquifer was assumed to be the distance from the bottom of the confining unit to the bottom of the screened interval of the pumped well.
     - A hydraulic conductivity anisotropy ratio (vertical hydraulic conductivity:horizontal hydraulic conductivity) of 1.0 was assumed for the pumped aquifer. Analysis was conducted to determine the sensitivity of the solutions to this assumption. It was determined that for all analyses where the pumping well was fully penetrating as well as for all analyses conducted with the Neuman-Witherspoon Method, changing the hydraulic conductivity anisotropy ratio from 1.0 to 0.1 had no observable effect. Furthermore, it was determined that for wells whose screened intervals perforated at least 80 percent of the saturated aquifer, the effect observed from changing the hydraulic conductivity anisotropy ratio from 1.0 to 0.1 was non-significant. The only pumping well whose screened interval does not penetrate at least 80 percent of the saturated aquifer was well V014GA. For this well, generated solutions for the Hantush-Jacob Method and the Hantush Method could change by up to an order of magnitude if the hydraulic conductivity anisotropy ratio were decreased from 1.0 to 0.1.
   - Pumping Well Data
     - If the pumping well was screened over the full saturated aquifer thickness, (as defined above), then the well was assumed to be fully penetrating. Otherwise, the pumping well was assumed to be partially penetrating.
     - A constant pumping rate was assumed for the duration of the aquifer test. (Note: One exception was made to this assumption for well V014GA. This well was pumped for 240 minutes at one pumping rate, and then the pumping rate was doubled for the remainder of the test. This change in pumping rate was modeled during the analysis.)
     - If data from the pumping well were used for analysis, the radial distance chosen was equal to the borehole radius.
   - Observation Well Data
     - If the observation well was screened over the full saturated aquifer thickness, (as defined above), then the well was assumed to be fully penetrating. Otherwise, the observation well was assumed to be partially penetrating.

3. Determine curve-matching techniques:
   - Initially, AQTESOLV's "automatic curve-matching feature" was utilized.
   - If a match was obtained, AQTESOLV's "tweak" feature, which allows the user to make slight adjustments in the generated parameters and observe the effect on the shape of the match curve, was utilized to determine the sensitivity of the curve to variations in each of the generated parameters. Also, the generated aquifer transmissivity and storativity values were compared with existing LADWP estimates (found in the pump test packets) to check for order of magnitude agreement.
   - If the curve was sensitive to all generated parameters, no closer visual match could be obtained using the "tweak" feature, and the generated aquifer transmissivity and storativity estimates were within an order of magnitude of existing LADWP estimates, then the match obtained by the automatic curve-matching feature was selected as the "best match".
   - If any of the three criteria described in the previous bullet were not met, the parameters were adjusted manually such that the best visual match was obtained, (taking into account parameters generated by prior analyses with other solutions as well as existing LADWP estimates for aquifer transmissivity and storativity). Then, the automatic curve-matching feature was utilized once more to create the "best match".
   - At this point, the "tweak" feature was used once more to determine the sensitivity of the curve to the parameters generated. Assuming that the curve was sensitive at least to the parameters necessary to calculate vertical hydraulic conductivity, the analysis was considered complete. The reason that this criterion was applied was to assure that discrete solutions (as opposed to values within a range of possible solutions) were found for the parameters utilized to calculate confining unit properties. The AQTESOLV parameters needed to calculate vertical hydraulic conductivity (or the verticaly hydraulic conductivity/storativity product for the Hantush Method) are listed below by method (see **Appendix A** for a glossary of variables and terms):
     - Hantush-Jacob Method: aquifer transmissivity and r/B value
     - Hantush Method:aquifer transmissivity, aquifer storativity, and β_H value
     - Neuman-Witherspoon Method: aquifer transmissivity and r/B value
   - If no automatic match could be converged upon, a visual match was created by tweaking the parameters as described above to create a "representative" solution.
   - For consistency, it was determined that all parameter solutions generated by AQTESOLV as well as all calculated values based on these parameter solutions would be presented to three significant figures unless otherwise stated.

AQUIFER TEST ANALYSIS RESULTS

The results of the aquifer test analyses are presented herein by wellfield for each of the nine selected aquifer test data sets. This technical memorandum contains the following information:

- A glossary of variables and terms (**Appendix A**),
- Schematic diagrams of the nine aquifer systems analyzed (**Appendix B**),
- Drawdown vs. time data analyzed for each data set (**Appendix C**),

- Residual statistics and parameter solutions produced by the AQTESOLV analysis for each data set (**Appendices D – L**),
- Discussions of the three final solutions obtained for each data set,
- Two calculated confining unit vertical hydraulic conductivity values for each data set based on the parameter solutions for the Hantush-Jacob Method and the Neuman-Witherspoon Method as well as an estimation of the representative value for each data set. (Note: The confining unit vertical hydraulic conductivity could not be isolated with the Hantush Method, but the confining unit vertical hydraulic conductivity/storativity product is presented.), and
- A sample calculation for vertical hydraulic conductivity using the Hantush-Jacob Method and the Neuman-Witherspoon Method as well as a sample calculation for the vertical hydraulic conductivity/storativity product using the Hantush Method (**Appendix M**).

Additionally, a summary of the inputs to AQTESOLV that were used during analysis of each of the nine aquifer tests is provided in **Table 2**.

LADWP Well W387 EM (Laws Wellfield)

One observation well, well T734, was monitored in addition to the pumping well during the aquifer test conducted at well W387 EM. However, upon looking at the drawdown vs. time plot for the observation well, it was determined that this well seems to be affected by some outside pumping source and/or external influences, due to significant variation in observed drawdown at late time. For this reason, only the pumping well data from well W387 EM were chosen for analysis, and all of the measurements were analyzed, (except for data collected less than 10 minutes into the test). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well W387 EM was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 3** presents a summary of the aquifer test analysis results for well W387 EM. The final solution curves for each analysis method are presented in **Appendix D**.

It is important to note that the top 20 feet of the screened interval for well W387 EM are located in a potential confining/low permeability unit, (fine to medium sand with small gravel, 70 percent brown clay). Because the well was screened in this area, this 20-foot unit of low permeability was considered to be part of the confined aquifer. (AQTESOLV expects the screened interval of a pumping well to begin below the confining unit.) However, if analysis was performed assuming the 20-foot low permeability unit to be part of the confining unit and assuming the screened interval to start immediately below this unit, different results might be obtained.

Table 2
Summary of AQTESOLV Inputs for Aquifer Test Analysis

		Laws		Big Pine				Independence-Oak		Symmes-Shepherd
		Well W387 EM	Well W398 AQ	Well V014GA	Well V016GA	Well W379 EM	Well W389 EM	Well W383 EM	Well W384 EM	Well W395 AQ
AQUIFER CHARACTERISTIC INPUTS	Saturated Aquifer Thickness	370 feet	367 feet	65 feet	48 feet	200 feet	200 feet	355 feet	340 feet	462 feet
	Kr/Kz Ratio	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1	1:1
	Confining Unit Thickness[1] (see Appendix B – Schematic Diagrams)	50 feet	109 feet	190 feet	140 feet	100 feet	110 feet	150 feet	50 feet	30 feet
PUMPING WELL INPUTS	Fully vs. Partially Penetrating Well	Partially	Partially	Partially	Partially	Fully	Fully	Partially	Fully	Partially
	Distance from Base of Confining Unit to Top of Perforated Interval	40 feet	17 feet	25 feet	8 feet	0 feet	0 feet	54 feet	0 feet	32 feet
	Distance from Base of Confining Unit to Bottom of Perforated Interval	370 feet	367 feet	65 feet	48 feet	200 feet	200 feet	355 feet	340 feet	462 feet
	Pumping Rate	482.6 ft^3/min (3610 gpm)	401.0 ft^3/min (3000 gpm)	12.7 ft^3/min (95 pgm) for time ≤ 240 min 25.4 ft^3/min (190 gpm) for time > 240 min	34.6 ft^3/min (259 gpm)	409.1 ft^3/min (3060 gpm)	418.4 ft^3/min (3130 gpm)	297.0 ft^3/min (2222 gpm)	126.9 ft^3/min (949 gpm)	407.7 ft^3/min (3050 gpm)
INPUTS FOR WELL SELECTED FOR DATA ANALYSIS	Well Name	W387 EM	W398 AQ	V014GA	V016GA	T627	T736	T632	T633	W395 AQ
	Radial Distance from Pumping Well	1.17 feet (based on 28" borehole diameter)	1.17 feet (based on 28" borehole diameter)	0.667 feet (based on 16" borehole diameter)	0.625 feet (based on 15" borehole diameter)	57 feet	48.5 feet	81.5 feet	88.5 feet	1.17 feet (based on 28" borehole diameter)
	Fully vs. Partially Penetrating Well	Partially	Partially	Partially	Partially	Partially	Partially	Partially	Partially	Partially
	Distance from Base of Confining Unit to Top of Perforated Interval	40 feet	17 feet	25 feet	8 feet	100 feet	100 feet	160 feet	200 feet	32 feet
	Distance from Base of Confining Unit to Bottom of Perforated Interval	370 feet	367 feet	65 feet	48 feet	150 feet	150 feet	200 feet	240 feet	462 feet
	Number of Time vs. Drawdown Measurements Analyzed	42	32	40	17	25	45	47	51	65

[1]The confining unit thickness is not an input used during AQTESOLV analysis. However, it is provided in this table as it is needed to calculate vertical hydraulic conductivity values from the parameters yielded by AQTESOLV analysis.

Table 3
Summary of Aquifer Test Analysis Results for Well W387 EM

Analysis Results	Aquifer Test Analysis Method		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics[1]			
Mean	-0.0001757	-0.00002489	-0.002161
Variance	0.2422	0.2699	0.2456
Standard Error	0.4921	0.5196	0.4956
Parameter Solutions[2]			
T [gpd/ft]	57,100	56,800	53,600
S [unitless]	4.25×10^{-3}	3.75×10^{-3}	2.73×10^{-3}
r/B [unitless]	1.34×10^{-3}	Not Applicable	1.34×10^{-3}
β_H [unitless]	Not Applicable	2.97×10^{-4}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	3.30×10^{-4}
T^U [gpd/ft]	Not Applicable	Not Applicable	**1.34×10^{-1}**
S^U [unitless]	Not Applicable	Not Applicable	**1.00×10^{0}**

[1] Residual statistics presented for the Hantush Method should not be compared with values from the other two methods as this analysis was performed only on a subset of the data used for analysis with the other two methods.
[2] Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush-Jacob (1955) Analysis

Analysis with the Hantush-Jacob Method produced a solution curve that provides a very good visual match with the pumping well data. Calculated transmissivity and storativity values agree with earlier estimates by the LADWP (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity.

Hantush (1960) Analysis

Analysis with the Hantush Method was conducted only on the first 420 minutes of data, (excluding the first 10 minutes). This analysis produced a solution curve that provides a good visual match with the pumping well data, and calculated transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity/storativity product.

Neuman-Witherspoon (1969) Analysis

Analysis with the Neuman-Witherspoon Method produced a solution curve that provides a very good visual match with the pumping well data. Calculated confined aquifer transmissivity and storativity values agree with earlier LADWP estimates (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity. (However, it should be noted that the calculated unconfined aquifer transmissivity and storativity values can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well W387 EM

Calculated vertical hydraulic conductivity values for the confining unit present at well W387 EM are presented in **Table 4**. (Note: A sample calculation of these values is presented in **Appendix M**.) From this table, it is observed that the confining unit vertical hydraulic conductivity values calculated from the Hantush-Jacob solution and the Neuman-Witherspoon solution are virtually identical. The representative confining unit vertical hydraulic conductivity near well W387 EM is estimated to be an average of the two solutions, or 3.64 gpd/ft^2.

Table 4
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well W387 EM

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	3.73	Not Applicable
Hantush (1960)[1]	Not Applicable	0.0110
Neuman-Witherspoon (1969)	3.54	Not Applicable
Representative Value	**3.64**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

LADWP Well W398 AQ (Laws Wellfield)

The pumping well data were selected for analysis of the aquifer test conducted at well W398 AQ. No observation wells screened in the same aquifer as well W398 AQ were monitored during this test. All of the pumping well data were analyzed, (except for data collected less than 10 minutes into the test). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well W398 AQ was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 5** presents a summary of the aquifer test analysis results for well W398 AQ. The final solution curves for each analysis method are presented in **Appendix E**.

Hantush-Jacob (1955) Analysis

Automatic curve matching analysis of the data from well W398 AQ with the Hantush-Jacob Method was not successful. AQTESOLV was unable to converge on a reasonable solution. This failure is attributed to the low quality of the data. The data imply that there were numerous changes in pumping rate. In order to generate some estimate of the aquifer properties near well W398 AQ, a visual match was obtained by setting the transmissivity and storativity near earlier estimates by the LADWP (LADWP, 1991). Next, the parameters were tweaked as little as possible to obtain a reasonable visual match. The results of this match are presented in **Table 5**. However, other solutions are possible, and these values should be used with caution as they were estimated based on visual inspection alone.

Table 5
Summary of Aquifer Test Analysis Results for Well W398 AQ

Analysis Results	**Aquifer Test Analysis Method**		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics[1]			
Mean	Not Applicable	Not Applicable	Not Applicable
Variance	Not Applicable	Not Applicable	Not Applicable
Standard Error	Not Applicable	Not Applicable	Not Applicable
Parameter Solutions[2]			
T [gpd/ft]	81,600	74,400	71,100
S [unitless]	5.76×10^{-4}	1.02×10^{-3}	1.41×10^{-3}
r/B [unitless]	3.72×10^{-4}	Not Applicable	8.32×10^{-4}
β_H [unitless]	Not Applicable	4.57×10^{-4}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	3.98×10^{-4}
T^U [gpd/ft]	Not Applicable	Not Applicable	**$1.08 \times 10^{+3}$**
S^U [unitless]	Not Applicable	Not Applicable	1.00×10^{-1}

[1] No residual information is available as AQTESOLV could not converge on a solution for this data set.
[2] All solutions presented in this table are estimated only and should be used with caution.
[3] Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush (1960) Analysis

Similar to the Hantush-Jacob Method, automatic curve-matching analysis with the Hantush Method was unsuccessful. Again AQTESOLV could not converge on a solution; therefore, an estimated solution was obtained by creating a reasonable visual match as described above. The results of this match are presented in **Table 5**, but again, these results are not unique and should be used with caution.

Neuman-Witherspoon (1969) Analysis

As with the other two methods, automatic curve-matching analysis with the Neuman-Witherspoon Method was unsuccessful. Again AQTESOLV could not converge on a solution, so an estimated solution was obtained by creating a reasonable visual match as described above. The results of this match are presented in **Table 5**, but again, these results are not unique and should be used with caution. (Note also that the calculated unconfined aquifer transmissivity can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well W398 AQ

Calculated vertical hydraulic conductivity values for the confining unit present at well W398 AQ are presented in **Table 6**. A comparison between the confining unit vertical hydraulic conductivity values calculated by the Hantush-Jacob Method and the Neuman-Witherspoon Method reveals that the two values are within an order of magnitude of each other. However, these values are based on highly questionable parameter solutions, and with the low quality of available data, there is no reason to rely in the results generated by either method. For this reason, the representative confining unit vertical hydraulic conductivity near well W398 AQ is estimated to be an average of the two solutions, or 2.41 gpd/ft^2.

Table 6
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well W398 AQ

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	0.897	Not Applicable
Hantush (1960)[1]	Not Applicable	0.0202
Neuman-Witherspoon (1969)	3.92	Not Applicable
Representative Value	**2.41**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

U.S. Geological Survey Well V014GA (Big Pine Wellfield)

The pumping well data were selected for analysis of the aquifer test conducted at well V014GA. No observation wells screened in the same aquifer as well V014GA were monitored during this test. All of the pumping well data were analyzed, (except for data collected less than 10 minutes into the test and less than 10 minutes after the change in pumping rate at 240 minutes). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well V014GA was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 7** presents a summary of the aquifer test analysis results for well V014GA. The final solution curves for each analysis method are presented in **Appendix F**.

Hantush-Jacob (1955) Analysis

Analysis with the Hantush-Jacob Method produced a solution curve that provides a relatively good visual match with the pumping well data collected at well V014GA. However, the curve does not fit the data obtained before the increase in pumping rate. The calculated transmissivity value agrees well with earlier estimates by the LADWP (LADWP, 1985). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity.

Table 7
Summary of Aquifer Test Analysis Results for Well V014GA

Analysis Results	Aquifer Test Analysis Method		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics[1]			
Mean	-0.1378	-0.0002322	-0.0358
Variance	0.0315	0.0004548	0.01982
Standard Error	0.1775	0.02133	0.1408
Parameter Solutions[2]			
T [gpd/ft]	40,600	36,200	32,600
S [unitless]	3.41×10^{-3}	2.75×10^{-2}	1.41×10^{-3}
r/B [unitless]	4.56×10^{-4}	Not Applicable	4.96×10^{-4}
β_H [unitless]	Not Applicable	5.16×10^{-4}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	1.11×10^{-4}
T^U [gpd/ft]	Not Applicable	Not Applicable	**1.13×10^{0}**
S^U [unitless]	Not Applicable	Not Applicable	1.58×10^{-2}

1 Residual statistics presented for the Hantush Method should not be compared with values from the other two methods as this analysis was performed only on a subset of the data used for analysis with the other two methods.
2 Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush (1960) Analysis

Analysis with the Hantush Method was conducted only on the first 240 minutes of data, (excluding the first 10 minutes). This analysis produced a solution curve that provides a relatively good visual match with the pumping well data, and the calculated transmissivity value agrees well with earlier LADWP estimates (LADWP, 1985). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity/storativity product.

Neuman-Witherspoon (1969) Analysis

Analysis with the Neuman-Witherspoon Method produced a solution curve that provides a relatively good match with the pumping well data. However, the curve does not match the data obtained immediately after the increase in pumping rate. Calculated confined aquifer transmissivity agrees well with earlier LADWP estimates (LADWP, 1985). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity. (However, it should be noted that the calculated unconfined aquifer transmissivity can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well V014GA

Calculated vertical hydraulic conductivity values for the confining unit present at well V014GA are presented in **Table 8**. From this table, it is observed that the confining unit vertical hydraulic conductivity values calculated from the Hantush-Jacob solution and the Neuman-Witherspoon solution are virtually identical. The representative confining unit vertical hydraulic conductivity near well V014GA is therefore estimated as the average of the two values, or 3.52 gpd/ft^2.

Table 8
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well V014GA

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	3.60	Not Applicable
Hantush (1960)[1]	Not Applicable	1.81
Neuman-Witherspoon (1969)	3.43	Not Applicable
Representative Value	**3.52**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

U.S. Geological Survey Well V016GA (Big Pine Wellfield)

The pumping well data were selected for analysis of the aquifer test conducted at well V016GA. No observation wells screened in the same aquifer as well V016GA were monitored during this test. Only early-time pumping well data were analyzed, (excluding data collected less than 10 minutes into the test), as changes in the pumping rate at time greater than 150 minutes adversely affected the quality of the data. A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well V016GA was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 9** presents a summary of the aquifer test analysis results for well V016GA. The final solution curves for each analysis method are presented in **Appendix G**.

Hantush-Jacob (1955) Analysis

Automatic curve-matching analysis of the data from well V016GA with the Hantush-Jacob Method was not successful. AQTESOLV was unable to converge on a reasonable solution. This failure is attributed to the fact that only 150 minutes of acceptable data exist for this well. In order to generate some estimate of the aquifer properties near well V016GA, a visual match was obtained by setting the transmissivity near the earlier estimates by the LADWP, (LADWP, 1985), and by setting the storativity close to the value obtained at well V014GA (which is located very close to well V016GA). Then, the parameters were tweaked as little as possible to obtain a reasonable visual match. The results of this match are presented in **Table 9**. However, other solutions are possible, and these values should be used with caution as they were estimated based on visual inspection alone.

Table 9
Summary of Aquifer Test Analysis Results for Well V016GA

Analysis Results	Aquifer Test Analysis Method: Hantush-Jacob (1955)	Hantush (1960)	Neuman-Witherspoon (1969)
Residual Statistics[1]			
Mean	Not Applicable	Not Applicable	Not Applicable
Variance	Not Applicable	Not Applicable	Not Applicable
Standard Error	Not Applicable	Not Applicable	Not Applicable
Parameter Solutions[2,3]			
T [gpd/ft]	25,700	23,800	19,900
S [unitless]	3.16×10^{-4}	5.65×10^{-4}	1.59×10^{-3}
r/B [unitless]	7.41×10^{-4}	Not Applicable	2.69×10^{-3}
β_H [unitless]	Not Applicable	4.80×10^{-4}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	4.18×10^{-4}
T^U [gpd/ft]	Not Applicable	Not Applicable	**$1.08 \times 10^{+3}$**
S^U [unitless]	Not Applicable	Not Applicable	8.91×10^{-2}

[1] No residual information is available as AQTESOLV could not converge on a solution for this data set.
[2] All solutions presented in this table are estimated only and should be used with caution.
[3] Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush (1960) Analysis

Similar to the Hantush-Jacob Method, automatic curve-matching analysis with the Hantush Method was unsuccessful. Again AQTESOLV could not converge on a solution; therefore, an estimated solution was obtained by creating a reasonable visual match as described above. The results of this match are presented in **Table 9**, but again, these results are not unique and should be used with caution.

Neuman-Witherspoon (1969) Analysis

As with the other two methods, automatic curve-matching analysis with the Neuman-Witherspoon Method was unsuccessful. Again AQTESOLV could not converge on a solution; therefore, an estimated solution was obtained by creating a reasonable visual match as described above. The results of this match are presented in **Table 9**, but again, these results are not unique and should be used with caution. (Note also that the calculated unconfined aquifer transmissivity can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well V016GA

Calculated vertical hydraulic conductivity values for the confining unit present at well V016GA are presented in **Table 10**. A comparison between the confining unit vertical hydraulic conductivity values calculated by the Hantush-Jacob Method and the Neuman-Witherspoon Method reveals that the latter value is approximately one order of magnitude higher than the former value. However, these values are based on highly questionable parameter solutions, and with the limited data available, there is no reason to favor the results of either method. For this reason, the representative confining unit vertical hydraulic conductivity near well V016GA is estimated to be an average of the two solutions, or 24.4 gpd/ft^2.

Table 10
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well V016GA

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	4.33	Not Applicable
Hantush (1960)[1]	Not Applicable	0.0152
Neuman-Witherspoon (1969)	44.4	Not Applicable
Representative Value	**24.4**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

LADWP Well W379 EM (Big Pine Wellfield)

Two observation wells, well T627 and well W378 EM, were monitored in addition to the pumping well during the aquifer test conducted at well W379 EM. However, well W378 EM is located almost 700 feet from well W379 EM whereas well T627 is located only 57 feet from the pumping well. Because of the distance of well W378 EM from the pumping well, there is an increased likelihood that this well could be influenced by external factors other than the pumping of well W379 EM. For this reason, observation measurements from well T627 only were chosen for analysis. All of the observation well data from well T627 were analyzed, (except for data collected less than 10 minutes into the test). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well W379 EM was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 11** presents a summary of the aquifer test analysis results for well W379 EM. The final solution curves for each analysis method are presented in **Appendix H**.

Hantush-Jacob (1955) Analysis

Analysis with the Hantush-Jacob Method produced a solution curve that provides a good visual match with the observation data collected at well T627. Calculated transmissivity and storativity values agree well with earlier estimates by the LADWP (LADWP, 1992). The curve shape is sensitive to aquifer transmissivity; however, not enough late-time data exist to accurately estimate the r/B value. The value converged upon by AQTESOLV, $1x10^{-5}$, can be manually increased to approximately $5x10^{-3}$ without affecting the early-time shape of the Hantush-Jacob curve for which data exist. For this reason, the latter r/B value was used to calculate the upper limit of the vertical hydraulic conductivity for this system.

Table 11
Summary of Aquifer Test Analysis Results for Well W379 EM

Analysis Results	Aquifer Test Analysis Method		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics			
Mean	0.005037	0.0004869	0.002433
Variance	0.1087	0.1088	0.126
Standard Error	0.3297	0.3299	0.355
Parameter Solutions[1,2]			
T [gpd/ft]	90,300	90,200	90,200
S [unitless]	1.38×10^{-3}	1.38×10^{-3}	1.38×10^{-3}
r/B [unitless]	*5.00×10^{-3}*	Not Applicable	*3.00×10^{-3}*
β_H [unitless]	Not Applicable	*5.00×10^{-4}*	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	**1.00×10^{-5}**
T^U [gpd/ft]	Not Applicable	Not Applicable	**$6.93 \times 10^{+7}$**
S^U [unitless]	Not Applicable	Not Applicable	**1.00×10^{0}**

[1] Italicized values represent the upper limit of a range of possible values for a given parameter.
[2] Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush (1960) Analysis

Analysis with the Hantush Method was conducted on all of the observation data and produced a solution curve that provides a good visual match with the observation well data. Calculated transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1992). The curve shape is sensitive to aquifer transmissivity and storativity; however, the data collected were not sufficient to identify a unique value for β_H. The value converged upon, 1×10^{-5}, can be increased to approximately 5×10^{-4} without affecting the early-time shape of the Hantush curve for which data exist. For this reason, the latter β_H value was used to calculate the upper limit of the confining unit vertical hydraulic conductivity/storativity product for this system.

Neuman-Witherspoon (1969) Analysis

Analysis with the Neuman-Witherspoon Method produced a solution curve provides a good visual match with the available observation data collected at well T627. Again, calculated confined aquifer transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1992). The curve shape is sensitive to confined aquifer transmissivity; however, as with the Hantush-Jacob analysis, not enough late-time data exist to accurately estimate the r/B value. The value converged upon by AQTESOLV, 1×10^{-5}, can be manually increased to approximately 3×10^{-3} without affecting the early-time shape of the Neuman-Witherspoon curve for which data exist. For this reason, the latter r/B value was used to calculate the upper limit of the vertical hydraulic conductivity for this system. (Note that the calculated β_{NW}, unconfined aquifer transmissivity, and unconfined aquifer storativity values can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well W379 EM

Calculated upper limits for vertical hydraulic conductivity for the confining unit present at well W379 EM are presented in **Table 12**. From this table, it is observed that the confining unit vertical hydraulic conductivity value calculated from the Hantush-Jacob solution is approximately three times greater than the value calculated from the Neuman-Witherspoon solution. Because both of the solutions present equally good visual matches and generate equally low standard errors, the representative upper limit of the confining unit vertical hydraulic conductivity near well W379 EM is estimated to be an average of the two solutions, or 0.0473 gpd/ft^2.

Table 12
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well W379 EM[1]

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	0.0695	Not Applicable
Hantush (1960)[2]	Not Applicable	0.0000153
Neuman-Witherspoon (1969)	0.0250	Not Applicable
Representative Value	**0.0473**	**Not Applicable**

[1] The values that are presented in this table are upper limit values only. This is because unique solutions could not be obtained for the parameters used to calculate these values.
[2] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

LADWP Well W389 EM (Big Pine Wellfield)

One observation well, well T736, was monitored in addition to the pumping well during the aquifer test conducted at well W389 EM. Observation measurements from well T736 were chosen for analysis, and all of the measurements were analyzed, (except for data collected less than 10 minutes into the test). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well W389 EM was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 13** presents a summary of the aquifer test analysis results for well W389 EM. The final solution curves for each analysis method are presented in **Appendix I**.

It is important to note that the top 30 feet of the screened interval for well W387 EM are located in a potential confining/low permeability unit, (greenish blue silt and clay with medium sand lenses). Because the well was screened in this area, this 30-foot low permeability unit was considered to be part of the confined aquifer. (AQTESOLV expects the screened interval of a pumping well to begin below the confining unit.) However, if analysis was performed assuming the low permeability unit to be part of the confining unit and assuming the screened interval to start immediately below this unit, different results might be obtained.

Table 13
Summary of Aquifer Test Analysis Results for Well W389 EM

Analysis Results	Aquifer Test Analysis Method		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics[1]			
Mean	0.0000842	0.00000821	-0.004598
Variance	0.08938	0.0181	0.09644
Standard Error	0.299	0.1345	0.3105
Parameter Solutions[2]			
T [gpd/ft]	90,200	82,900	90,700
S [unitless]	1.61×10^{-3}	1.76×10^{-3}	1.57×10^{-3}
r/B [unitless]	6.05×10^{-3}	Not Applicable	5.10×10^{-3}
β_H [unitless]	Not Applicable	7.17×10^{-3}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	**1.40×10^{-4}**
T^U [gpd/ft]	Not Applicable	Not Applicable	**3.91×10^{-1}**
S^U [unitless]	Not Applicable	Not Applicable	**8.18×10^{-1}**

1 Residual statistics presented for the Hantush Method should not be compared with values from the other two methods as this analysis was performed only on a subset of the data used for analysis with the other two methods.
2 Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush-Jacob (1955) Analysis

Analysis with the Hantush-Jacob Method produced a solution curve that provides a very good visual match with the observation data collected at well T734, including late-time data. Calculated transmissivity and storativity values agree well with earlier estimates by the LADWP (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity.

Hantush (1960) Analysis

Analysis with the Hantush Method was conducted only on the first 210 minutes of data, (excluding the first 10 minutes). This analysis produced a solution curve that provides a very good visual match with the observation data, and calculated transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity/storativity product.

Neuman-Witherspoon (1969) Analysis

Analysis with the Neuman-Witherspoon Method produced a solution curve that provides a very good visual match with the observation data, including late-time data. Calculated confined aquifer transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity. (However, it should be noted that the calculated β_{NW}, unconfined aquifer transmissivity, and unconfined aquifer storativity values can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well W389 EM

Calculated vertical hydraulic conductivity values for the confining unit present at well W389 EM are presented in **Table 14**. From this table, it is observed that the confining unit vertical hydraulic conductivity values calculated from the Hantush-Jacob solution and the Neuman-Witherspoon solution are virtually identical. The representative confining unit vertical hydraulic conductivity near well W389 EM is estimated to be an average of the two, or 0.133 gpd/ft^2.

Table 14
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well W389 EM

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	0.155	Not Applicable
Hantush (1960)[1]	Not Applicable	0.00563
Neuman-Witherspoon (1969)	0.110	Not Applicable
Representative Value	**0.133**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

LADWP Well W383 EM (Independence-Oak Wellfield)

One observation well, well T632, was monitored in addition to the pumping well during the aquifer test conducted at well W383 EM. Observation measurements from well T632 were chosen for analysis, and all of the measurements were analyzed, (except for data collected less than 10 minutes into the test). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well W383 EM was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 15** presents a summary of the aquifer test analysis results for well W383 EM. The final solution curves for each analysis method are presented in **Appendix J**.

Hantush-Jacob (1955) Analysis

Analysis with the Hantush-Jacob Method produced a solution curve that provides a reasonable visual match with the observation data collected at well T632. However, the curve does not match the data measured at time greater than 1000 minutes, nor does it match the data measured at time less than 15 minutes. Calculated transmissivity and storativity values agree well with earlier estimates by the LADWP (LADWP, 1992). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity.

Table 15
Summary of Aquifer Test Analysis Results for Well W383 EM

Analysis Results	Aquifer Test Analysis Method		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics[1]			
Mean	0.0000617	-0.0003572	-0.0004633
Variance	0.06749	0.03992	0.01913
Standard Error	0.2598	0.1998	0.1383
Parameter Solutions[2]			
T [gpd/ft]	56,400	43,100	50,000
S [unitless]	4.88×10^{-4}	6.05×10^{-4}	5.89×10^{-4}
r/B [unitless]	4.64×10^{-2}	Not Applicable	6.96×10^{-2}
β_H [unitless]	Not Applicable	4.27×10^{-2}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	**4.44×10^{-3}**
T^U [gpd/ft]	Not Applicable	Not Applicable	**1.08×10^{-1}**
S^U [unitless]	Not Applicable	Not Applicable	1.06×10^{-2}

[1] Residual statistics presented for the Hantush Method should not be compared with values from the other two methods as this analysis was performed only on a subset of the data used for analysis with the other two methods.
[2] Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush (1960) Analysis

Analysis with the Hantush Method was conducted only on the first 100 minutes of data, (excluding the first 10 minutes). This analysis produced a solution curve that provides a relatively good visual match with the observation data, and calculated transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1992). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity/storativity product.

Neuman-Witherspoon (1969) Analysis

Analysis with the Neuman-Witherspoon Method produced a solution curve that provides the best visual match of the three analysis methods with the observation data, matching both early- and late-time data. Calculated confined aquifer transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1992). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity. (However, it should be noted that the calculated β_{NW} and the unconfined aquifer transmissivity values can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well W383 EM

Calculated vertical hydraulic conductivity values for the confining unit present at well W383 EM are presented in **Table 16**. From this table, it is observed that the confining unit vertical hydraulic conductivity value calculated from the Neuman-Witherspoon solution is approximately two times greater than the value calculated from the Hantush-Jacob solution. Because the Neuman-Witherspoon solution presents a higher quality visual match as well as a lower standard error, the representative confining unit vertical hydraulic conductivity near well W383 EM is expected to be closer to the value calculated with the Neuman-Witherspoon solution, and is estimated to be 5.47 gpd/ft^2.

Table 16
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well W383 EM

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	2.74	Not Applicable
Hantush (1960)[1]	Not Applicable	0.0172
Neuman-Witherspoon (1969)	5.47	Not Applicable
Representative Value	**5.47**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

LADWP Well W384 EM (Independence-Oak Wellfield)

One observation well, well T633, was monitored in addition to the pumping well during the aquifer test conducted at well W384 EM. Observation measurements from well T633 were chosen for analysis, and all of the measurements were analyzed, (except for data collected less than 10 minutes into the test). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well W384 EM was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 17** presents a summary of the aquifer test analysis results for well W384 EM. The final solution curves for each analysis method are presented in **Appendix K**.

It is important to note that the top 40 feet of the screened interval for well W387 EM are located in a potential confining/low permeability unit, (sand and gravel, cemented). Because the well was screened in this area, this 40-foot low permeability unit was considered to be part of the confined aquifer. (AQTESOLV expects the screened interval of a pumping well to begin below the confining unit.) However, if analysis was performed assuming the low permeability unit to be part of the confining unit and assuming the screened interval to start immediately below this unit, different results might be obtained.

Hantush-Jacob (1955) Analysis

Analysis with the Hantush-Jacob Method produced a solution curve that provides an acceptable visual match with the observation data collected at well T633. However, the curve does not match the late-time data well, nor does it match data measured at time less than 15 minutes.

Calculated transmissivity and storativity values agree well with earlier estimates by the LADWP (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity.

Table 17
Summary of Aquifer Test Analysis Results for Well W384 EM

Analysis Results	Aquifer Test Analysis Method		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics[1]			
Mean	-0.0000309	-0.000170	-0.0004342
Variance	0.04908	0.007146	0.007922
Standard Error	0.2215	0.08453	0.08901
Parameter Solutions[2]			
T [gpd/ft]	36,600	27,200	24,300
S [unitless]	1.97×10^{-4}	2.79×10^{-4}	3.02×10^{-4}
r/B [unitless]	2.77×10^{-2}	Not Applicable	1.17×10^{-1}
β_H [unitless]	Not Applicable	3.58×10^{-2}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	5.68×10^{-2}
T^U [gpd/ft]	Not Applicable	Not Applicable	**1.08×10^{-1}**
S^U [unitless]	Not Applicable	Not Applicable	7.42×10^{-3}

1 Residual statistics presented for the Hantush Method should not be compared with values from the other two methods as this analysis was performed only on a subset of the data used for analysis with the other two methods.
2 Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush (1960) Analysis

Analysis with the Hantush Method was conducted only on the first 200 minutes of data, (excluding the first 10 minutes). This analysis produced a solution curve that provides a good visual match with the observation data, and calculated transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity/storativity product.

Neuman-Witherspoon (1969) Analysis

Analysis with the Neuman-Witherspoon Method produced a solution curve that provides the best visual match of the three analysis methods with the observation data. Calculated confined aquifer transmissivity and storativity values agree well with earlier LADWP estimates (LADWP, 1993). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity. (However, it should be noted that the calculated unconfined aquifer transmissivity can be varied over many orders of magnitude with no visual effect on the curve shape.)

Confining Unit Vertical Hydraulic Conductivity Near Well W384 EM

Calculated vertical hydraulic conductivity values for the confining unit present at well W384 EM are presented in **Table 18**. From this table, it is observed that the confining unit vertical hydraulic conductivity value calculated from the Neuman-Witherspoon solution is approximately one order of magnitude greater than the value calculated from the Hantush-Jacob solution. Because the Neuman-Witherspoon solution presents a higher quality visual match as well as a lower standard error, the representative confining unit vertical hydraulic conductivity near well W384 EM is expected to be closer to the value calculated with the Neuman-Witherspoon solution, and is estimated to be 2.11 gpd/ft^2.

Table 18
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well W384 EM

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	0.180	Not Applicable
Hantush (1960)[1]	Not Applicable	0.000992
Neuman-Witherspoon (1969)	2.11	Not Applicable
Representative Value	**2.11**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

LADWP Well W395 AQ (Symmes-Shepherd Wellfield)

Two observation wells, well T782 and well W394 AQ, were monitored in addition to the pumping well during the aquifer test conducted at well W395 AQ. However, upon looking at the drawdown vs. time plots for both observation wells, it was determined that both of these wells seem to be affected by some outside pumping source and/or external influences, due to significant variation in observed drawdown at late time. For this reason, only the pumping well data from well W395 AQ were chosen for analysis, and all of the measurements were analyzed, (except for data collected less than 10 minutes into the test). A summary of the AQTESOLV inputs used to conduct the aquifer test analysis for well W395 AQ was presented in **Table 2**, and the drawdown vs. time data that was used for this analysis is located in **Appendix C**. **Table 19** presents a summary of the aquifer test analysis results for well W395 AQ. The final solution curves for each analysis method are presented in **Appendix L**.

Hantush-Jacob (1955) Analysis

Analysis with the Hantush-Jacob Method produced a solution curve that provides a very good visual match with all of the pumping well data collected at well W395 AQ. Calculated transmissivity and storativity values agree with earlier estimates by the LADWP (LADWP, 1992).

Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity.

Table 19
Summary of Aquifer Test Analysis Results for Well W395 AQ

Analysis Results	Aquifer Test Analysis Method		
	Hantush-Jacob (1955)	**Hantush (1960)**	**Neuman-Witherspoon (1969)**
Residual Statistics[1]			
Mean	0.0000163	-0.0004988	-0.00000601
Variance	0.02339	0.01451	0.02166
Standard Error	0.153	0.1205	0.1472
Parameter Solutions[2]			
T [gpd/ft]	245,800	235,700	225,200
S [unitless]	7.49×10^{-4}	1.23×10^{-3}	1.27×10^{-3}
r/B [unitless]	1.02×10^{-4}	Not Applicable	2.30×10^{-4}
β_H [unitless]	Not Applicable	2.69×10^{-5}	Not Applicable
β_{NW} [unitless]	Not Applicable	Not Applicable	4.24×10^{-5}
T^U [gpd/ft]	Not Applicable	Not Applicable	$1.69 \times 10^{+5}$
S^U [unitless]	Not Applicable	Not Applicable	1.32×10^{-3}

1 Residual statistics presented for the Hantush Method should not be compared with values from the other two methods as this analysis was performed only on a subset of the data used for analysis with the other two methods.
2 Bolded parameters can be varied over orders of magnitude without affecting the curve shape.

Hantush (1960) Analysis

Analysis with the Hantush Method was conducted only on the first 1,260 minutes of data, (excluding the first 10 minutes). This analysis produced a solution curve that provides a very good visual match with the pumping well data, and calculated transmissivity and storativity values agree with earlier LADWP estimates (LADWP, 1992). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity/storativity product.

Neuman-Witherspoon (1969) Analysis

Analysis with the Neuman-Witherspoon Method produced a solution curve that provides a very good visual match with all of the pumping well data. Calculated confined aquifer transmissivity and storativity values agree with earlier LADWP estimates (LADWP, 1992). Additionally, the curve shape is sensitive to the parameters needed to calculate the confining unit vertical hydraulic conductivity.

Confining Unit Vertical Hydraulic Conductivity Near Well W395 AQ

Calculated vertical hydraulic conductivity values for the confining unit present at well W395 AQ are presented in **Table 20**. From this table, it is observed that the confining unit vertical hydraulic conductivity value calculated from the Hantush-Jacob solution is approximately five times greater than the value calculated from the Neuman-Witherspoon solution. Because both of the solutions present equally good visual matches and generate equally low standard errors, the representative confining unit vertical hydraulic conductivity near well W395 AQ is estimated to be an average of the two solutions, or 0.158 gpd/ft^2.

Table 20
Estimation of the Confining Unit Vertical Hydraulic Conductivity Near Well W395 AQ

Analysis Method	Confining Unit Vertical Hydraulic Conductivity [gpd/ft^2]	Confining Unit Vertical Hydraulic Conductivity/Storativity Product [gpd/ft^2]
Hantush-Jacob (1955)	0.0560	Not Applicable
Hantush (1960)[1]	Not Applicable	0.0000736
Neuman-Witherspoon (1969)	0.260	Not Applicable
Representative Value	**0.158**	**Not Applicable**

[1] For the Hantush Method (1960), only the product of confining unit vertical hydraulic conductivity and confining unit storativity can be calculated.

SUMMARY OF FINDINGS

Table 21 presents a comparison between the confined aquifer transmissivity and storativity values calculated during this analysis and the existing LADWP estimates. Also included in this table are the estimated representative vertical hydraulic conductivity values of the confining unit based on the analyses presented in this report.

Calculated aquifer transmissivity ranges from 20,000 gpd/ft near well V016GA (Big Pine Wellfield) up to 246,000 gpd/ft at Well W395 (Symmes-Shepherd Wellfield), spanning an order of magnitude. Previous LADWP estimates for transmissivity were presented as either ranges or as a single value. For the six pump test packets where ranges were presented, 16 of the 18 new transmissivity estimates fall within the previously estimated ranges. The two values that lie outside of the previously estimated ranges are both associated with well W384 EM in the Independence-Oak Wellfield. Both estimates are within a factor of two of the range's lower bound. For the three pump test packets that present single transmissivity estimates, all new transmissivity values are within a factor of three of the existing estimates.

Table 21
Summary of Aquifer and Confining Unit Parameters[1]

		Laws		Big Pine				Independence-Oak		Symmes-Shepherd
		W387 EM	**W398 AQ**	**V014GA**	**V016GA**	**W379 EM**	**W389 EM**	**W383 EM**	**W384 EM**	**W395 AQ**
Confined Aquifer Parameters[2]										
T (gpd/ft)	Existing LADWP Estimate	50,000-80,000	120,000	36,000	45,000	80,000-90,000	80,000-100,000	40,000-60,000	35,000-40,000	220,000-300,000
	AQTESOLV Value – Hantush-Jacob (1955)	57,000	**82,000**	41,000	**26,000**	90,000	90,000	56,000	37,000	246,000
	AQTESOLV Value – Hantush (1960)	57,000	**74,000**	36,000	**24,000**	90,000	83,000	43,000	27,000	236,000
	AQTESOLV Value – Neuman-Witherspoon (1969)	54,000	**71,000**	33,000	**20,000**	90,000	91,000	50,000	24,000	225,000
S (unitless)	Existing LADWP Estimate	3×10^{-3}	2×10^{-3}	Not Applicable	Not Applicable	1×10^{-3}	1×10^{-3}	7×10^{-4}	2×10^{-4}	3×10^{-4}
	AQTESOLV Value – Hantush-Jacob (1955)	4×10^{-3}	**6×10^{-4}**	3×10^{-3}	**3×10^{-4}**	1×10^{-3}	2×10^{-3}	5×10^{-4}	2×10^{-4}	7×10^{-4}
	AQTESOLV Value – Hantush (1960)	4×10^{-3}	**1×10^{-3}**	3×10^{-2}	**6×10^{-4}**	1×10^{-3}	2×10^{-3}	6×10^{-4}	3×10^{-4}	1×10^{-3}
	AQTESOLV Value – Neuman-Witherspoon (1969)	3×10^{-3}	**1×10^{-3}**	1×10^{-3}	**2×10^{-3}**	1×10^{-3}	2×10^{-3}	6×10^{-4}	3×10^{-4}	1×10^{-3}
Analysis Method for Existing LADWP Estimates		Modified Theis, Hantush, Modified Hantush	Modified Theis, Hantush	Modified Theis	Modified Theis	Modified Theis, Hantush, Modified Hantush	Modified Theis	Modified Theis, Hantush	Modified Theis	Modified Theis, Hantush, Modified Hantush
Confining Unit Parameters										
Confining Unit Materials Based on Well Log Descriptions		Fine med sand, gravel, and clay	Fine to medium sand with clay and cobbles	Sand, silt, and tight clay	Silty sand, silt, and tight clay	Clay	Silt , clay, and gravel/sand lenses	Sand, clay, gravel	Sand, cemented, black rock	Red sticky clay mixed with fine sand
Representative Aquitard Vertical Hydraulic Conductivity	gpd/ft^2	3.64	**2.41**	3.52	**24.4**	0.0473	0.133	5.47	2.11	0.158
	ft/day	0.486	**0.322**	0.470	**3.26**	0.00632	0.0177	0.731	0.282	0.0211

[1] Bolded numbers represent estimated values to be used with caution because AQTESOLV could not converge on solutions for these data sets.
[2] In this table, transmissivity and storativity values estimated during this analysis have been rounded to the same number of significant figures as the existing LADWP estimates for the purpose of comparison.

The calculated storativity values vary from 3 x 10^{-2} at well V014GA (Big Pine Wellfield) to 2 x 10^{-4} at well W384 EM (Independence-Oak Wellfield), spanning approximately two orders of magnitude. All calculated storativity values demonstrate order of magnitude agreement with previous LADWP estimates. In fact, all storativity values estimated during this analysis are within a factor of four of the existing LADWP estimates.

The calculated confining unit vertical hydraulic conductivity values vary from as low as 0.0473 gpd/ft^2 at well W379 EM (Big Pine Wellfield) to as high as 24.4 gpd/ft^2 at well V016GA (Big Pine Wellfield). An average value was calculated to be approximately 4.65 gpd/ft^2. According to Hollett and others (1991), vertical hydraulic conductivity for the confining unit described as Hydrostratigraphic Unit 2 ranges from 0.006 gpd/ft^2 to 0.015 gpd/ft^2.

The aquifer parameters shown in **Table 21** provide guidance on the typical aquifer parameters found in the Owens Valley, as well as estimated values at specific locations. It is clear from the lithologic data presented in **Appendix B** that the nature of the confining unit is highly variable across the Valley. Only in rare cases (such as the lower portion of the confining unit at V014GA) does the confining unit consist purely of typical low-permeability materials such as "tight clay". In most cases, the confining unit consists of stratified clays, silts, sands, and even gravels. Because horizontal hydraulic conductivities may exceed vertical hydraulic conductivities by a factor of 100 in highly stratified material (Walton, 1988), "leaky"-type behavior is expected even in the absence of an obvious confining unit.

Comparison of the lithologic description to the calculated vertical hydraulic conductivity of the confining unit does not reveal a consistent, reliable pattern of lithologic description and computed vertical hydraulic conductivity. The absence of a consistent, reliable pattern is believed to be the result of lithologic descriptions (as reported on well construction logs) that are not detailed or consistent enough for valid comparison, thereby highlighting the need for careful and detailed lithologic logging by a qualified geologist during drilling.

It is important to note that because the lithologic logs contain the only information available in order to estimate thicknesses for the confining unit and for the confined aquifer for each location being examined, the level of confidence in the results obtained during this analysis is directly related to the level of confidence placed on the lithologic logs themselves. Confined aquifer thickness and especially confining unit thickness are important parameters needed to ultimately determine the vertical hydraulic conductivity of the confining unit. Re-definition of these parameters based on more accurate lithologic information and additional geophysical information could have a significant effect on the hydraulic conductivity values obtained during this study.

RECOMMENDATIONS FOR FUTURE AQUIFER TESTING

The analysis of previous aquifer tests has resulted not only in improved estimates of the transmissivity and storage coefficient of the confined aquifer, but also what are believed to be reasonable estimates of the vertical hydraulic conductivity of the overlying confining unit. Future aquifer testing in the Owens Valley could be improved by the recommendations presented herein:

- In many cases, the lithologic descriptions of the penetrated materials are generalized, and lack sufficient detail. Lithologic generalizations make it difficult to determine the exact nature of the confining unit and aquifer. During the construction of future wells, careful lithologic logging conducted by a qualified geologist, preferably under the supervision of a Registered Geologist in the State of California, is recommended. In addition, geophysical logging is also recommended.
- During constant-rate aquifer tests, the pumping rate should be kept constant at all times. Evaluation of the nine tests demonstrated that even small changes in pumping rate produce jumps in observed drawdown that are difficult to reconcile during analysis of the results. (See **Appendix H**, which presents the results for well W379 EM for an example.) Control of the pumping rate is facilitated by the use of a flow valve and instantaneous-read flow meter with totalizer.
- Automated dataloggers should be utilized whenever possible (at least in the pumping well) to detect rapidly increasing drawdown during the initial portion of the test. Data loggers are also valuable in detecting variations in pumping rate in the pumped well.
- The length of the constant-rate test must be sufficiently long to observe the late-time effects of leakage if reliable estimates of confining unit properties are to be generated. In general, data obtained after 1,000 minutes (after about 17 hours) was crucial in identifying the leakage factor with both the Hantush-Jacob Method and the Neuman-Witherspoon Method. Late-time data are not needed to create a good match with the Hantush Method; however, this method is significantly less valuable for determining confining layer properties, as this method yields only the product of confining unit vertical hydraulic conductivity and confining unit storativity. For this reason, aquifer test durations of at least 24 hours are recommended, and much longer-term duration tests may be advantageous, depending on the drawdown pattern observed during testing, and the distance to observation wells.
- Because all transient analysis methods used in this report are very sensitive to the radius of observation when the radius is low, and the methods assume a well of infinitesimal diameter, observation wells should be monitored in addition to monitoring drawdown in the pumping well. Ideally, the observation wells should be screened in the same aquifer as the pumping well, and multiple observation wells at various azimuths and distances would be ideal in order to evaluate the horizontal anisotropy and heterogeneity of the aquifer. In general, a more representative and regional evaluation can be made with multiple observation wells at varying distances.
- If feasible and practical, aquifer tests should also include monitoring of the shallow aquifer above the confining unit. All of the methods used in this report assume that there is negligible drawdown in this aquifer, and this appears to have been documented by previous testing (Harrington, 2001). Nevertheless, the shallow aquifer should be monitored during testing to confirm this assumption. In addition, the shallow aquifer is of significant concern from an ecological perspective.

- During aquifer testing, external influences, such as turning off or on of adjacent wells and major changes in surface flow, should be avoided.

REFERENCES

AQTESOLV for Windows, Version 3.01, by HydroSOLVE, Inc.

Hantush, M. S., 1960, Modification of the Theory of Leaky Aquifers, Journal of Geophysical Research, Vol. 65, No. 11, 3713-3725.

Hantush, M. S. and Jacob, C. E., 1955, Non-Steady Radial Flow in an Infinite Leaky Aquifer, Transactions, American Geophysical Union, Vol. 36, No. 1, 95-100.

Harrington, R., 2001, Operational tests of wells 375W, 380W, 381W, and 382W: results from previous tests and recommendations for future tests and management, 37 pages.

Hollett, K. J., W. R. Danskin, W. F. McCaffrey, and C. L. Walti, 1991, Geology and Water Resources of Owens Valley, California, USGS Water-Supply Paper 2370-B, 77 pages.

LADWP Pump Test Packets:

- "E/M Well W384 EM Aquifer Test – Independence-Oak Well Field" (February, 1993)
- "Report on the Deep Well Aquifer Test at the Big Pine East of the Owens River Site" (November, 1985)
- "USGS/LA/Inyo-Owens Valley Groundwater Investigation Deep Well Aquifer Test – Big Pine West of Owens River Site" (February, 1985)
- "Well W379 EM Aquifer Test – Big Pine Well Field" (October, 1992)
- "Well W383 EM Aquifer Test – Independence-Oak Well Field" (October, 1992)
- "Well W387 EM Test – Laws Field" (May, 1993)
- "Well W389 EM Test – Big Pine Field" (September, 1993)
- "Well W395 AQ Aquifer Test – Symmes/Shepherd Well Field" (September, 1992)
- "Well W398 AQ Aquifer Test – Laws Well Field" (October, 1991)

MWH, 2002, Technical Memorandum on the Identification of Methods and Tools for Characterization of the Confining Layer, 22 pages.

Neuman, S. P. and Witherspoon, P. A., 1969, Theory of Flow in a Confined Two Aquifer System, Water Resources Research, Vol. 5, No. 4, 803-816.

Walton, W.C., 1988, Practical Aspects of Ground Water Modeling – Flow, Mass, and Heat Transport, and Subsidence – Analytical and Computer Models. National Water Well Association, Worthington, Ohio.

Appendix A
Glossary of Variables and Terms

Appendix A
Glossary of Variables and Terms

VARIABLES

b'	Confining unit thickness
B	Leakage factor
β_H	Mathematical value calculated by the Hantush Method (This value is used to calculate the confining unit vertical hydraulic conductivity/storativity product with the Hantush Method.)
β_{NW}	Mathematical value calculated by the Neuman-Witherspoon Method (This value is not needed to calculate the confining unit vertical hydraulic conductivity with the Neuman-Witherspoon Method.)
K_r	Aquifer hydraulic conductivity for horizontal flow
K_z	Aquifer hydraulic conductivity for vertical flow
K_z'	Confining unit hydraulic conductivity for vertical flow
r	Distance from the pumped well to the observation well
S	Aquifer storativity
S'	Confined aquifer storativity (In Appendices D – L, however, S' denotes unconfined aquifer storativity for the Neuman-Witherspoon Method)
S^U	Unconfined aquifer storativity (In Appendices D – L, the unconfined aquifer storativity calculated by the Neuman-Witherspoon Method is denoted as S')
T	Aquifer transmissivity
T^U	Unconfined aquifer transmissivity (In Appendices D – L, the unconfined aquifer transmissivity calculated by the Neuman-Witherspoon Method is denoted as T')

DEFINITIONS

Hydraulic Conductivity (K) is the capacity of a porous medium to transmit water. It is measured as the volume of water moving through a unit area of aquifer perpendicular to the direction of flow in unit time under a unit hydraulic gradient.

Leakage Factor (B) is a measure for the spatial distribution of the leakage through a confining unit into a leaky aquifer and vice versa. It is defined by the following equation:

$$B = \sqrt{\frac{Tb'}{K_z'}}$$

Mean as defined as the sum of the differences between each actual y-value and its predicted y-value (from the best-fit line) divided by the total number of measurements.

$$\text{Mean} = \frac{\sum (y_{measured} - y_{estimated})}{N}$$

where: $y_{measured}$ = The measured y-value
$y_{estimated}$ = The predicted y-value (from the regression line)
N = The total number of measurements

Standard Error is defined as the square root of the variance. Standard error is represented by the following equation:

$$\text{Standard Error} = \sqrt{\frac{\sum (y_{measured} - y_{estimated})^2}{N}}$$

where: $y_{measured}$ = The measured y-value
$y_{estimated}$ = The predicted y-value (from the regression line)
N = The total number of measurements

Storativity (S) is the volume of water that a permeable unit releases or takes into storage per unit surface area of the aquifer per unit change in head.

Transmissivity (T) is the capacity of an aquifer to transmit water of the prevailing kinematic viscosity. It is measured as the rate of flow under a unit hydraulic gradient through a cross-section of aquifer having a unit width and full saturated thickness.

Variance is a measure of the dispersion or scatter of a set of values from their predicted values. Variance can be represented by the following equation:

$$\text{Variance} = \frac{\sum (y_{measured} - y_{estimated})^2}{N}$$

where: $y_{measured}$ = The measured y-value
$y_{estimated}$ = The predicted y-value (from the regression line)
N = The total number of measurements

Appendix B
Schematic Representations of the Nine Pumping Tests Selected for Aquifer Test Analysis

Figure B-1
Schematic Representation of Well W387 EM (Laws)

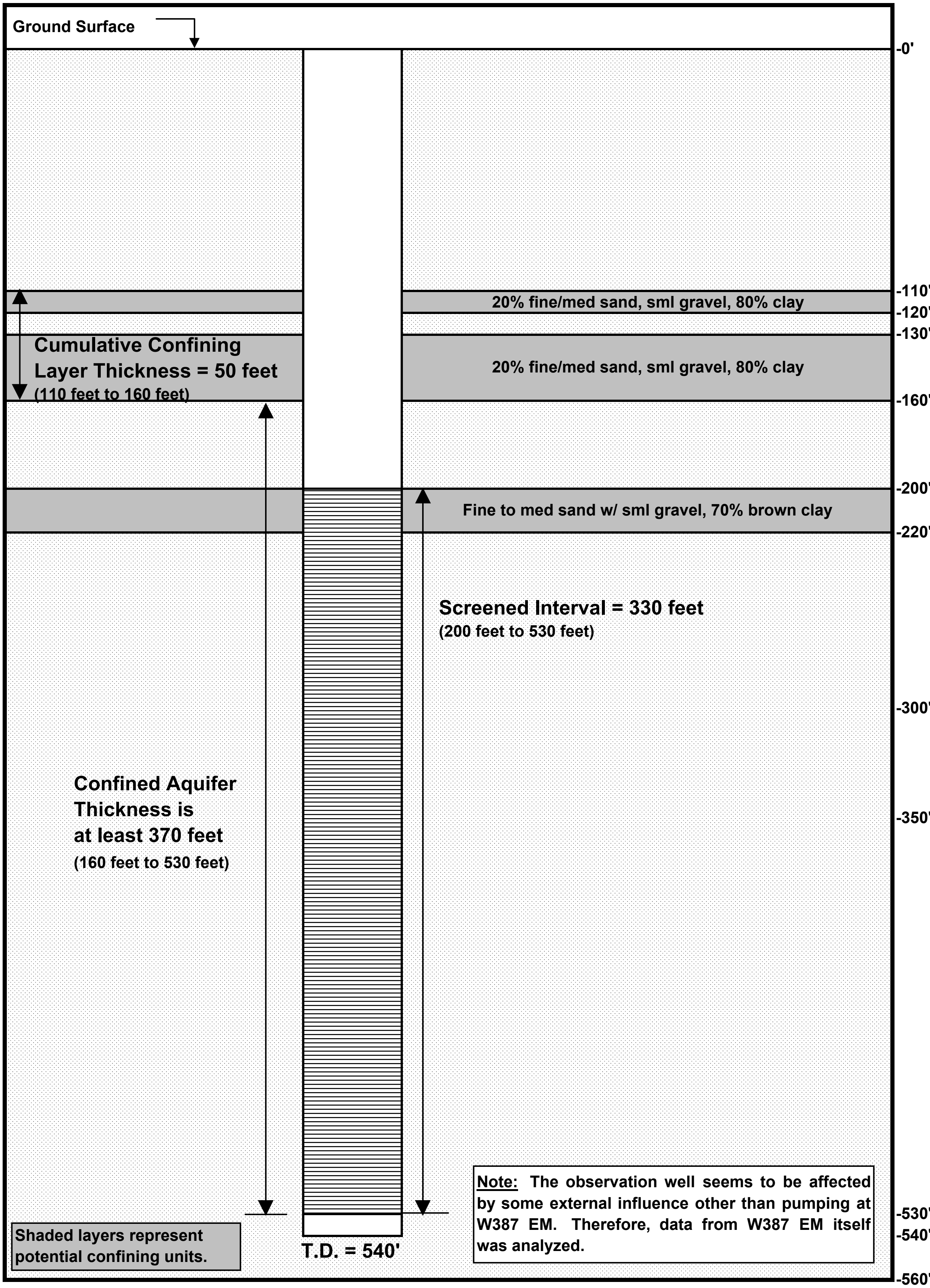


Figure B-2
Schematic Representation of Well W398 AQ (Laws)

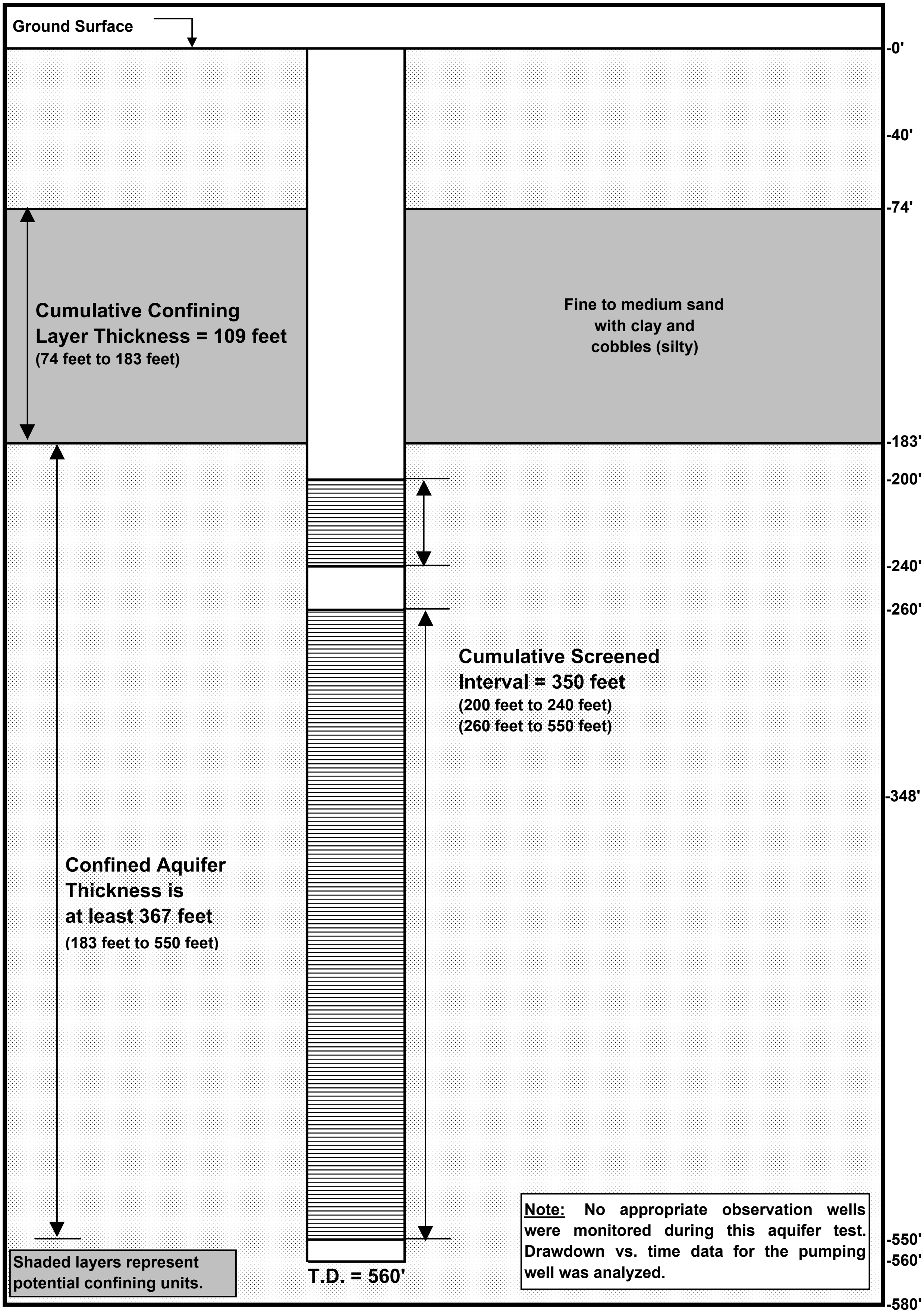


Figure B-3
Schematic Representation of Well V014GA (Big Pine)

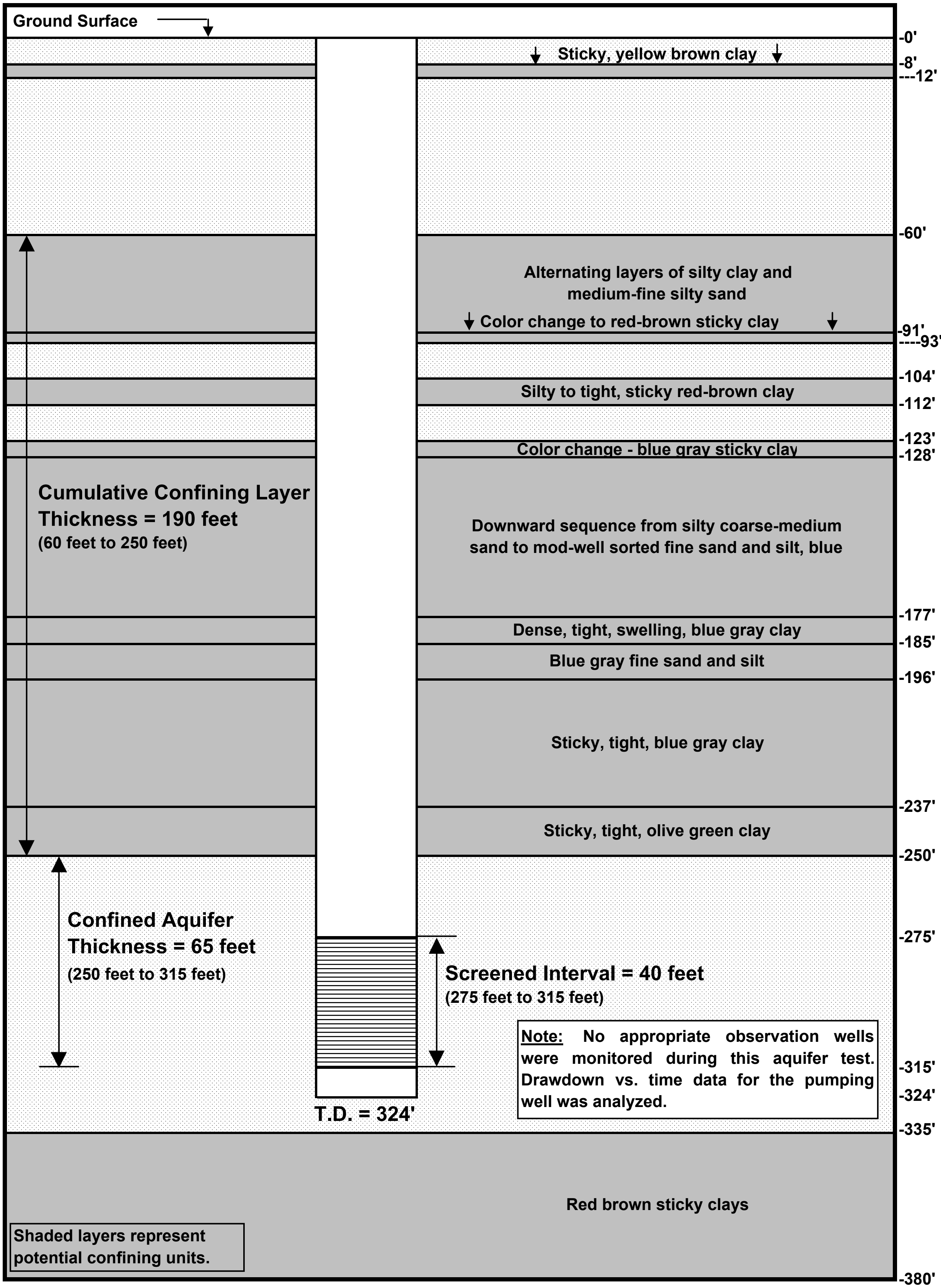


Figure B-4
Schematic Representation of Well V016GA (Big Pine)

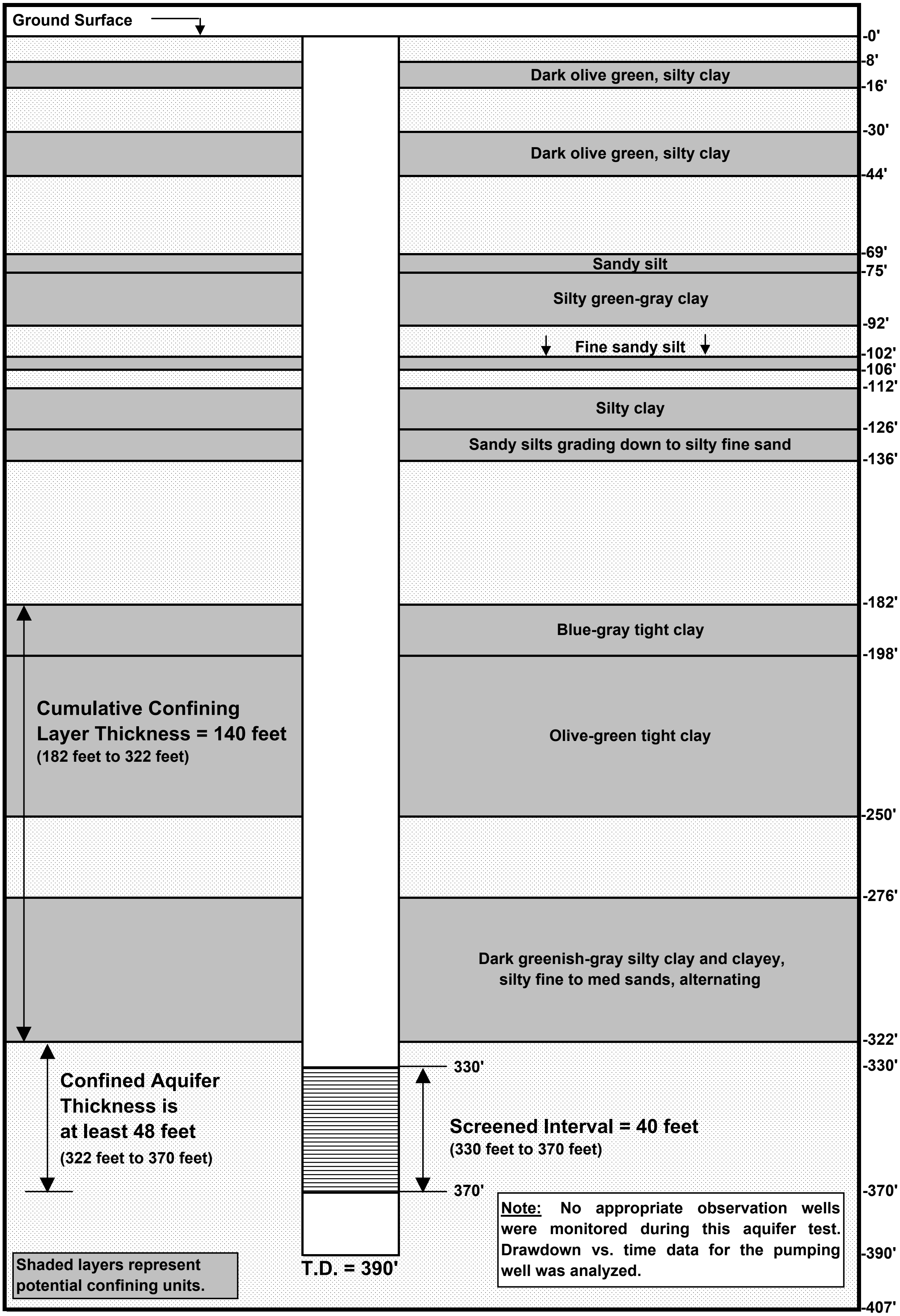


Figure B-5
Schematic Representation of Well W379 EM (Big Pine)

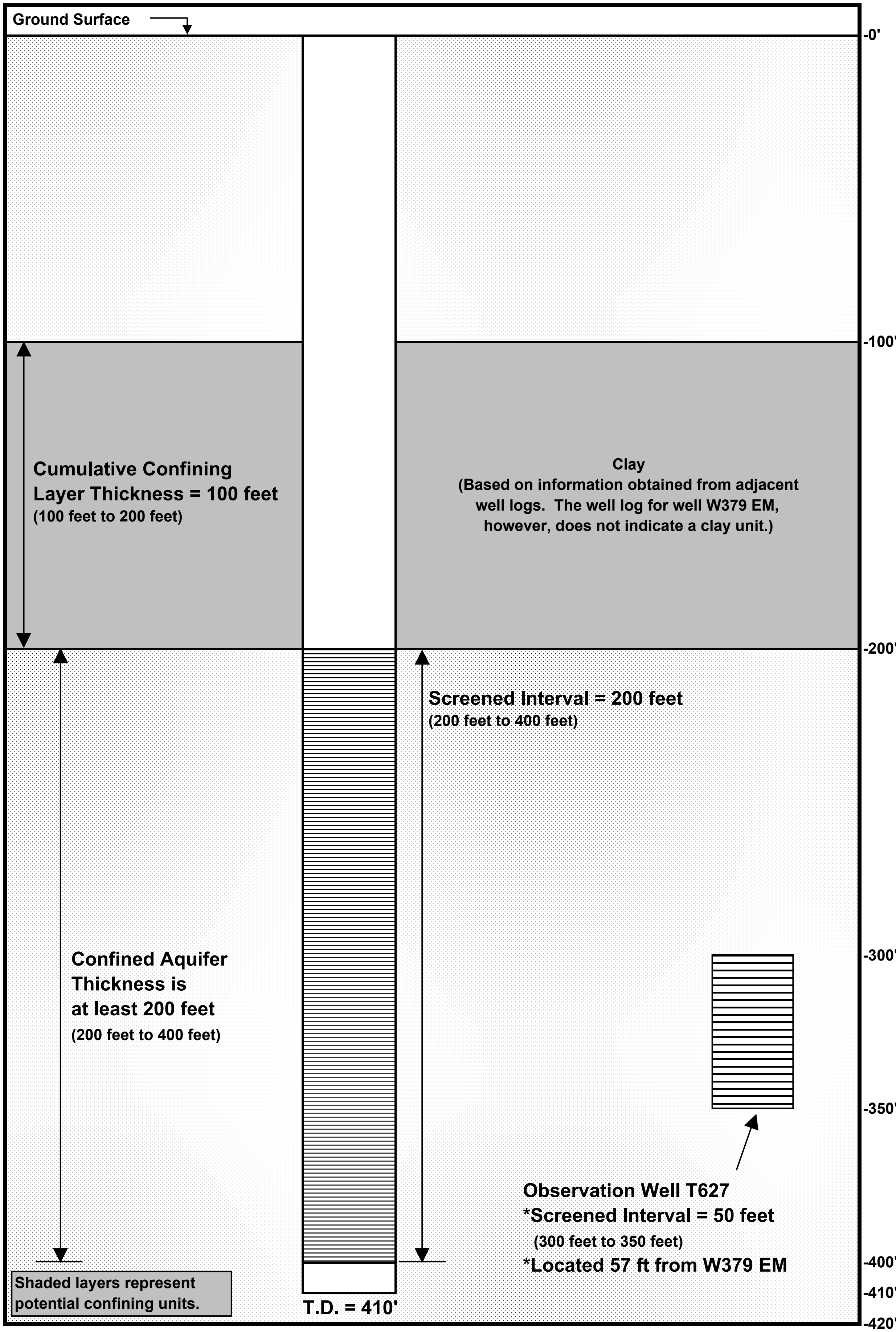


Figure B-6
Schematic Representation of Well W389 EM (Big Pine)

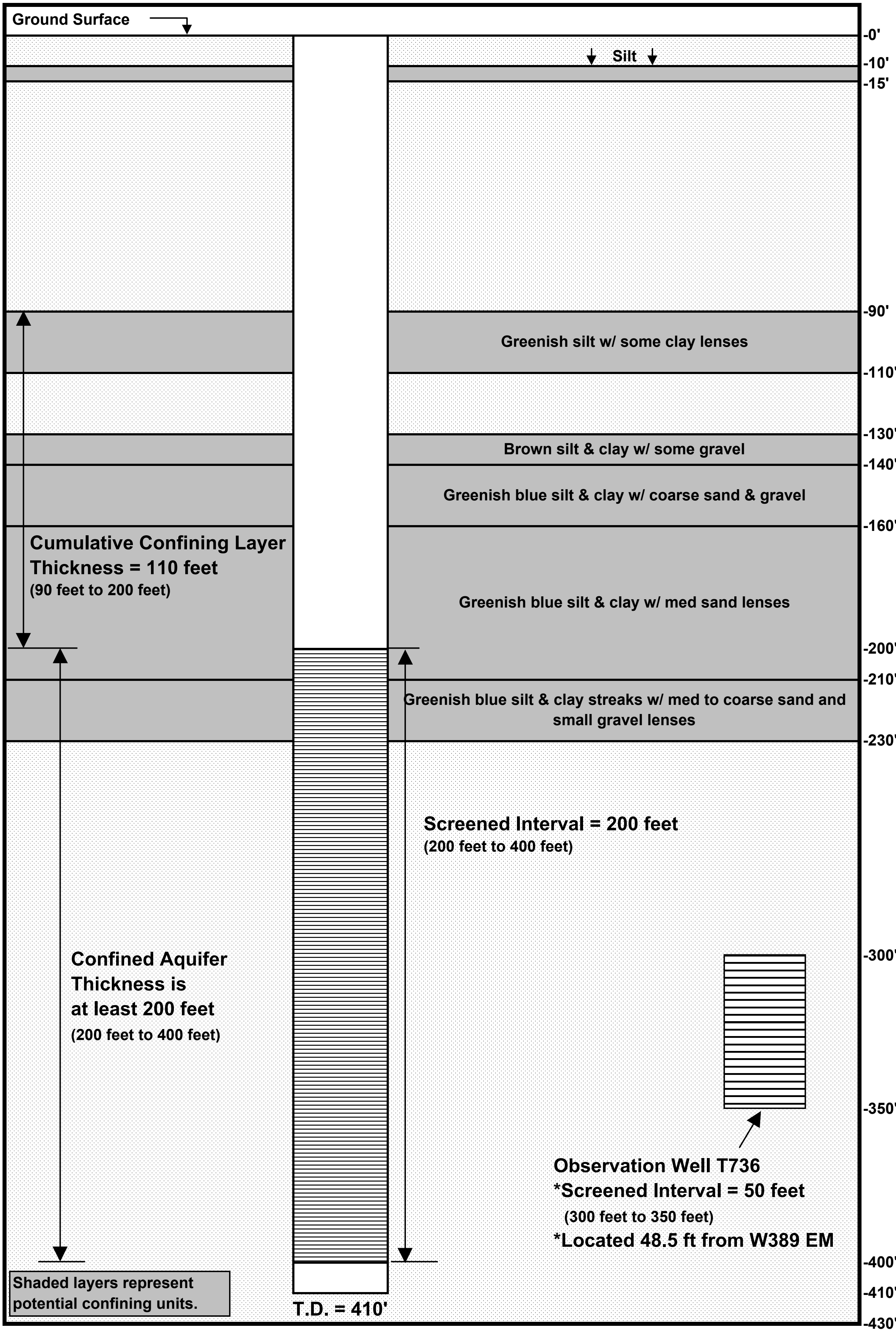


Figure B-7
Schematic Representation of Well W383 EM (Independence-Oak)

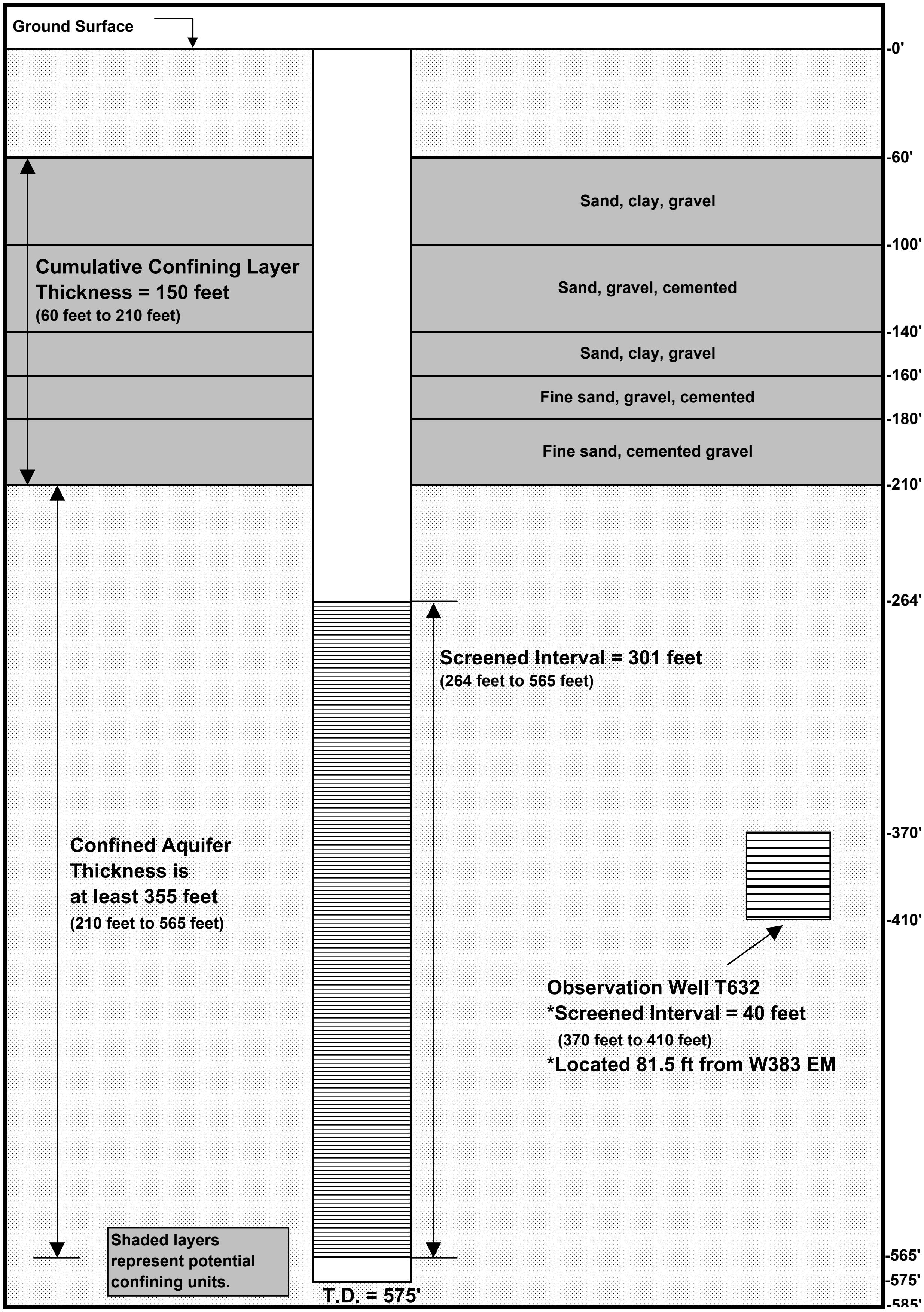


Figure B-8
Schematic Representation of Well W384 EM (Independence-Oak)

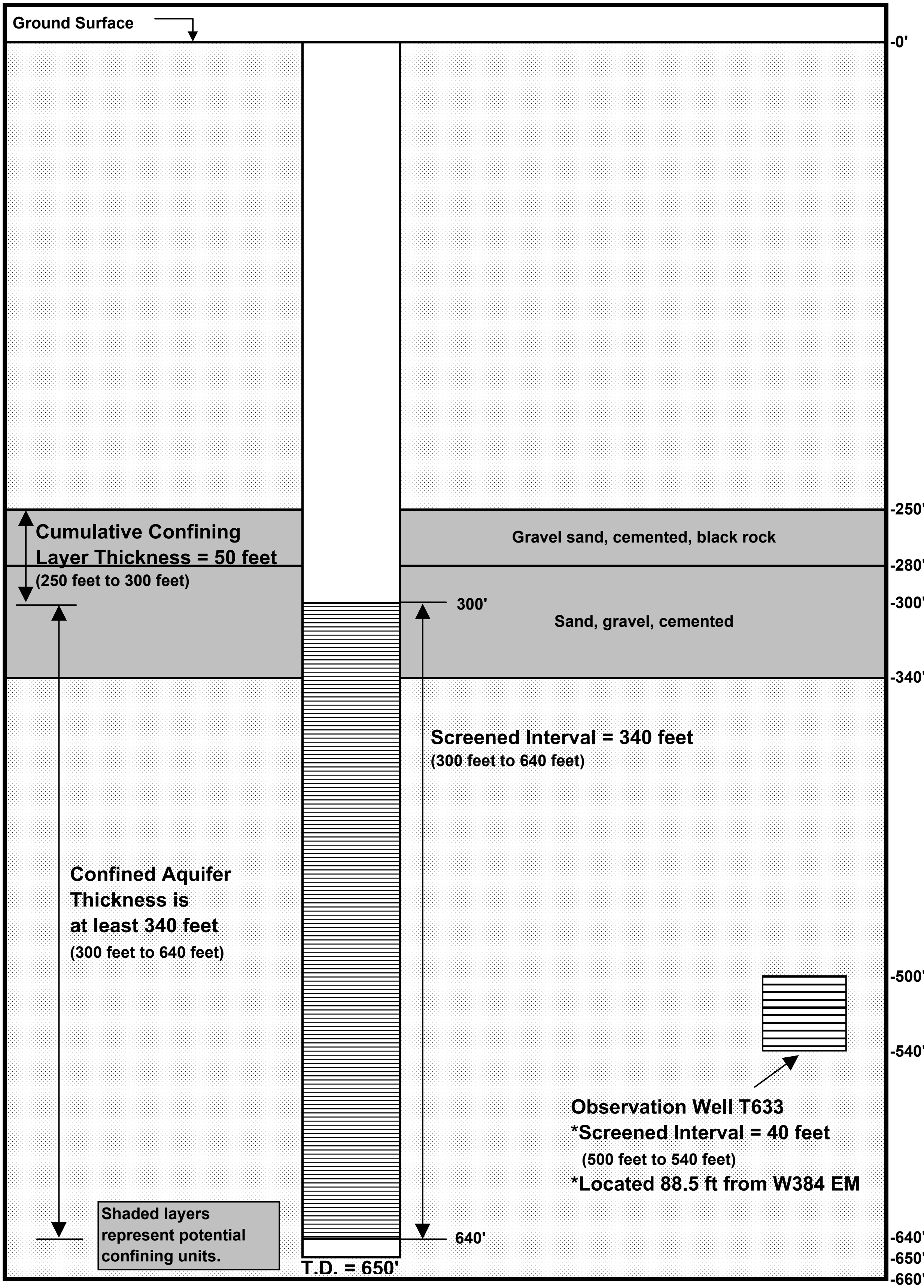
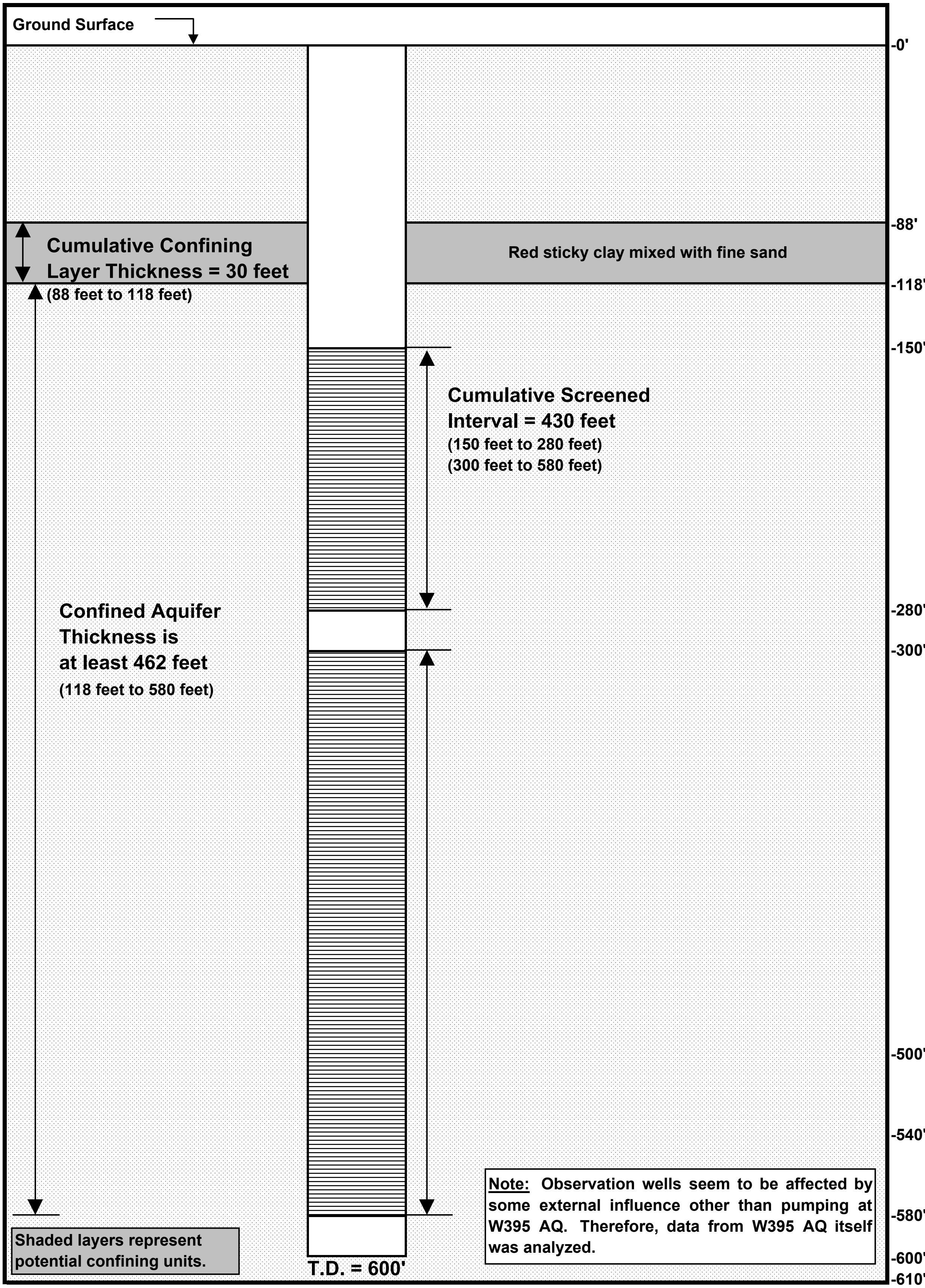


Figure B-9
Schematic Representation of Well W395 AQ (Symmes-Shepherd)



Appendix C
Drawdown vs. Time Data from the Nine Data Sets Selected for Aquifer Test Analysis

Table C-1
Drawdown vs. Time Data for the Aquifer Test Conducted at Well W387 EM (Laws)

Pumping Well Data	
Well W387	
Time (min)	Drawdown (ft)
8	77.83
14	**80.53**
16	**82.36**
31	**86.13**
35	**86.96**
40	**87.74**
45	**88.37**
50	**89.24**
60	**90.04**
70	**91.97**
82	**92.74**
90	**93.04**
100	**93.55**
110	**93.78**
120	**94.22**
140	**95.79**
160	**96.37**
180	**96.73**
200	**98.66**
220	**99.18**
240	**99.44**
290	**100.05**
330	**99.97**
360	**99.88**
390	**102.09**
420	**102.02**
480	**101.92**
540	**101.99**
600	**101.89**
660	**102.79**
720	**102.39**
780	**102.39**
840	**103.39**
900	**103.39**
960	**103.39**
1020	**103.39**
1080	**102.89**
1140	**102.89**
1200	**103.89**
1260	**103.39**
1290	**103.69**
1310	**103.99**
1319	**103.69**

***Only bolded measurements were analyzed**

Table C-2
Drawdown vs. Time Data for the Aquifer Test Conducted at Well W398 AQ (Laws)

Pumping Well Data	
Well W398	
Time (min)	Drawdown (ft)
1	48.36
2	48.36
3	48.93
4	50.09
5	50.67
6	51.24
7	52.40
8	52.40
9	53.55
10	**53.55**
12	**54.13**
14	**54.71**
16	**54.71**
18	**55.86**
20	**56.44**
22	**56.44**
24	**57.02**
26	**57.02**
28	**57.02**
30	**57.02**
35	**58.17**
40	**58.17**
45	**58.17**
50	**58.75**
55	**59.33**
60	**59.33**
70	**60.48**
80	**60.48**
90	**60.48**
100	**60.48**
130	**61.64**
160	**61.64**
220	**62.80**
280	**64.13**
340	**64.70**
400	**65.28**
500	**66.44**
600	**67.59**
800	**68.57**
1000	**68.57**
1140	**68.57**

***Only bolded measurements were analyzed**

Table C-3
Drawdown vs. Time Data for the Aquifer Test Conducted at Well V014GA (Big Pine)

Pumping Well Data			
Well V014GA		Well V014GA (continued)	
Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)
1	2.87	**455**	**9.81**
2	3.00	**1430**	**10.25**
3	3.56	**1900**	**10.21**
4	3.44	**2950**	**10.41**
5	3.50	**3330**	**10.35**
6	3.58	**4318**	**10.55**
7	3.62		
8	3.67		
9	3.73		
10	3.76		
12	**3.81**		
14	**3.85**		
16	**3.90**		
18	**3.93**		
20	**3.98**		
25	**4.04**		
30	**4.14**		
35	**4.14**		
40	**4.19**		
45	**4.22**		
50	**4.24**		
55	**4.27**		
60	**4.30**		
70	**4.32**		
80	**4.37**		
90	**4.41**		
100	**4.44**		
110	**4.47**		
120	**4.48**		
135	**4.50**		
150	**4.52**		
165	**4.54**		
180	**4.56**		
195	**4.57**		
210	**4.58**		
225	**4.59**		
240	**4.60**		
241	8.02		
242	8.28		
243	8.39		
244	8.51		
245	8.59		
246	8.66		
247	8.69		
248	8.74		
249	8.79		
250	**8.83**		
255	**8.95**		
260	**9.06**		
265	**9.13**		
270	**9.20**		
275	**9.26**		

***Only bolded measurements were analyzed.**

Table C-4
Drawdown vs. Time Data for the Aquifer Test Conducted at Well V016GA (Big Pine)

Pumping Well Data			
Well V016GA		Well V016GA (cont.)	
Time (min)	Drawdown(ft)	Time (min)	Drawdown(ft)
16	**16.69**	1110	40.31
25	**17.17**	1115	40.53
30	**17.11**	1120	40.80
35	**17.36**	1125	41.00
40	**17.42**	1130	41.07
45	**17.50**	1135	41.20
50	**17.56**	1140	41.32
55	**17.60**	1150	41.07
60	**17.64**	1160	41.22
70	**17.74**	1170	41.38
80	**17.80**	1180	41.54
90	**17.86**	1190	41.75
100	**17.93**	1200	41.82
110	**17.97**	1215	42.11
120	**18.00**	1230	42.24
135	**18.04**	1245	42.43
150	**18.08**	1260	42.55
151	3.21	2637	43.41
152	2.40	5585	45.04
153	2.26	7035	45.16
154	1.78	8425	46.66
155	1.66	9900	45.53
156	1.54	12780	46.32
157	1.42	14220	46.11
158	1.36	15660	46.63
159	1.33		
160	1.27		
165	1.10		
170	0.87		
175	0.82		
180	0.74		
185	0.64		
190	0.58		
195	0.52		
200	0.47		
205	0.43		
210	0.40		
220	0.35		
230	0.27		
240	0.22		
1075	0.02		
1080	0.00		
1087	38.17		
1088	38.37		
1089	38.55		
1090	38.70		
1092	38.98		
1094	39.23		
1096	39.43		
1098	39.59		
1100	39.37		
1105	40.07		

***Only bolded measurements were analyzed.**

Table C-5
Drawdown vs. Time Data for the Aquifer Test Conducted at Well W379 EM (Big Pine)

Observation Well Data		Pumping Well Data (not analyzed)	
Well T627		Well W379	
Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)
1	7.40	1	24.90
2	8.62	2	27.30
3	10.68	3	29.60
4	11.83	4.3	31.70
5	12.65	5	32.50
6	13.32	6.5	32.90
7	13.64	7	33.20
8	14.17	8	33.95
9	14.59	9.5	34.18
10	**15.02**	10.5	35.00
15	**16.51**	12	35.60
20	**17.41**	14	36.16
25	**18.10**	16	36.71
30	**18.69**	18	37.15
40	**19.82**	20.5	36.90
50	**20.89**	22	37.12
60	**21.33**	24	37.49
70	**21.94**	26	37.78
80	**22.39**	28	38.10
90	**22.78**	30	38.20
105	**23.41**	35	38.90
120	**23.77**	40	39.40
135	**24.18**	45	39.95
150	**24.61**	50	40.24
165	**24.90**	56	40.70
180	**25.31**	60	40.60
210	**26.67**	70	41.45
240	**27.26**	84	42.05
270	**27.69**	90	42.20
300	**28.05**	92	42.37
330	**28.37**	100	42.60
360	**28.66**	110	42.87
390	**29.04**	120	42.95
420	**29.24**	130	43.28
		142	43.53
		150	43.74
		160	44.02
		170	44.27
		181	44.33
		193	46.42
		200	46.46
		211	46.95
		220	47.05
		240	47.38
		250	47.60
		260	47.60
		271	47.85
		285	48.00
		300	48.14
		315	48.18
		330	48.27
		360	48.62
		380	48.86
		420	49.00

***Only bolded measurements were analyzed.**

Table C-6
Drawdown vs. Time Data for the Aquifer Test Conducted at Well W389 EM (Big Pine)

Observation Well Data		Pumping Well Data (not analyzed)			
Well T736		Well W389		Well W389 (cont.)	
Time (min)	Drawdown (ft)	Time (min)	Drawdown(ft)	Time (min)	Drawdown(ft)
1	6.07	1	29.60	720	59.70
2	9.23	2	36.30	780	60.10
3	11.04	3	38.80	840	60.50
4	12.37	4	40.30	900	60.50
5	13.42	5	41.50	960	60.70
6	14.22	6	42.20	1020	60.70
7	14.62	7	42.10	1080	60.80
8	15.09	8	42.70	1140	61.50
9	15.50	9	43.10	1200	61.70
10	**15.75**	10	43.30	1260	61.90
12	**16.37**	12	43.90		
14	**16.97**	14	44.40		
16	**17.48**	16	44.90		
18	**17.94**	18	45.40		
20	**18.37**	20	45.80		
25	**19.25**	25	46.60		
30	**19.97**	30	47.40		
43	**21.40**	35	48.00		
45	**21.56**	40.5	48.50		
50	**21.93**	45	48.80		
55	**22.31**	50	49.10		
60	**22.63**	55	49.50		
66	**22.97**	60	49.70		
70	**23.23**	65	50.00		
75	**22.80**	70	50.30		
80	**23.76**	75	50.70		
85	**24.04**	80	51.00		
90	**24.20**	85	51.30		
97	**24.45**	90	51.30		
100	**24.54**	95	51.40		
105	**24.72**	100	51.50		
110	**24.86**	110	51.70		
115	**25.04**	120	52.10		
120	**25.20**	135	52.60		
135	**25.66**	150	52.70		
150	**25.97**	165	52.80		
165	**26.24**	180	53.00		
180	**26.47**	195	53.30		
195	**26.79**	210	53.60		
210	**27.07**	240	56.20		
225	**28.01**	255	56.30		
240	**28.40**	270	56.60		
255	**28.62**	289	56.60		
270	**28.85**	300	56.80		
285	**29.99**	315	56.90		
300	**29.18**	330	57.10		
330	**29.52**	345	57.40		
360	**29.85**	360	57.30		
390	**30.13**	390	57.60		
420	**30.42**	420	57.90		
1203	**34.09**	480	58.40		
1215	**34.10**	540	58.70		
1230	**34.16**	600	58.80		
1245	**34.26**	660	59.30		

***Only bolded measurements were analyzed**

Table C-7
Drawdown vs. Time Data for the Aquifer Test Conducted at Well W383 EM (Independence-Oak)

Observation Well Data		Pumping Well Data (not analyzed)			
Well T632		Well W383		Well W383 (continued)	
Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)
1	3.69	3	96.41	690	143.26
2	7.21	4	97.61	720	143.91
3	9.44	6	125.16	750	144.21
4	11.04	7	126.66	780	144.48
5	12.28	8	127.51	810	144.54
6	13.29	9	128.41	840	144.18
7	14.19	10	129.31	870	144.76
8	14.91	12	130.96	900	144.41
9	15.58	14	132.46	930	143.75
10	**16.17**	16	132.71	960	143.84
12	**17.15**	18	133.11	990	144.19
14	**17.95**	20	133.71	1020	144.34
16	**18.66**	22	134.11	1050	144.48
18	**19.24**	24	134.61	1080	144.56
20	**19.73**	26	134.96	1110	144.43
22	**20.16**	28	135.09	1140	145.26
24	**20.53**	30	135.46	1170	145.43
26	**20.94**	35	135.56	1200	145.54
28	**21.29**	40	136.21	1230	145.43
30	**21.59**	45	136.51	1260	146.09
35	**22.24**	50	136.76	1290	145.13
40	**22.78**	55	136.66		
45	**23.26**	60	136.71		
50	**23.63**	65	136.85		
55	**23.94**	70	137.31		
60	**24.21**	75	137.26		
65	**24.50**	80	137.42		
70	**24.75**	85	137.39		
75	**25.00**	90	137.55		
80	**25.18**	100	138.31		
85	**25.36**	110	138.88		
90	**25.53**	120	138.84		
100	**25.78**	130	139.46		
110	**26.13**	140	139.39		
120	**26.31**	150	139.66		
130	**26.54**	160	139.94		
140	**26.71**	170	139.71		
150	**26.92**	180	139.66		
161	**27.06**	200	139.56		
170	**27.18**	220	138.91		
180	**27.28**	240	138.62		
200	**27.42**	260	142.62		
220	**27.50**	280	142.51		
240	**27.57**	300	142.35		
260	**28.15**	330	141.97		
280	**28.29**	360	141.89		
300	**28.41**	390	141.66		
330	**28.50**	420	141.59		
360	**28.58**	450	140.99		
390	**28.61**	480	143.53		
420	**28.63**	510	143.01		
450	**28.65**	540	142.60		
480	**29.07**	570	142.83		
1275	**29.99**	600	143.32		
1290	**29.94**	630	143.47		
1320	**29.89**	660	142.56		

***Only bolded measurements were analyzed.**

Table C-8
Drawdown vs. Time Data for the Aquifer Test Conducted at Well W384 EM (Independence-Oak)

Observation Well Data				Pumping Well Data (not analyzed)			
Well T633		Well T633 (continued)		Well W384		Well W384 (continued)	
Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)
1	1.92	**450**	**20.55**	5	68.33	630	78.30
2	4.49	**465**	**20.54**	6	69.88	660	78.22
3	6.24	**480**	**20.56**	7	71.13	690	78.07
4	7.48	**1290**	**22.33**	8	71.33	720	78.20
5	8.43	**1305**	**22.30**	9	72.03	750	84.40
6	9.18	**1320**	**22.31**	10	72.63	780	84.64
7	9.80			12	73.53	810	81.68
8	10.34			14	74.18	840	81.31
9	10.79			16	74.73	870	81.24
10	**11.16**			18	75.23	900	81.21
12	**11.82**			20	75.53	930	81.32
14	**12.37**			25	75.98	960	83.95
16	**12.84**			30	76.53	990	85.14
18	**13.23**			35	76.63	1020	85.60
20	**13.56**			40	77.03	1050	85.12
22	**13.87**			45	77.18	1080	83.13
24	**14.14**			50	77.34	1110	83.32
26	**14.41**			55	77.58	1140	83.40
28	**14.63**			60	77.83	1170	83.34
30	**14.82**			65	77.83	1200	83.27
35	**15.24**			70	78.10	1230	83.15
40	**15.63**			75	78.08	1260	83.10
45	**15.94**			85	78.13	1290	83.30
50	**16.23**			90	78.18	1320	83.36
55	**16.53**			100	78.33		
60	**16.73**			110	78.38		
65	**16.92**			120	78.53		
70	**17.15**			130	78.66		
75	**17.33**			140	79.48		
80	**17.46**			150	79.33		
85	**17.62**			160	79.83		
90	**17.73**			170	80.10		
100	**17.97**			180	79.58		
110	**18.21**			190	79.78		
120	**18.43**			200	79.75		
130	**18.63**			210	79.40		
140	**18.85**			225	79.53		
150	**19.03**			240	79.13		
160	**19.21**			260	79.58		
170	**19.39**			280	80.13		
180	**19.47**			300	79.73		
190	**19.59**			330	79.63		
200	**19.67**			360	79.08		
210	**19.70**			390	74.88		
225	**19.82**			405	74.18		
240	**19.89**			420	80.13		
260	**20.06**			435	79.47		
280	**20.21**			450	79.02		
300	**20.28**			465	78.88		
320	**20.32**			480	78.73		
340	**20.35**			510	78.68		
360	**20.31**			540	78.48		
420	**20.54**			570	78.63		
435	**20.57**			600	78.53		

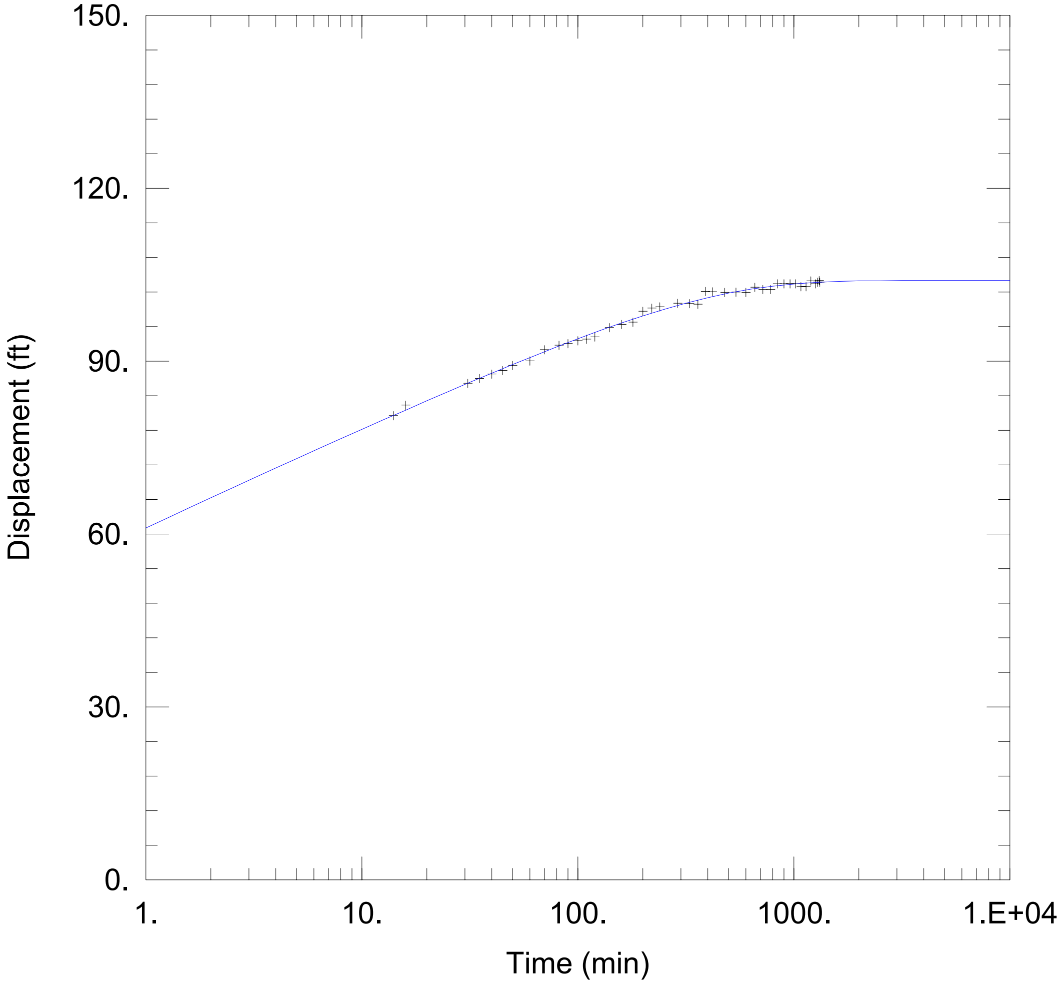
***Only bolded measurements were analyzed.**

Table C-9
Drawdown vs. Time Data for the Aquifer Test Conducted at Well W395 AQ (Symmes-Shepherd)

Pumping Well Data			
Well W395		Well W395 (cont.)	
Time (min)	Drawdown (ft)	Time (min)	Drawdown (ft)
2	16.64	**1200**	**25.85**
3	17.05	**1260**	**25.77**
4	17.55	**1380**	**25.75**
5	17.97	**1560**	**25.75**
6	18.35	**1740**	**25.65**
7	18.59	**1800**	**25.91**
8	18.75	**1980**	**26.01**
9	18.98	**2160**	**26.38**
10	**19.29**	**2400**	**26.46**
12	**19.53**	**2640**	**26.59**
14	**19.78**	**2880**	**26.75**
16	**19.98**	**3000**	**26.67**
18	**20.22**	**3360**	**26.85**
20	**20.46**	**3720**	**26.94**
25	**20.78**	**4080**	**27.07**
30	**20.81**	**4320**	**26.95**
40	**21.43**	**4440**	**26.95**
45	**21.50**	**4800**	**26.97**
50	**21.80**	**5160**	**27.02**
55	**21.94**	**5520**	**27.00**
60	**22.06**	**5755**	**27.04**
70	**22.07**		
80	**22.36**		
90	**22.64**		
100	**22.76**		
110	**22.75**		
120	**22.87**		
130	**22.90**		
140	**22.99**		
150	**23.12**		
160	**23.27**		
170	**23.26**		
180	**23.40**		
195	**23.45**		
210	**23.48**		
240	**23.64**		
270	**24.15**		
300	**24.25**		
360	**24.50**		
420	**24.73**		
480	**25.06**		
540	**25.06**		
600	**25.15**		
660	**25.27**		
720	**25.35**		
780	**25.46**		
840	**25.50**		
900	**25.54**		
960	**25.76**		
1020	**25.78**		
1080	**25.58**		
1140	**25.75**		

***Only bolded measurements were analyzed**

Appendix D
AQTESOLV Output for
Well W387 EM (Laws)



WELL TEST ANALYSIS

Data Set: \...\387 EM_HJ.aqt
Date: 12/04/02 Time: 14:58:37

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W387 EM
Test Date: April 1987

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W387 EM	0	0

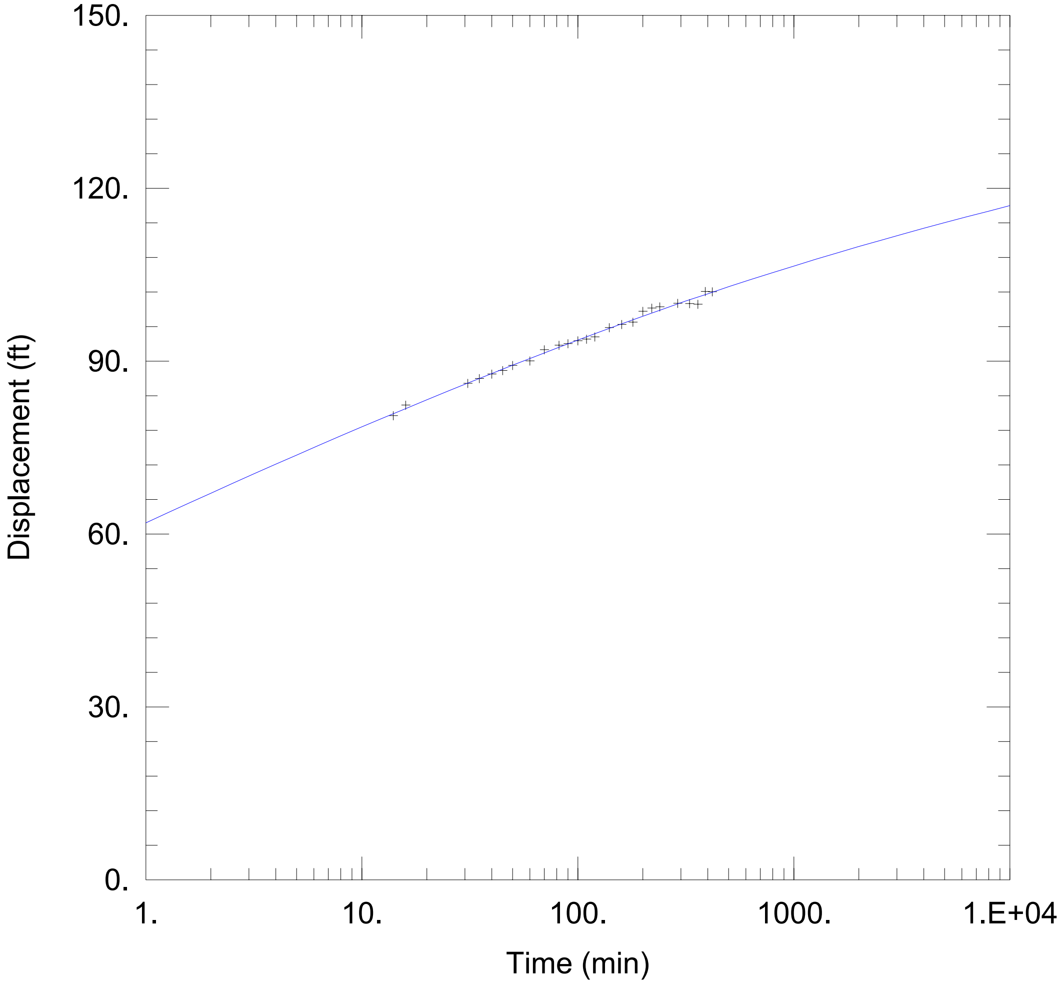
Observation Wells

Well Name	X (ft)	Y (ft)
+ W387 EM	1.17	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob

T = 5.298 ft^2/min
S = 0.004245
r/B = 0.001337
Kz/Kr = 1.
b = 370. ft



WELL TEST ANALYSIS

Data Set: \...\387 EM_H.aqt
Date: 12/04/02 Time: 14:58:50

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W387 EM
Test Date: April 1987

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W387 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
+ W387 EM	1.17	0

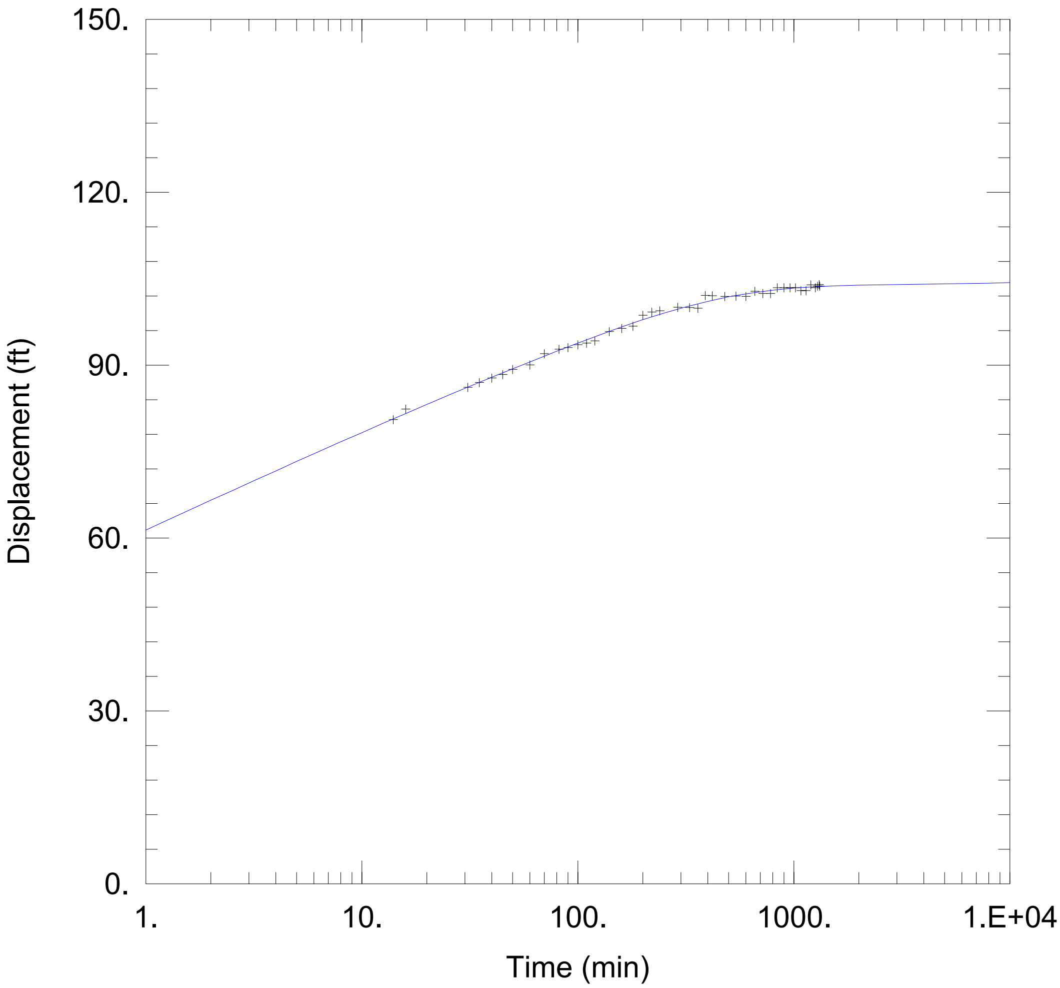
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush

T = 5.273 ft^2/min
ß = 0.0002972
b = 370. ft

S = 0.003745
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\387 EM_NW.aqt
Date: 12/04/02 Time: 14:58:58

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W387 EM
Test Date: April 1987

AQUIFER DATA

Saturated Thickness: 370. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W387 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
+ W387 EM	1.17	0

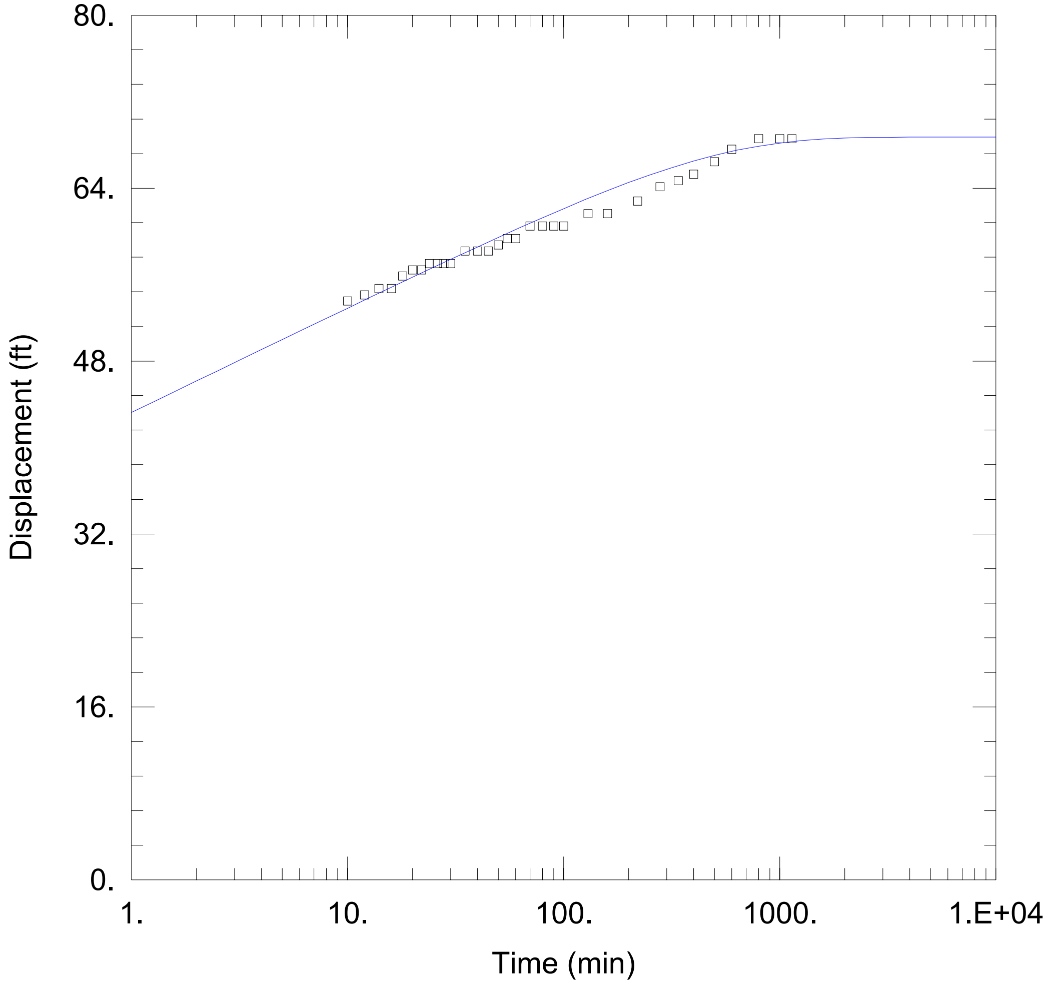
SOLUTION

Aquifer Model: Leaky Solution Method: Neuman-Witherspoon

T = 4.976 ft^2/min
r/B = 0.001344
T' = 1.243E-05 ft^2/min

S = 0.002734
ß = 0.0003301
S' = 1.

Appendix E
AQTESOLV Output for
Well W398 AQ (Laws)



WELL TEST ANALYSIS

Data Set: \...\398 AQ_HJ.aqt
Date: 11/14/02 Time: 18:06:59

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W398 AQ
Test Date: April 1991

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W398 AQ	0	0

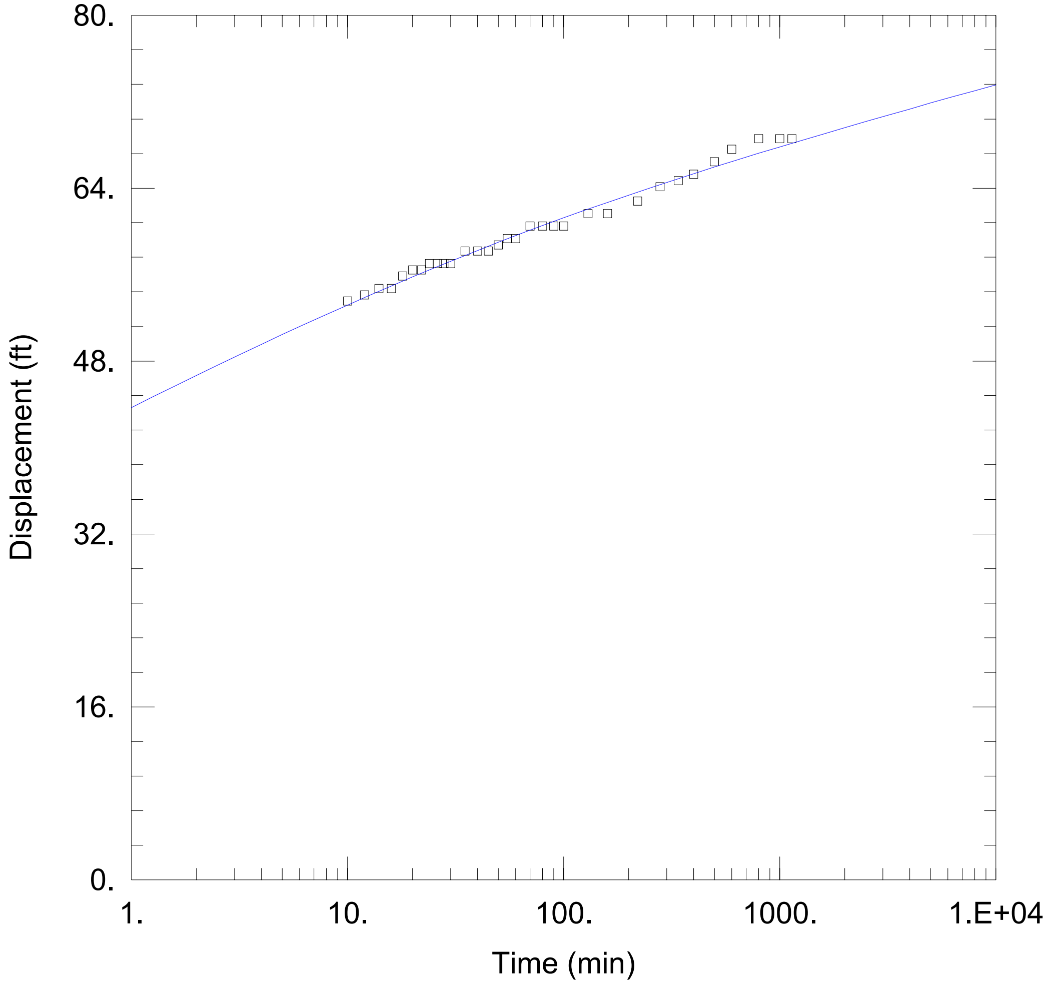
Observation Wells

Well Name	X (ft)	Y (ft)
□ W398 AQ	1.17	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob

T = 7.575 ft^2/min
S = 0.0005757
r/B = 0.0003715
Kz/Kr = 1.
b = 367. ft



WELL TEST ANALYSIS

Data Set: \...\398 AQ_H.aqt
Date: 11/14/02 Time: 18:09:05

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W398 AQ
Test Date: April 1991

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W398 AQ	0	0

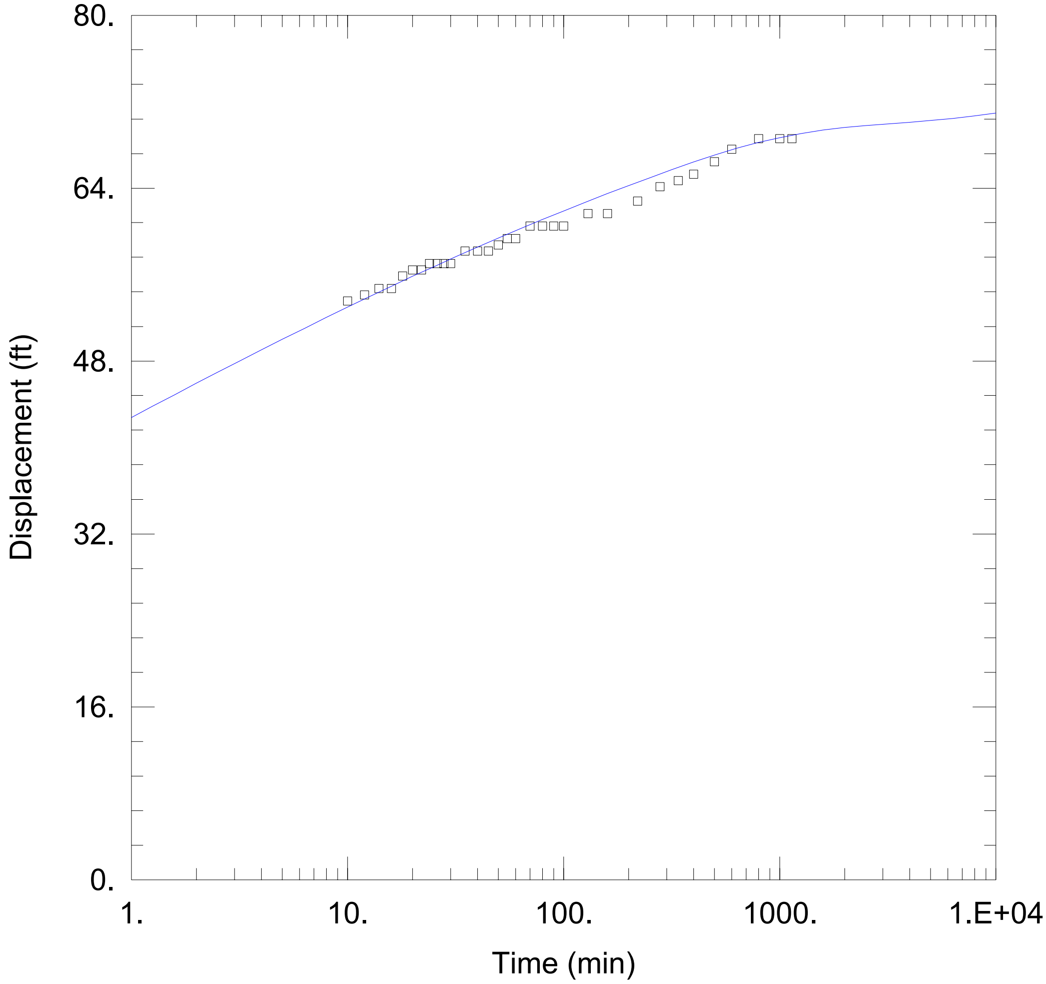
Observation Wells

Well Name	X (ft)	Y (ft)
□ W398 AQ	1.17	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 6.908 ft^2/min
S = 0.001019
ß = 0.0004571
Kz/Kr = 1.
b = 367. ft



WELL TEST ANALYSIS

Data Set: \...\398 AQ_NW.aqt
Date: 11/14/02

Time: 18:14:56

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W398 AQ
Test Date: April 1991

AQUIFER DATA

Saturated Thickness: 367. ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W398 AQ	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ W398 AQ	1.17	0

SOLUTION

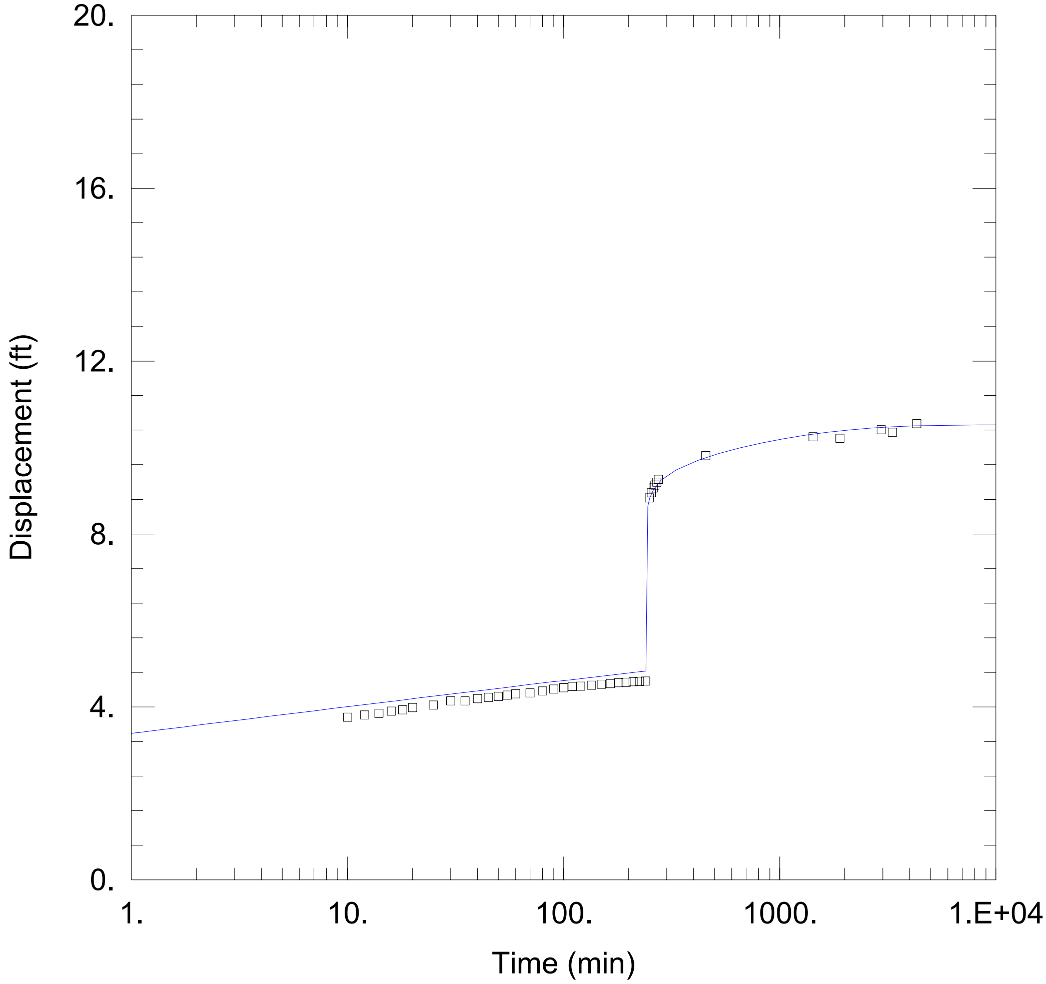
Aquifer Model: Leaky

Solution Method: Neuman-Witherspoon

T = 6.597 ft^2/min
r/B = 0.0008318
T' = 0.1 ft^2/min

S = 0.001411
ß = 0.0003981
S' = 0.1

Appendix F
AQTESOLV Output for
Well V014GA (Big Pine)



WELL TEST ANALYSIS

Data Set: \...\V014GA_HJ.aqt
Date: 11/14/02 Time: 11:01:13

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: V014GA
Test Date: September 1984

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
V014GA	0	0

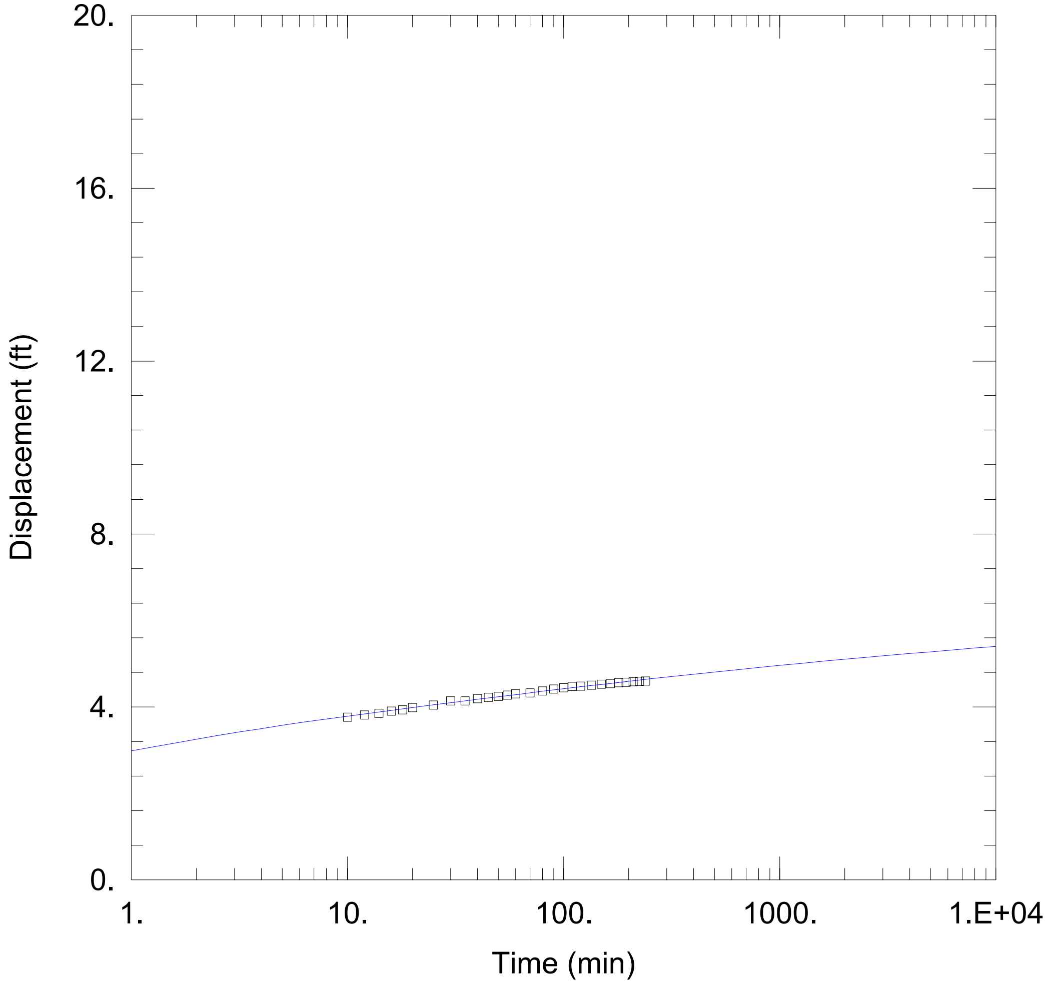
Observation Wells

Well Name	X (ft)	Y (ft)
□ V014GA	0.667	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob

T = 3.767 ft^2/min
S = 0.003406
r/B = 0.0004555
Kz/Kr = 1.
b = 65. ft



WELL TEST ANALYSIS

Data Set: \...\V014GA_H.aqt
Date: 11/14/02 Time: 15:11:01

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: V014GA
Test Date: September 1984

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
V014GA	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ V014GA	0.667	0

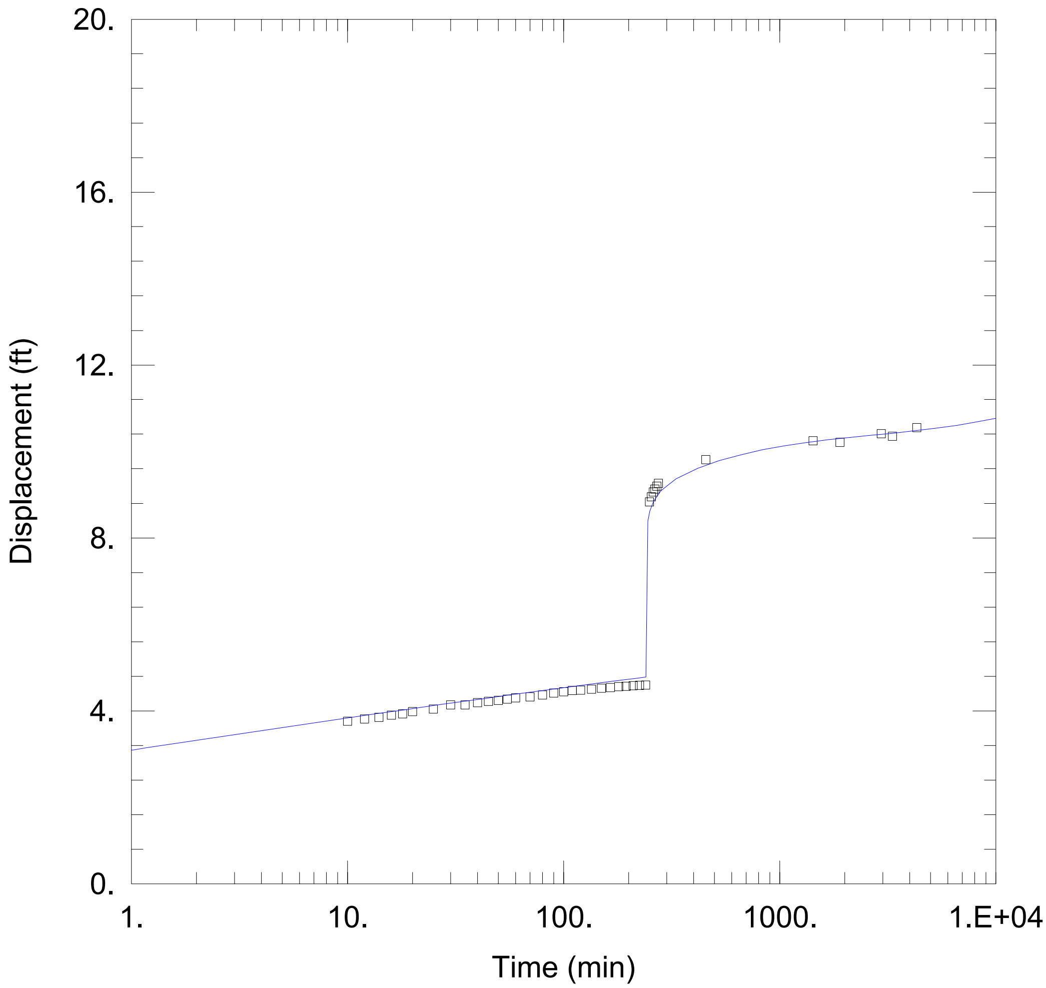
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush

T = 3.36 ft^2/min
ß = 0.0005159
b = 65. ft

S = 0.02747
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\V014GA_NW.aqt
Date: 11/14/02 Time: 13:16:50

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: V014GA
Test Date: September 1984

AQUIFER DATA

Saturated Thickness: 65. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
V014GA	0	0

Observation Wells

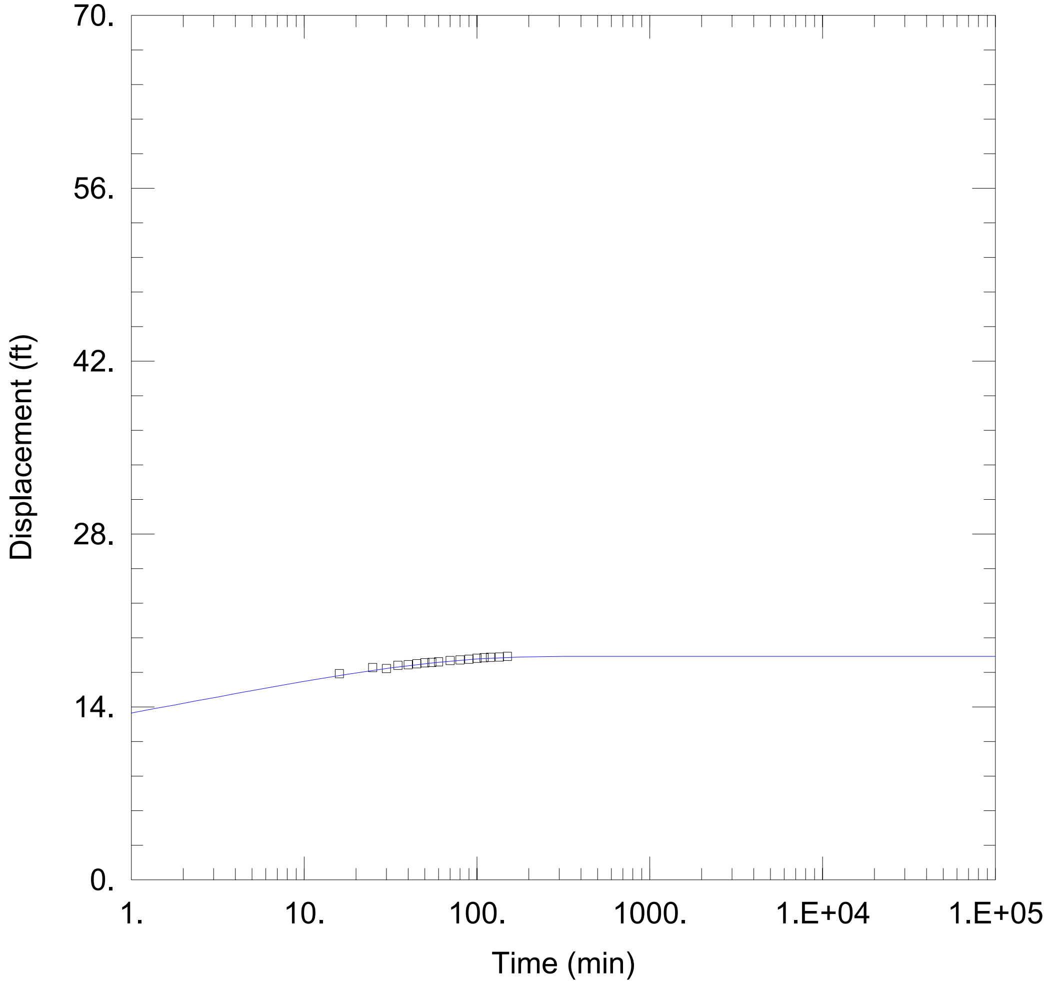
Well Name	X (ft)	Y (ft)
□ V014GA	0.667	0

SOLUTION

Aquifer Model: Leaky Solution Method: Neuman-Witherspoon

T = 3.03 ft^2/min
r/B = 0.0004962
T' = 0.0001049 ft^2/min
S = 0.001406
ß = 0.0001114
S' = 0.01583

Appendix G
AQTESOLV Output for
Well V016GA (Big Pine)



WELL TEST ANALYSIS

Data Set: \...\V016GA_HJ.aqt
Date: 11/14/02 Time: 18:25:27

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: V016GA
Test Date: June 1985

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
V016GA	0	0

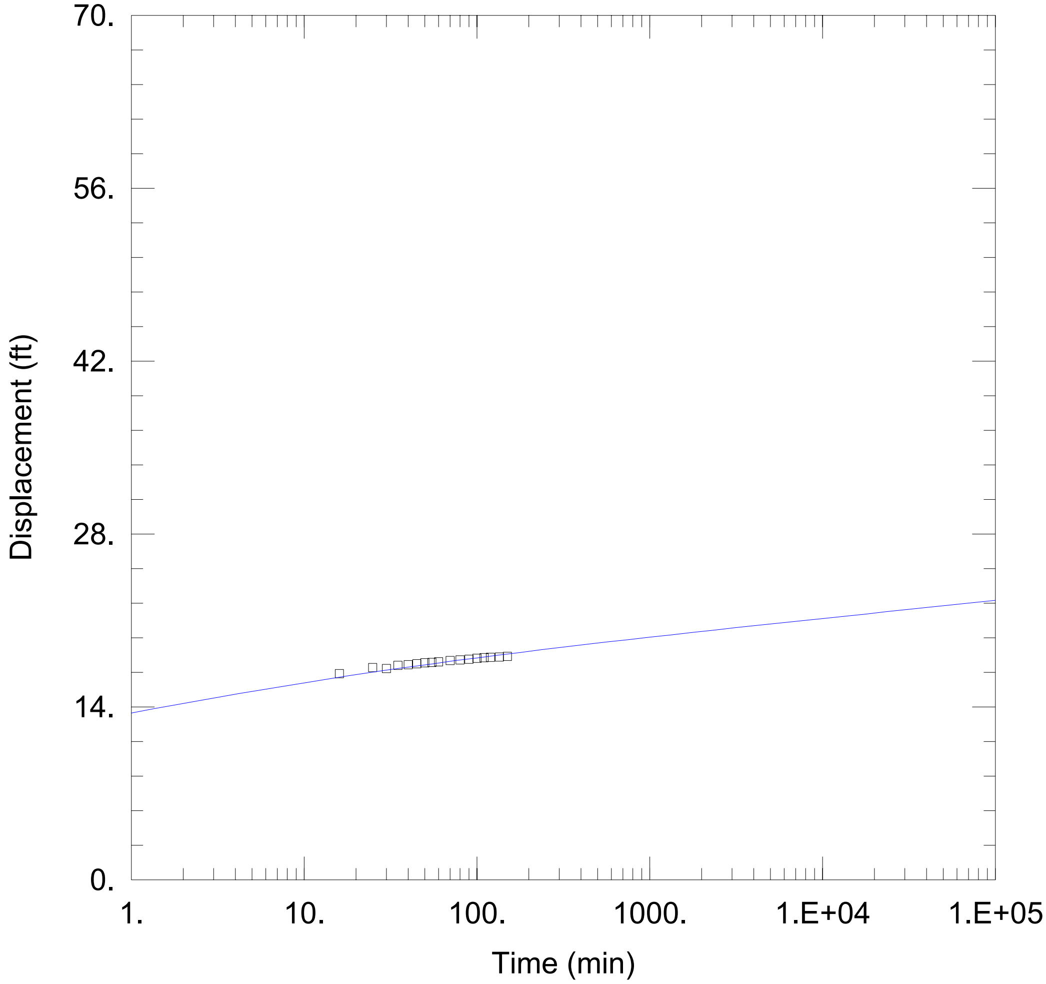
Observation Wells

Well Name	X (ft)	Y (ft)
□ V016GA	0.625	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush-Jacob

T = 2.383 ft^2/min
S = 0.0003162
r/B = 0.0007413
Kz/Kr = 1.
b = 48. ft



WELL TEST ANALYSIS

Data Set: \...\V016GA_H.aqt
Date: 11/14/02
Time: 18:42:15

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: V016GA
Test Date: June 1985

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
V016GA	0	0

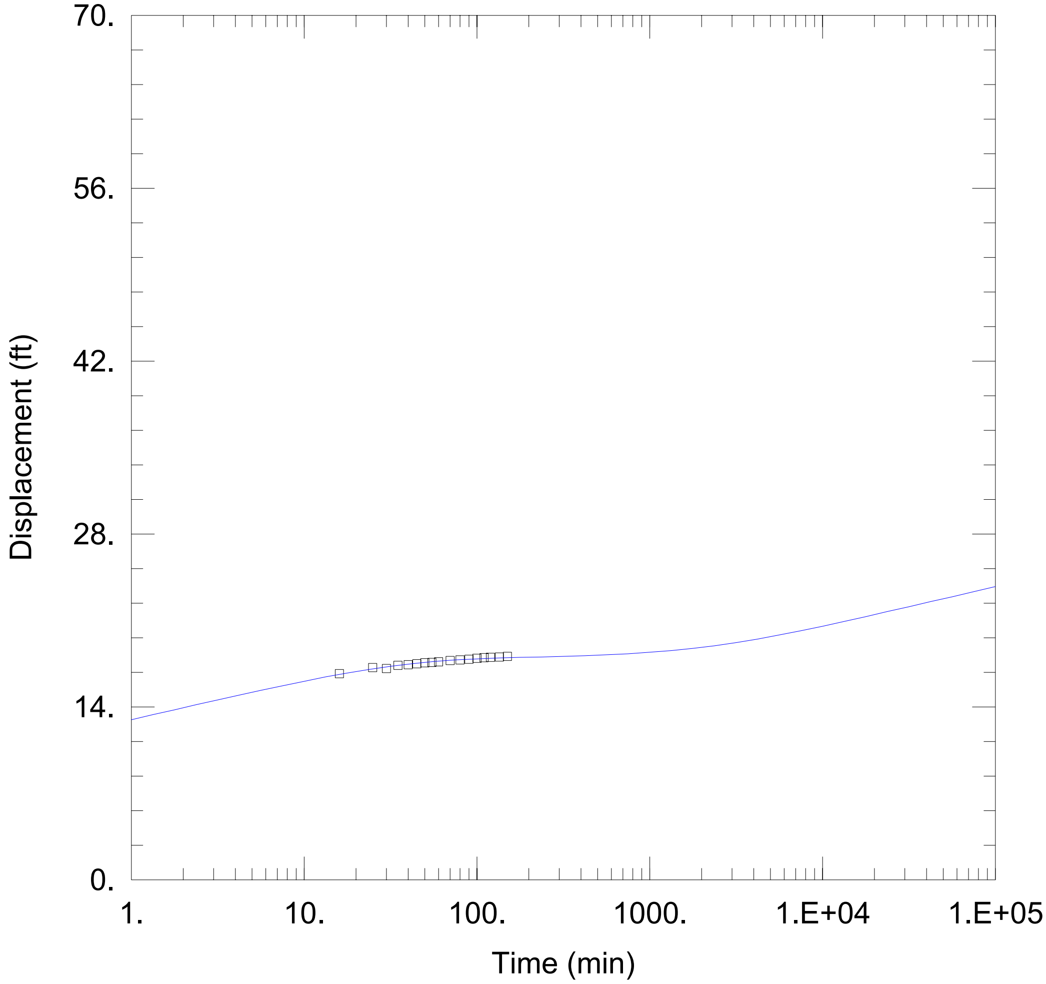
Observation Wells

Well Name	X (ft)	Y (ft)
□ V016GA	0.625	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 2.21 ft^2/min
S = 0.0005653
ß = 0.0004798
Kz/Kr = 1.
b = 48. ft



WELL TEST ANALYSIS

Data Set: \...\V016GA_NW.aqt
Date: 11/14/02 Time: 18:46:39

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: V016GA
Test Date: June 1985

AQUIFER DATA

Saturated Thickness: 48. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
V016GA	0	0

Observation Wells

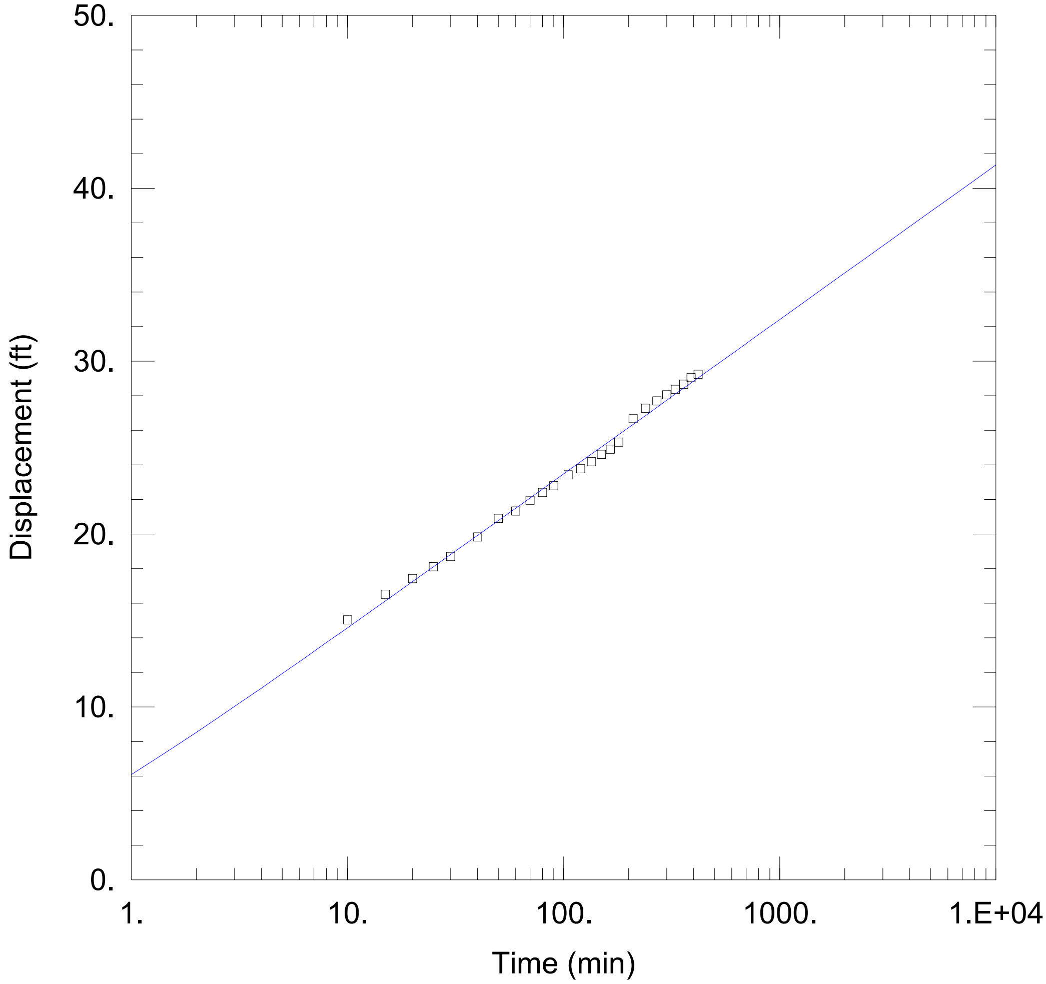
Well Name	X (ft)	Y (ft)
□ V016GA	0.625	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Neuman-Witherspoon

T = 1.852 ft^2/min
S = 0.001585
r/B = 0.002692
ß = 0.0004184
T' = 0.1 ft^2/min
S' = 0.08913

Appendix H
AQTESOLV Output for
Well W379 EM (Big Pine)



WELL TEST ANALYSIS

Data Set: \...\379 EM_HJ.aqt
Date: 11/14/02 Time: 15:37:56

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W379 EM
Test Date: August 1986

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W379 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ T627	57	0

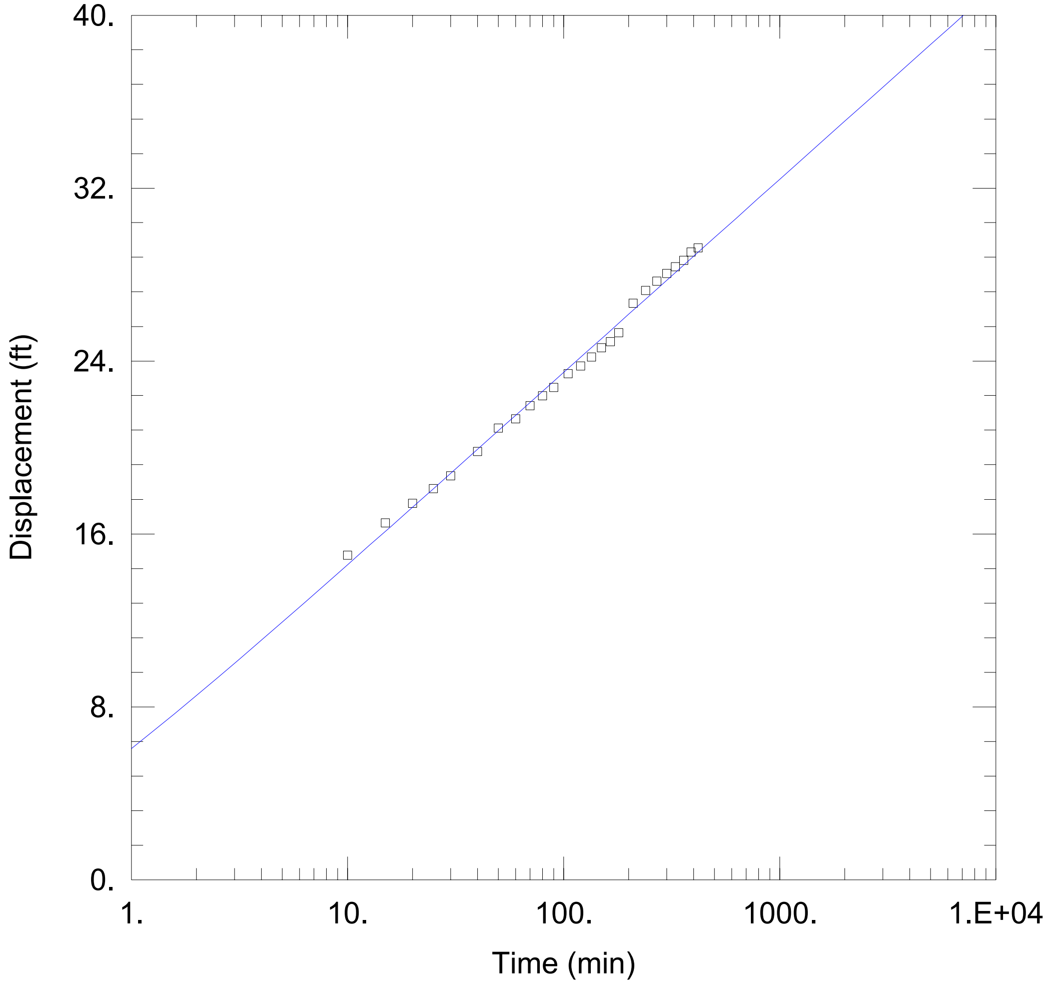
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush-Jacob

T = 8.385 ft^2/min
r/B = 1.E-05
b = 200. ft

S = 0.001378
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\379 EM_H.aqt
Date: 11/14/02 Time: 15:44:57

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W379 EM
Test Date: August 1986

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W379 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ T627	57	0

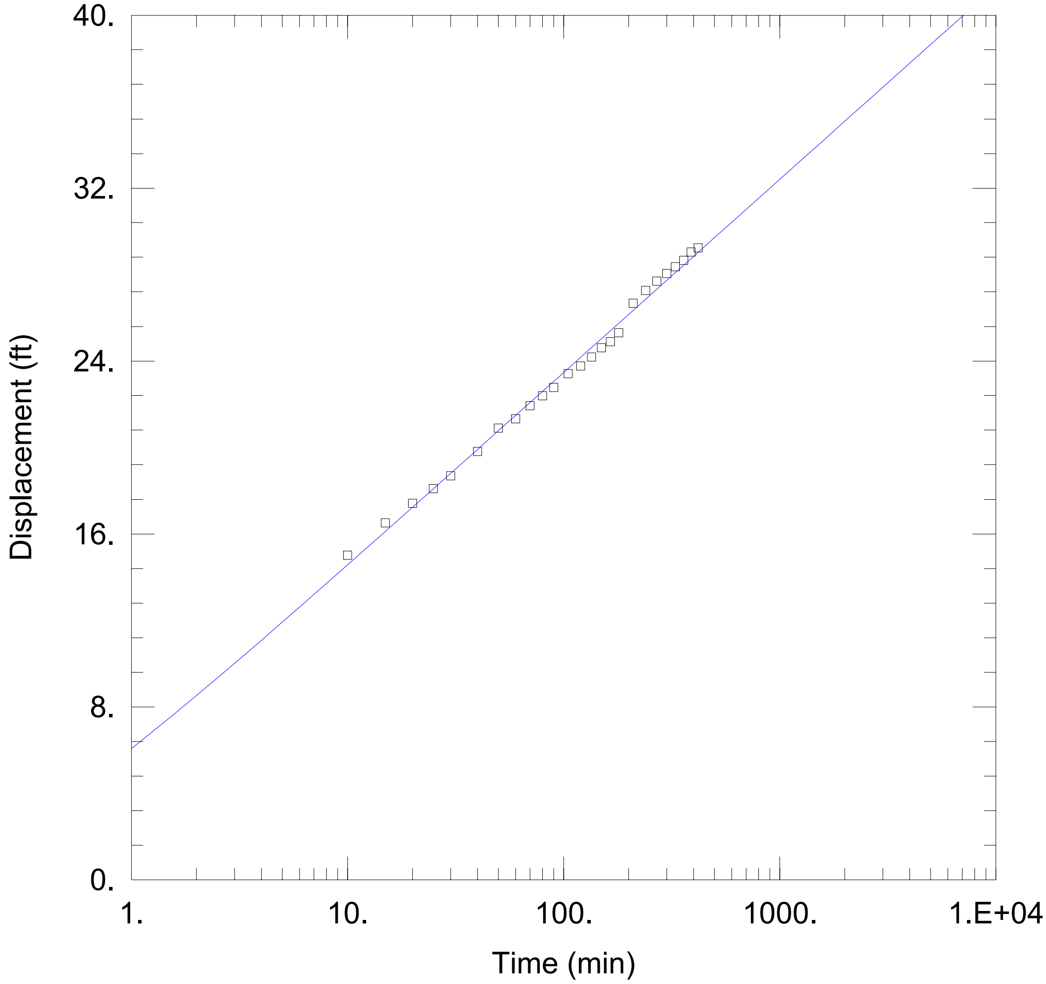
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush

T = 8.378 ft^2/min
ß = 1.E-05
b = 200. ft

S = 0.001381
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\379 EM_NW.aqt
Date: 11/14/02 Time: 15:55:56

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W379 EM
Test Date: August 1986

AQUIFER DATA

Saturated Thickness: 200. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W379 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ T627	57	0

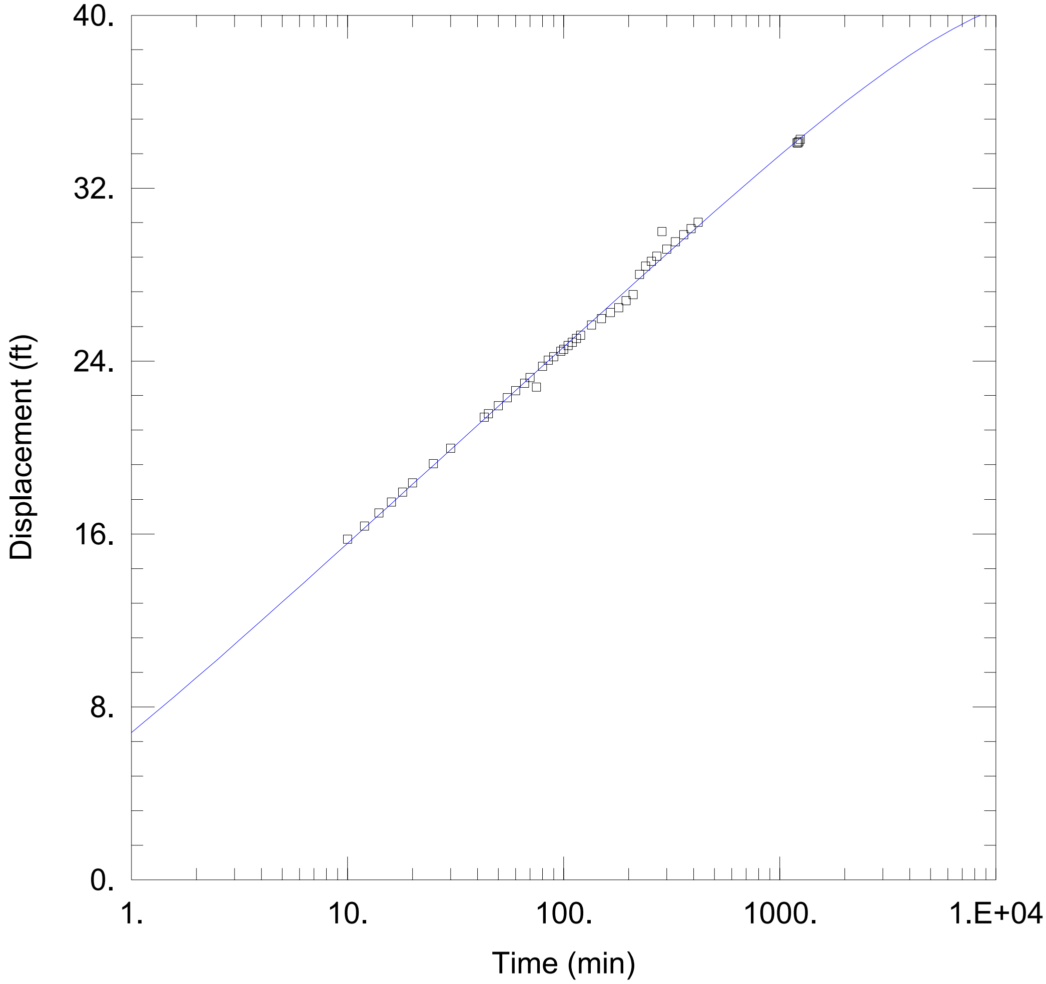
SOLUTION

Aquifer Model: Leaky Solution Method: Neuman-Witherspoon

T = 8.377 ft^2/min
r/B = 1.E-05
T' = 6430.2 ft^2/min

S = 0.001382
ß = 1.E-05
S' = 1.

Appendix I
AQTESOLV Output for
Well W389 EM (Big Pine)



WELL TEST ANALYSIS

Data Set: \...\389 EM_HJ.aqt
Date: 11/13/02   Time: 19:17:36

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W389 EM
Test Date: April 1987

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W389 EM	0	0

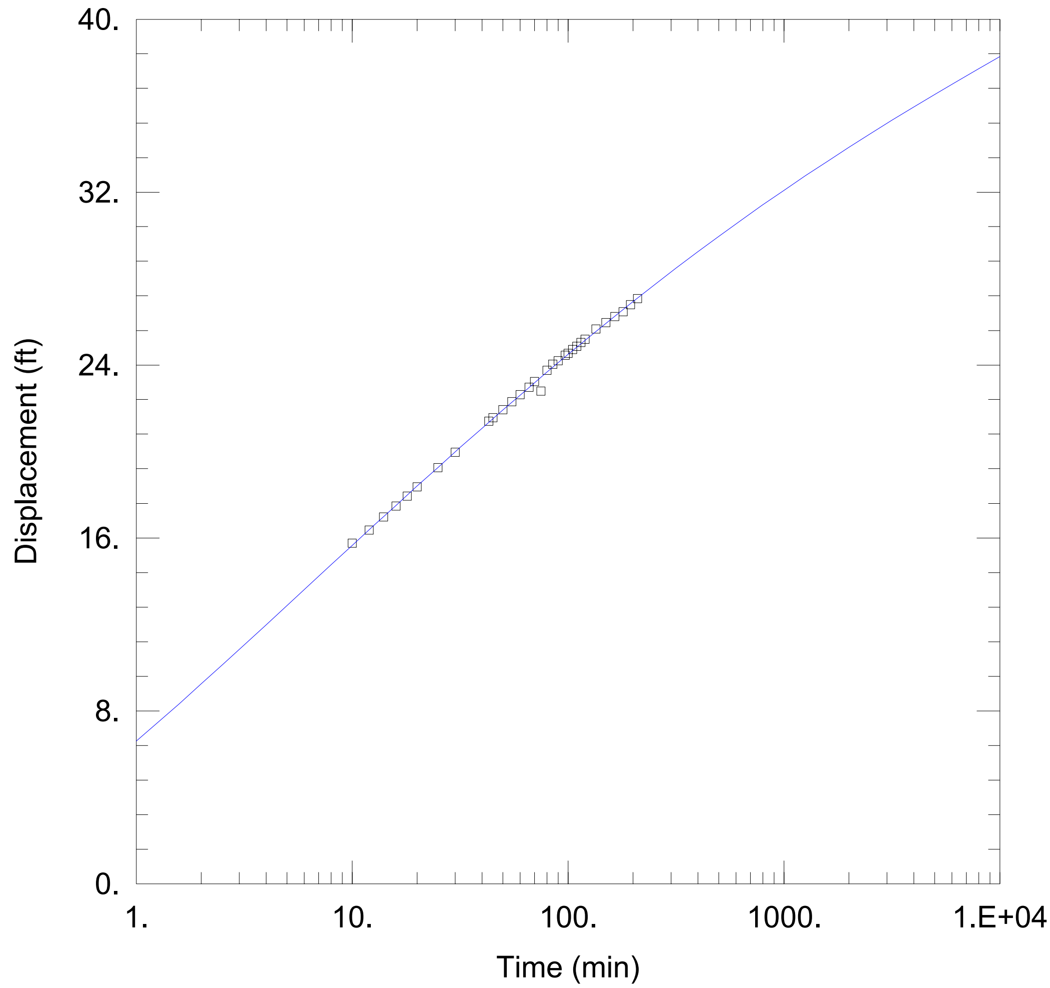
Observation Wells

Well Name	X (ft)	Y (ft)
□ T736	48.5	0

SOLUTION

Aquifer Model: Leaky   Solution Method: Hantush-Jacob

T = 8.376 ft^2/min   S = 0.001611
r/B = 0.006052   Kz/Kr = 1.
b = 200. ft



WELL TEST ANALYSIS

Data Set: \...\389 EM_H.aqt
Date: 11/14/02 Time: 10:22:12

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W389 EM
Test Date: April 1987

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W389 EM	0	0

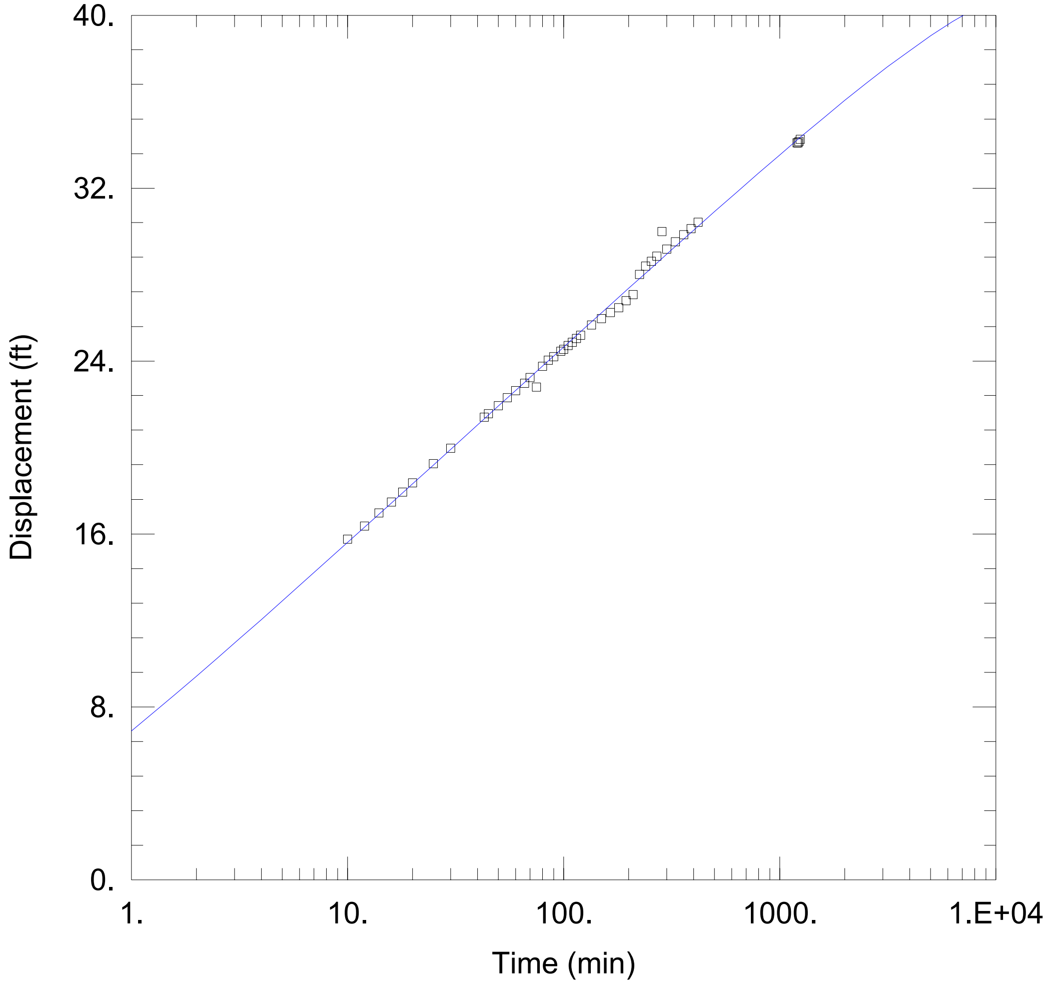
Observation Wells

Well Name	X (ft)	Y (ft)
□ T736	48.5	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 7.694 ft^2/min
S = 0.001763
ß = 0.007174
Kz/Kr = 1.
b = 200. ft



WELL TEST ANALYSIS

Data Set: \...\389 EM_NW.aqt
Date: 11/14/02 Time: 10:45:30

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W389 EM
Test Date: April 1987

AQUIFER DATA

Saturated Thickness: 200. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W389 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ T736	48.5	0

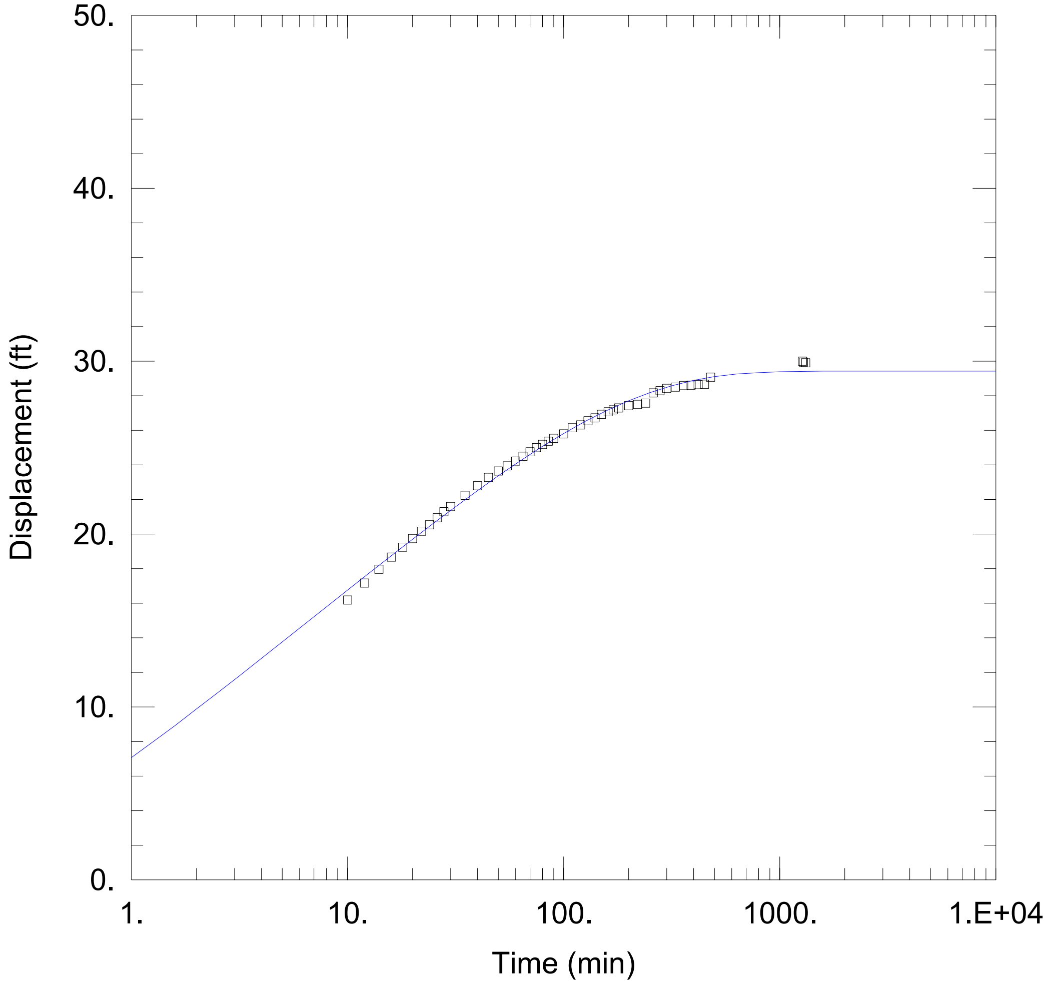
SOLUTION

Aquifer Model: Leaky Solution Method: Neuman-Witherspoon

T = 8.418 ft^2/min
r/B = 0.005099
T' = 3.626E-05 ft^2/min

S = 0.001568
ß = 0.0001397
S' = 0.818

Appendix J
AQTESOLV Output for
Well W383 EM (Independence-Oak)



WELL TEST ANALYSIS

Data Set: \...\383 EM_HJ.aqt
Date: 11/13/02 Time: 19:03:05

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W383 EM
Test Date: October 1986

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W383 EM	0	0

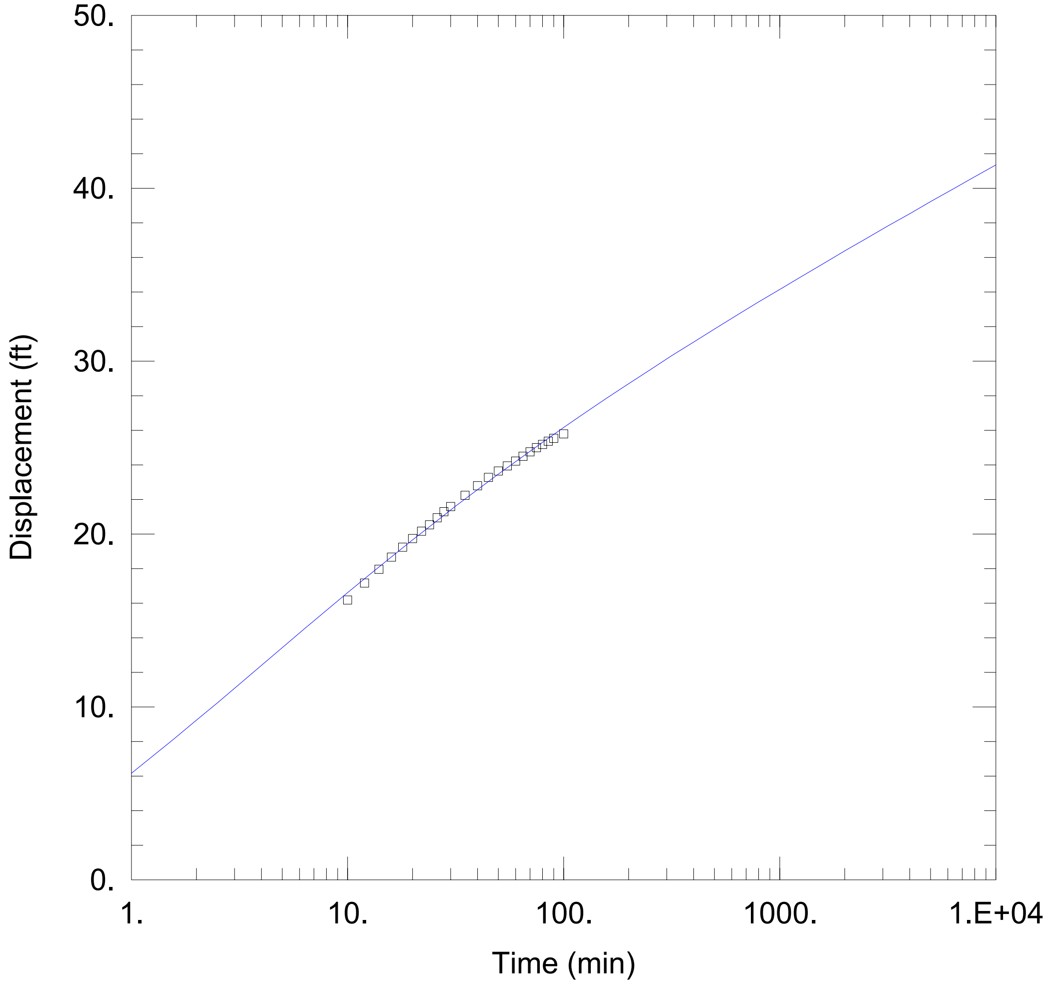
Observation Wells

Well Name	X (ft)	Y (ft)
□ T632	81.5	0

SOLUTION

Aquifer Model: Leaky Solution Method: Hantush-Jacob

T = 5.232 ft^2/min
r/B = 0.04637
b = 355. ft
S = 0.000488
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\383 EM_H.aqt
Date: 11/13/02 Time: 19:05:39

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W383 EM
Test Date: October 1986

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W383 EM	0	0

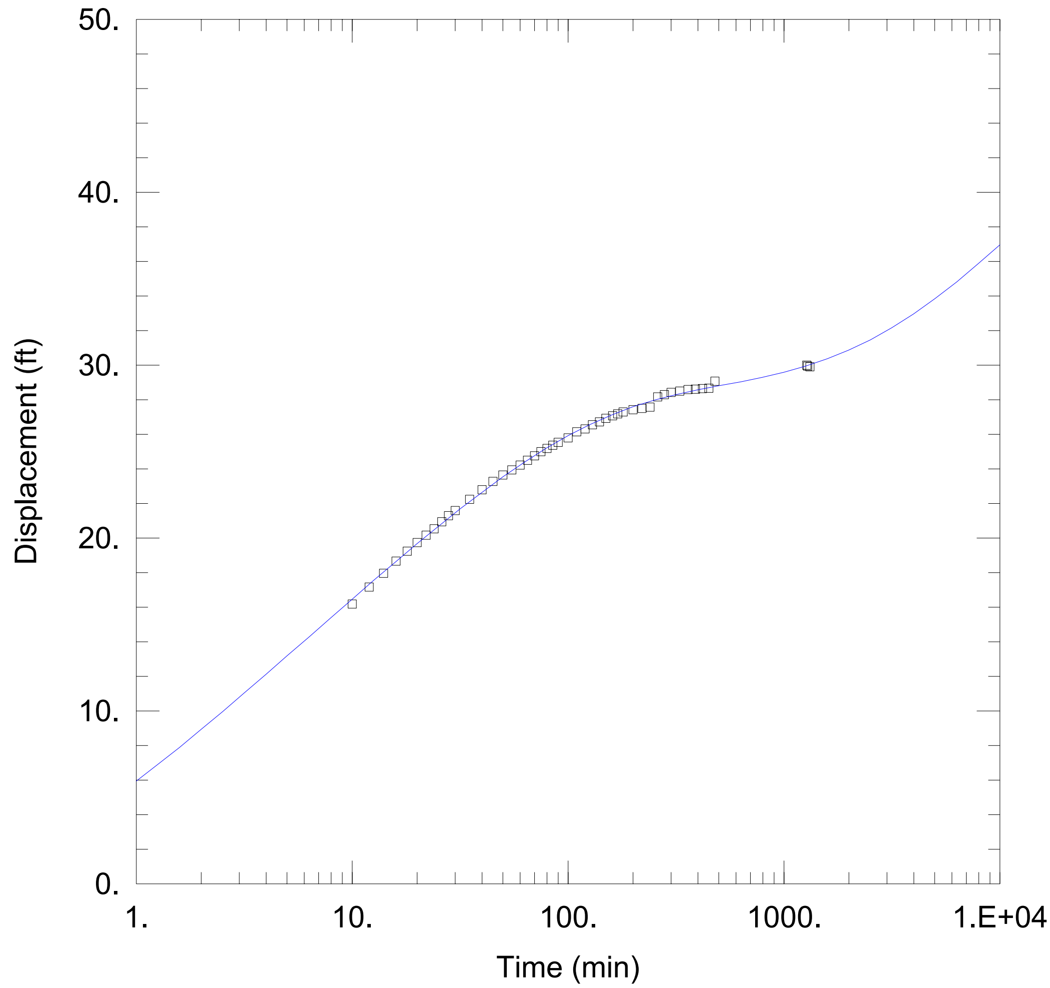
Observation Wells

Well Name	X (ft)	Y (ft)
□ T632	81.5	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 3.997 ft^2/min
ß = 0.0427
b = 355. ft
S = 0.0006054
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\383 EM_NW.aqt
Date: 11/13/02 Time: 19:08:44

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W383 EM
Test Date: October 1986

AQUIFER DATA

Saturated Thickness: 355. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W383 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ T632	81.5	0

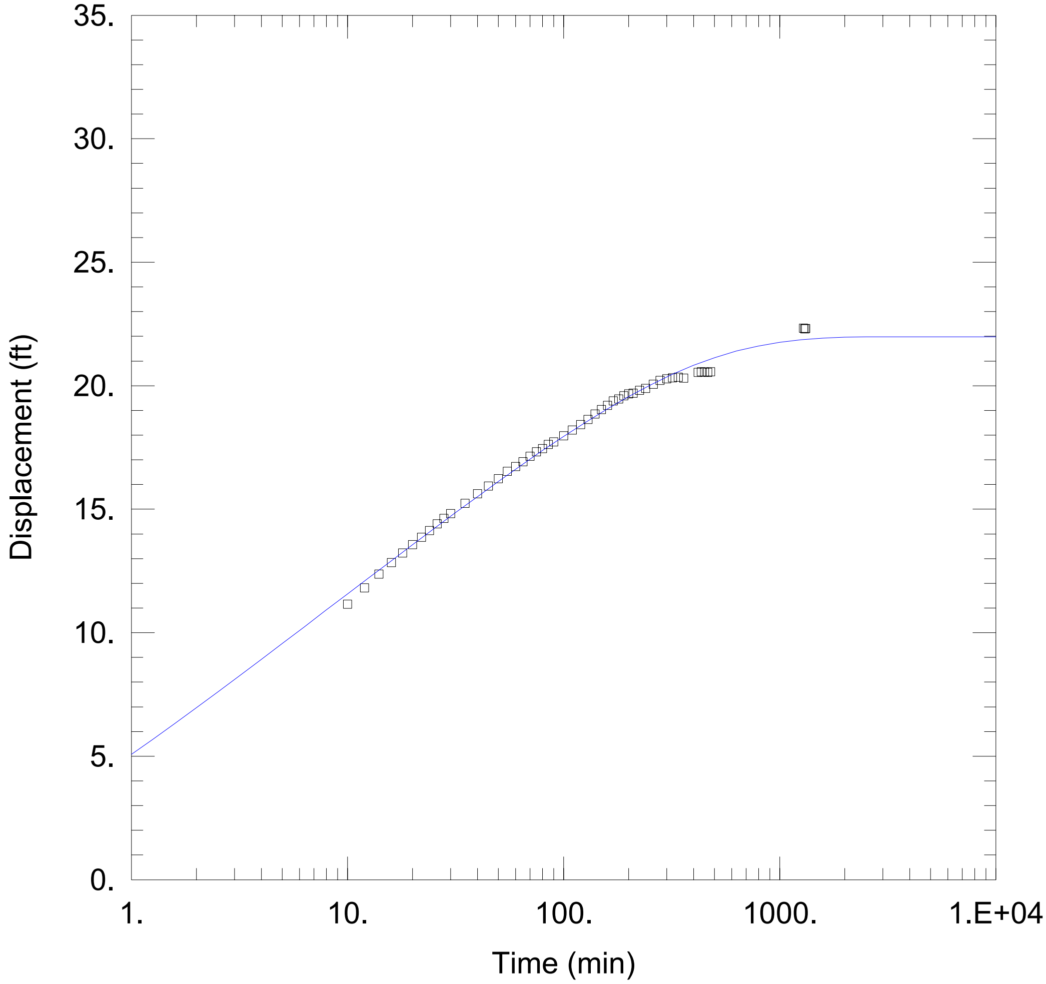
SOLUTION

Aquifer Model: Leaky Solution Method: Neuman-Witherspoon

T = 4.641 ft^2/min
r/B = 0.06958
T' = 1.E-05 ft^2/min

S = 0.0005891
ß = 0.004444
S' = 0.01057

Appendix K
AQTESOLV Output for
Well W384 EM (Independence-Oak)



WELL TEST ANALYSIS

Data Set: \...\384 EM_HJ.aqt
Date: 11/13/02 Time: 18:46:44

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W384 EM
Test Date: September 1986

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W384 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ T633	88.5	0

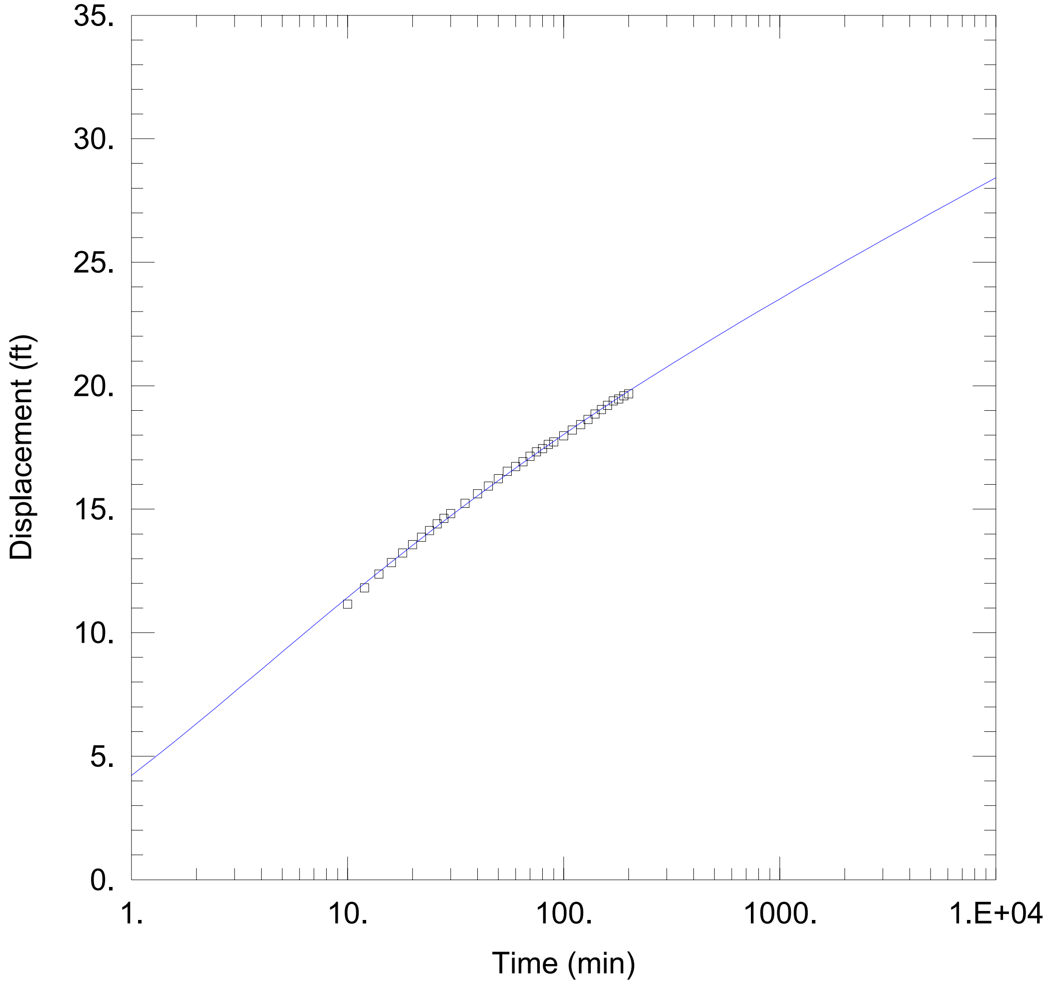
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush-Jacob

T = 3.401 ft^2/min
r/B = 0.02774
b = 340. ft

S = 0.0001972
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\384 EM_H.aqt
Date: 11/13/02 Time: 18:50:23

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W384 EM
Test Date: September 1986

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W384 EM	0	0

Observation Wells

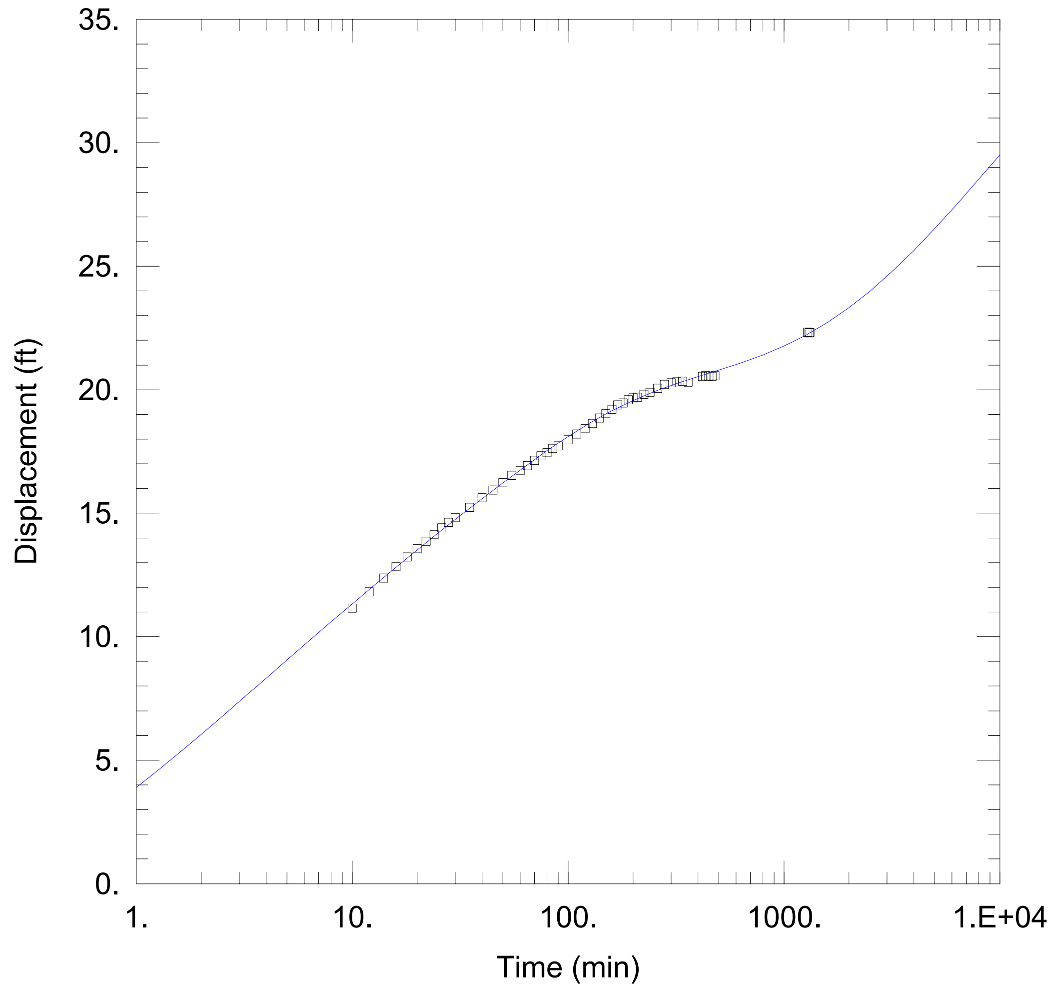
Well Name	X (ft)	Y (ft)
□ T633	88.5	0

SOLUTION

Aquifer Model: Leaky
Solution Method: Hantush

T = 2.526 ft^2/min
ß = 0.0358
b = 340. ft

S = 0.0002785
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\384 EM_NW.aqt
Date: 11/13/02 Time: 18:56:38

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W384 EM
Test Date: September 1986

AQUIFER DATA

Saturated Thickness: 340. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W384 EM	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ T633	88.5	0

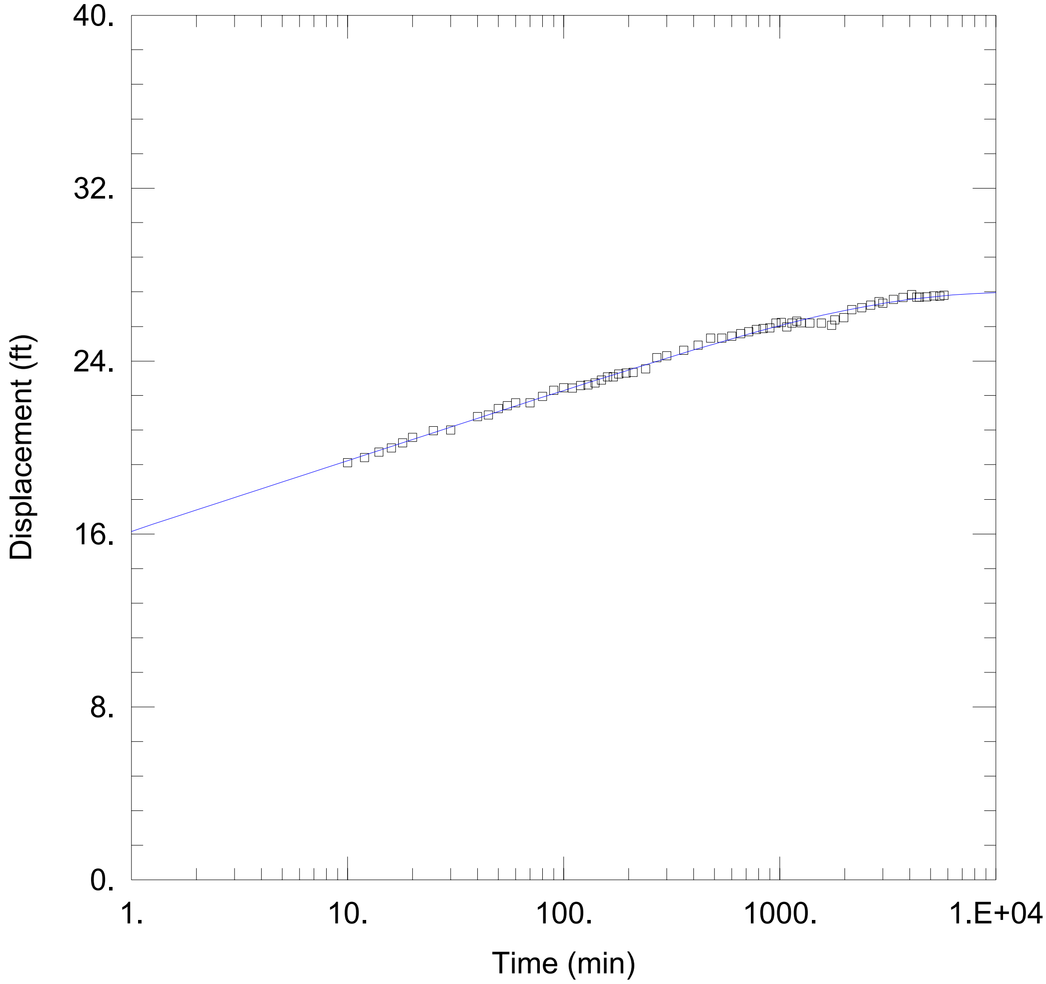
SOLUTION

Aquifer Model: Leaky Solution Method: Neuman-Witherspoon

T = 2.256 ft^2/min
r/B = 0.1166
T' = 1.E-05 ft^2/min

S = 0.0003022
ß = 0.05682
S' = 0.007418

Appendix L
AQTESOLV Output for
Well W395 AQ (Symmes-Shepherd)



WELL TEST ANALYSIS

Data Set: \...\395 AQ_HJ.aqt
Date: 11/14/02 Time: 16:22:39

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W395 AQ
Test Date: January 1989

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W395 AQ	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ W395 AQ	1.17	0

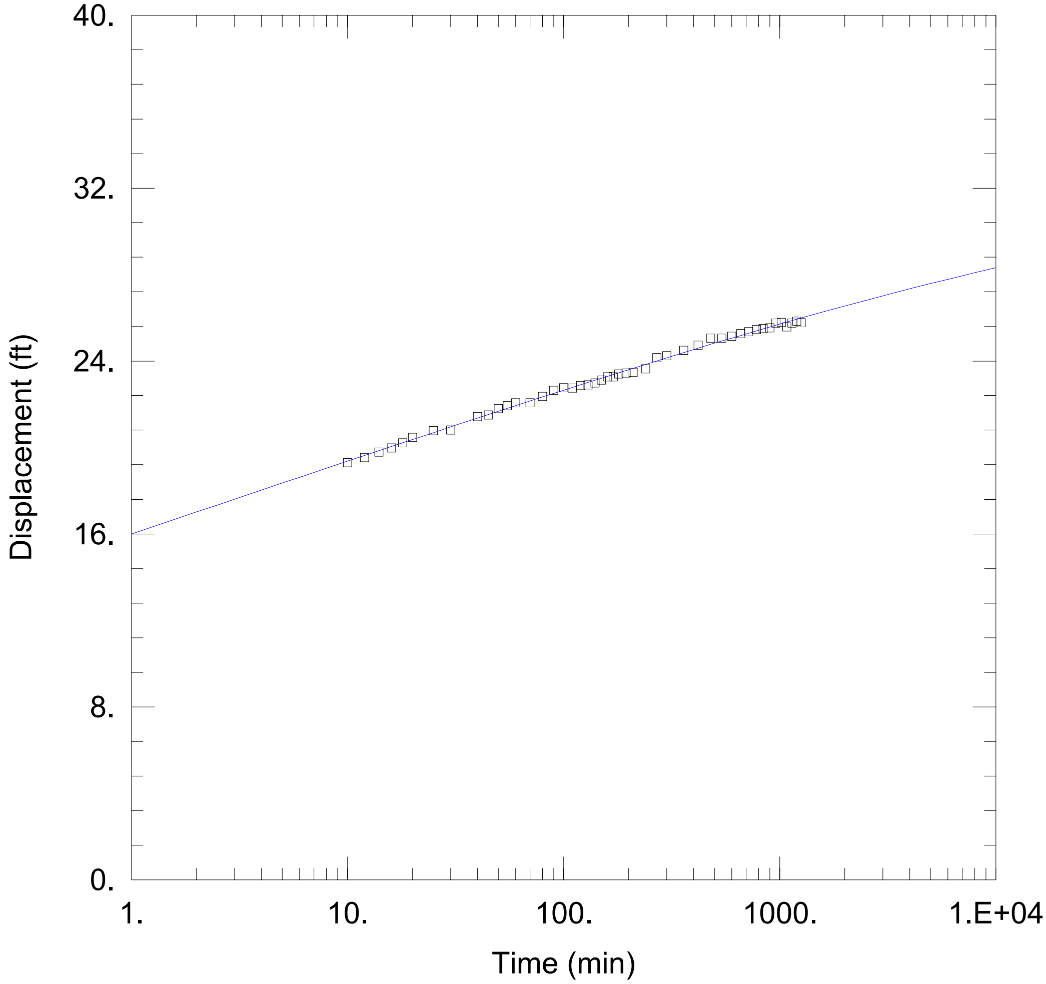
SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush-Jacob

T = 22.82 ft^2/min
r/B = 0.0001019
b = 462. ft

S = 0.0007491
Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\395 AQ_H.aqt
Date: 11/14/02 Time: 17:15:06

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W395 AQ
Test Date: January 1989

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W395 AQ	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ W395 AQ	1.17	0

SOLUTION

Aquifer Model: Leaky

Solution Method: Hantush

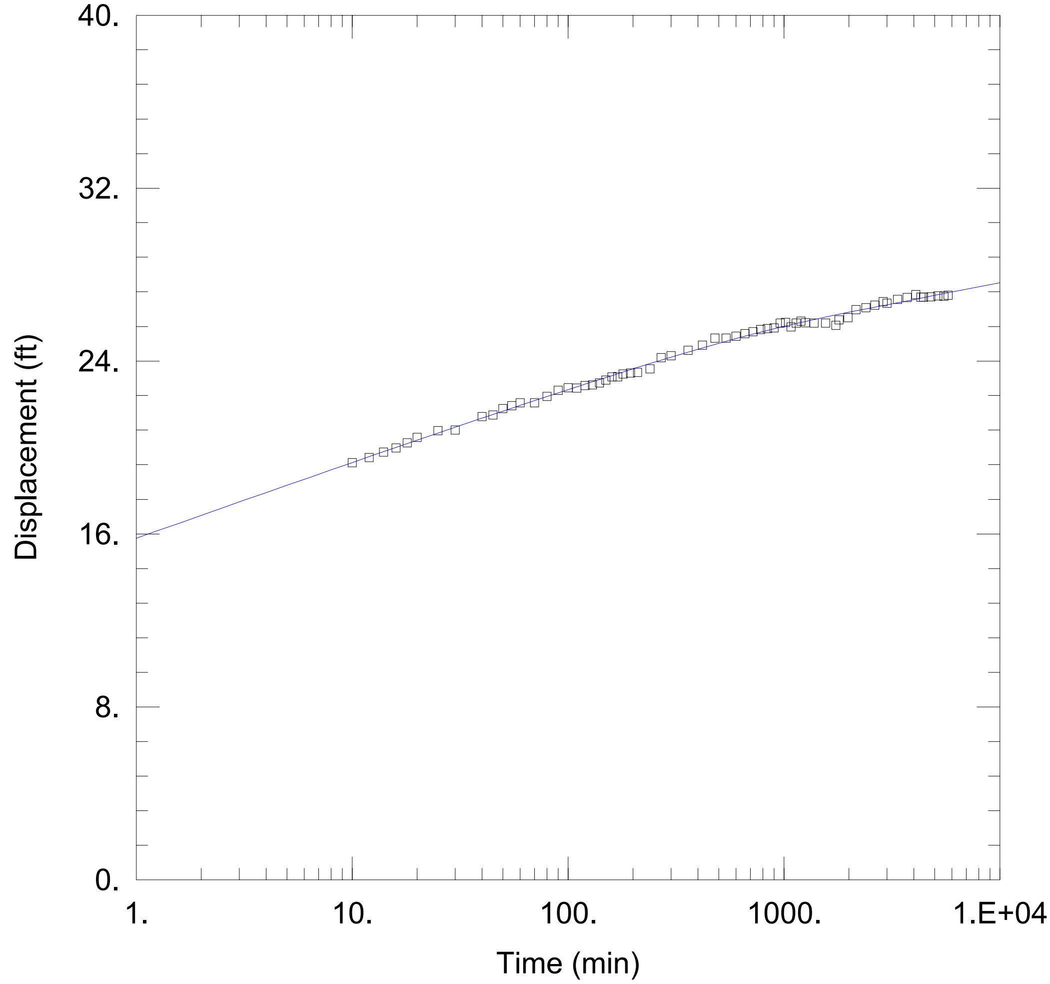
T = 21.88 ft^2/min

ß = 2.687E-05

b = 462. ft

S = 0.001233

Kz/Kr = 1.



WELL TEST ANALYSIS

Data Set: \...\395 AQ_NW.aqt
Date: 11/14/02 Time: 17:09:25

PROJECT INFORMATION

Company: MWH
Client: LADWP
Test Well: W395 AQ
Test Date: January 1989

AQUIFER DATA

Saturated Thickness: 462. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
W395 AQ	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ W395 AQ	1.17	0

SOLUTION

Aquifer Model: Leaky Solution Method: Neuman-Witherspoon

T = 20.91 ft^2/min
r/B = 0.0002295
T' = 15.7 ft^2/min
S = 0.001273
ß = 4.235E-05
S' = 0.001318

Appendix M
Sample Calculations

Appendix M
Sample Calculations

Sample Calculation #1:

Calculation of the Confining Unit Vertical Hydraulic Conductivity (K_z') using the Hantush-Jacob Method (1955) for Well W387 EM

Known Parameters	**Parameter Value for Well W387 EM Analysis**
Thickness of Confining Unit (b')	50 feet
Radial Distance from the Center of Pumping (r)	1.17 feet
Parameters Yielded by the Hantush-Jacob Method (1955)	**Parameter Value for Well W387 EM Analysis**
Aquifer Transmissivity (T)	5.298 ft^2/min
Aquifer Storativity (S)	0.004245
Radial distance divided by the leakage factor (r/B)	0.001337

By definition, $$\left(\frac{r}{B}\right) = \frac{r}{\sqrt{\dfrac{T \cdot b'}{K_z'}}}$$

So, $$K_z' = \frac{T \cdot b'}{r^2} \cdot \left(\frac{r}{B}\right)^2 = \frac{(5.298\ \text{ft}^2/\text{min}) \cdot (50\ \text{feet})}{(1.17\ \text{feet})^2} \cdot (0.001337)^2 = 0.000346\ \text{ft/min} = 3.73\ \text{gpd/ft}^2$$

Sample Calculation #2:

Calculation of the Confining Unit Vertical Hydraulic Conductivity/ Storativity Product $(K_z' \cdot S')$ using the Hantush Method (1960) for Well W387 EM

Known Parameters	Parameter Value for Well W387 EM Analysis
Thickness of Confining Unit (b')	50 feet
Radial Distance from the Center of Pumping (r)	1.17 feet
Parameters Yielded by the Hantush-Jacob Method (1955)	**Parameter Value for Well W387 EM Analysis**
Aquifer Transmissivity (T)	5.273 ft^2/min
Aquifer Storativity (S)	0.003745
Hantush β	0.0002972

$$\text{By definition, } \beta = \frac{r}{4} \cdot \sqrt{\frac{K_z' \cdot S'}{b' \cdot T \cdot S}}$$

$$\text{So, } K_z' \cdot S' = \frac{16 \cdot \beta^2 \cdot b' \cdot T \cdot S}{r^2} = \frac{16 \cdot (0.0002972)^2 \cdot (50\text{ feet}) \cdot (5.273\text{ ft}^2/\text{min}) \cdot (0.003745)}{(1.17\text{ feet})^2}$$

$$= 0.00000102\text{ ft/min} = 0.0110\text{ gpd/ft}^2$$

Note: The storativity of the confining unit may be estimated by dividing the confining unit vertical hydraulic conductivity/storativity product calculated with the Hantush Method by one of the confining unit vertical hydraulic conductivity estimates generated with either the Hantush-Jacob Method or the Neuman-Witherspoon Method. However, because the resultant storativity value would be highly uncertain due to the combination of two separate analysis methods, and because obtaining the confining unit storativity was not the ultimate objective of this analysis, this calculation was not performed.

Sample Calculation #3:

Calculation of the Confining Unit Vertical Hydraulic Conductivity (K_z') using the Neuman-Witherspoon Method (1969) for Well W387 EM

Known Parameters	**Parameter Value for Well W387 EM Analysis**
Thickness of Confining Unit (b')	50 feet
Radial Distance from the Center of Pumping (r)	1.17 feet
Parameters Yielded by the Hantush-Jacob Method (1955)	**Parameter Value for Well W387 EM Analysis**
Confined Aquifer Transmissivity (T)	4.976 ft^2/min
Confined Aquifer Storativity (S)	0.002734
Radial distance divided by the leakage factor (r/B)	0.001344
Neuman-Witherspoon β	0.0003301
Unconfined Aquifer Transmissivity (T^U)	0.00001243
Unconfined Aquifer Storativity (S^U)	1.0

By definition, $$\left(\frac{r}{B}\right) = \frac{r}{\sqrt{\frac{T \cdot b'}{K_z'}}}$$

So, $$K_z' = \frac{T \cdot b'}{r^2} \cdot \left(\frac{r}{B}\right)^2 = \frac{(4.976\ \text{ft}^2/\text{min}) \cdot (50\ \text{feet})}{(1.17\ \text{feet})^2} \cdot (0.001344)^2 = 0.000328\ \text{ft/min} = 3.54\ \text{gpd/ft}^2$$

Note, confining unit vertical hydraulic conductivity can also be obtained from the Neuman-Witherspoon β value. However, in order to perform this calculation, both the confined aquifer vertical hydraulic conductivity and the confining unit storativity must be known. See below:

By definition, $$\beta = \frac{r}{4b}\sqrt{\frac{K_z' \cdot S'}{K_z \cdot S}} \;\Rightarrow\; K_z' = \frac{16b^2 \cdot \beta^2}{r^2} \cdot \frac{K_z \cdot S}{S'}$$

Where: b = Confined Aquifer Thickness
K_z = Confined Aquifer Vertical Hydraulic Conductivity
S' = Confining Unit Storativity

Due to these limitations, calculation of the confining unit vertical hydraulic conductivity was performed only using the calculated r/B value for the purposes of this technical memorandum.

GIS Layers for the Confining Unit in the Owens Valley

MEMORANDUM

MWH

To:	Inyo/LA Cooperative Study Team	**Date:**	April 7, 2003
From:	MWH	**Reference:**	1341515.030204
Subject:	Development of GIS Layers for the Confining Unit in Owens Valley		

On August 1, 2002, the Los Angeles Department of Water and Power (LADWP) authorized Montgomery Watson Harza (MWH) to continue the Confining Layer Characteristics Cooperative Study with Task 3.2.3, entitled "*Compile, Analyze, and Review Existing Data Sets.*" Subtask 3.2.3.3 of this task is entitled, *"Development of GIS Layers for the Confining Unit."* The deliverable for this subtask was defined as follows: *"Four GIS layers will be generated and integrated into the LADWP GIS. Cumulative confining layer thickness and maximum confining layer thickness maps will be generated for delivery as a result of this subtask."*

MWH has completed this task per the scope of work, and this Memorandum is intended to be the cover document for transmittal of the confining unit GIS layers and associated low permeability layer maps. A description of methods employed to generate the data set used to create the maps, general attributes of the data, and conclusions is provided herein.

The attachments to this Memorandum consist of ten maps. These maps illustrate the confining layer data set by showing cumulative thickness of low permeability layers and maximum thickness of low permeability layers across the Owens Valley. Each category (cumulative and maximum thickness) has two sets of maps: one for North Owens Valley and one for South Owens Valley. Each set consists of a contour map and a graduated symbol map. The graduated symbol maps represent the raw data used to estimate the contour maps. Descriptions of the ten maps are provided below:

- Map No. 1, Cumulative Low Permeability Layer Thickness Map (Graduated Symbol), North Owens Valley.
- Map No. 2, Cumulative Low Permeability Layer Thickness Map (Graduated Symbol), South Owens Valley.
- Map No. 3, Cumulative Low Permeability Layer Thickness Map (Contour), North Owens Valley.
- Map No. 4, Cumulative Low Permeability Layer Thickness Map (Contour), South Owens Valley.
- Map No. 5, Maximum Low Permeability Layer Thickness Map (Graduated Symbol), North Owens Valley.
- Map No. 6, Maximum Low Permeability Layer Thickness Map (Graduated Symbol), South Owens Valley.
- Map No. 7, Maximum Low Permeability Layer Thickness Map (Contour), North Owens Valley.

- Map No. 8, Maximum Low Permeability Layer Thickness Map (Contour), South Owens Valley.
- Map No. 9, Flowing Wells and Extent of Confinement as Depicted by USGS (1991), North Owens Valley.
- Map No. 10, Flowing Wells and Extent of Confinement as Depicted by USGS (1991), South Owens Valley.

Map Generation

MWH was able to develop a single table from which multiple GIS layers can be constructed as desired by the user. Using the LADWP geologic database, a series of queries were developed to isolate the lithologic descriptions that were determined to constitute a low permeability layer. Using the results of the queries, general statistical analyses were conducted, and experimental variograms were constructed. Based on the results for the variograms, the data were contoured using a Kriging method. Data points and contours were then converted to GIS layers and used to produce maps for the presentation of results. **Figure 1** outlines the general process used to create the maps. In addition, each step in the process is described in more detail below.

Within the LADWP geologic database, each recorded geologic description is categorized by its permeability. There are eight permeability codes, whereby a "1" is the least permeable and a "5" is the most permeable. Codes "6" through "8" are for bedrock and unknown lithologic descriptions. **Table 1** lists each permeability code, code description, and common well log description.

Using the geologic database, a set of rules was established to define a low permeability layer. From these rules, database queries were conducted to determine points and magnitude of confinement. The determination of the definition of a confining layer in terms of permeability code, or "rules", is fundamental to the work completed. If the rules change, then resultant maps change. As will be explained later in this Memorandum, the significance of rules and of associated permeability class thickness contributes significantly to parameter estimation error. Rules employed are listed below:

- The bottom of any low permeability layer must be greater than 50 feet below ground surface.
- If the permeability code = 1, then the thickness of the layer must be greater than 5 feet.
- If the permeability code = 2, then the thickness of the layer must be greater than 20 feet.
- If the permeability code = 3, then the thickness of the layer must be greater than 30 feet.

Figure 1
Confining Layer Data Flow Diagram

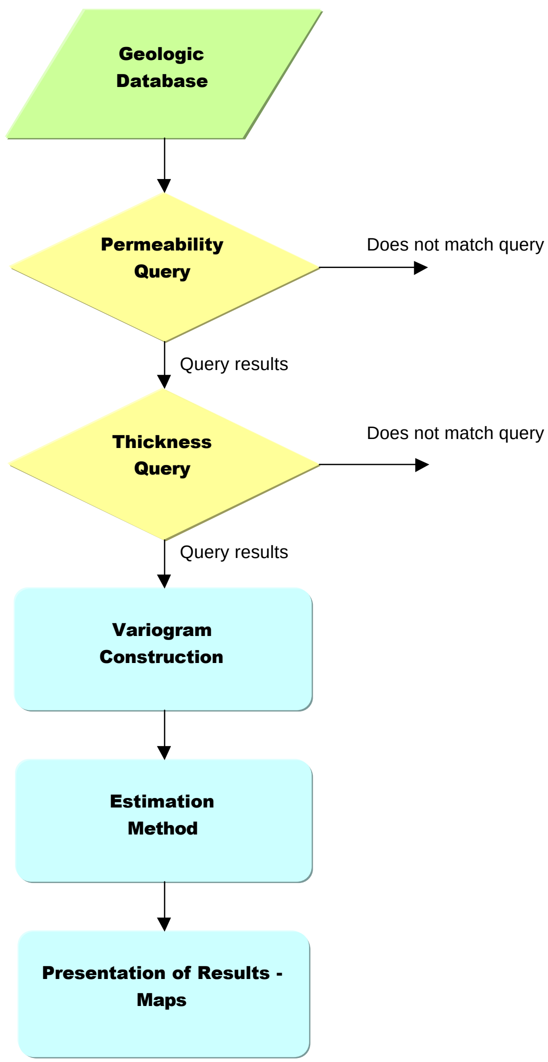


Table from Geologic Database

Code	Code Description	Well Log Description
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures
4	Permeable	Sand, sand/gravel mixtures, few fines
5	High Permeability	Gravel, "clean" gravel/coarse sand mixtures with no fines
6	Low Permeability	Granite/metamorphic
7	Variable Permeability	Volcanic
8		Unknown and no USCS description given

Permeability Query:
Permeability Code = 1, or = 2, or = 3
Bottom of layer is > 50 ft below ground surface

Thickness Query:
If permeability code = 1, then thickness > 5 ft
If permeability code = 2, then thickness > 10 ft
If permeability code = 3, then thickness > 30 ft

Construct Variograms:
Variograms constructed for all data points
Variograms constructed for local areas

Determine Best Estimation Method:
Kriging with inputs from best fit variogram
Results completed in Surfer files and ASCII Grid files
ASCII Grid files converted to ESRI SHP files

Presentation of Results in Map Form:
Contour maps produced
Graduated symbol maps produced

Table 1
Permeability Code Definition

Code	Code Description	Well Log Description
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey-cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures
4	Permeable	Sand, sand/gravel mixtures, few fines
5	High Permeability	Gravel, "clean" gravel/coarse sand mixtures with no fines
6	Low Permeability	Granite/metamorphic
7	Variable Permeability	Volcanic
8	Unknown Permeability	Unknown

These rules were applied to the geologic database to establish a table of well names with associated low permeability layers. Each associated well log may demonstrate the presence of more than one low permeability layer. If a well log did not contain any lithologic layers that met the query rules, then the well log was determined to indicate no confinement. From these data, a cumulative low permeability layer thickness for each well log location was compiled, and a maximum low permeability layer thickness for each well was compiled. The cumulative low permeability layer thickness is equivalent to the sum of all thicknesses that meet the query rules. The maximum low permeability layer thickness is the maximum thickness of a low permeability layer for a given well log.

Using the results of the queries, general statistical analyses were conducted, and experimental variograms were constructed. Univariate statistics are listed in **Table 2** for each analysis.

Table 2
Univariate Statistics for Cumulative and Maximum Thickness

Univariate Statistics for Cumulative Thickness:	Univariate Statistics for Maximum Thickness:
Minimum: 0 feet	Minimum: 0 feet
Median: 23 feet	Median: 17 feet
Maximum: 685 feet	Maximum: 250 feet
Mean: 86.0 feet	Mean: 29.5 feet
Standard Deviation: 120.6 feet	Standard Deviation: 39.0 feet
Variance: 14,537.9 feet	Variance: 1,522.9 feet
Coefficient of Variation: 1.4	Coefficient of Variation: 1.3
Coefficient of Skewness: 1.6	Coefficient of Skewness: 2.1

It is important to note that the data are skewed and not normally distributed. Skewed data sets do not lend themselves well to various estimation techniques because skewness increases estimation error.

Based on the results for the experimental variograms and the best-fit function, the data were contoured with a linear (point or punctual Kriging with ordinary no drift algorithms) Kriging method. An experimental variogram is a measure of spatial correlation, i.e. it is a function that relates semi-variance (dissimilarity) of the data points to the distance that separates them. By constructing an experimental variogram, one can determine the spatial structure of the data, association of the data, and guidance towards which function to use in order to estimate unknown points. The experimental variogram used was the result of a best-fit function. Several experimental variograms were constructed to determine the best function for estimation. Results of the variograms were not very successful for several reasons, discussed below, but should still yield results that are better than a standard linear Kriging interpolation. The poor variogram results illustrate the uncertainty of estimating cumulative low permeability layer thickness and maximum low permeability layer thickness.

Maps 9 and 10 are presented to illustrate other sources of confining/low permeability layer data. Maps 9 and 10 show all flowing wells within the Owens Valley and the generalized extent of confining layers as presented by Hollett and others (1991). The flowing wells are intended to show areas of artesian conditions, where it is most likely that confinement of the penetrated aquifer is under pressure creating an artesian well. The USGS confining layer (Hydrostratigraphic Unit 2) presented on Maps 9 and 10 is defined by Hollett and others (1991) as having a vertical hydraulic conductivity within the range of 0.002 feet per day for clays with gravel up to 0.00083 feet per day for massive clays.

Conclusions

Uncertainty related to estimation method is present in all of the maps. Listed below are sources of the existing uncertainty and potential estimation error.

- Distance between points causes poor source data resolution.
- Owens Valley faulting was not taken into consideration.
- Errors and variability exist in the drillers lithologic logs.
- The estimation function used to contour the data is incorrect, and the nugget observed is the sum of:
  - -Natural variability in the stratigraphy,
  - -Errors/variability in logging, and
  - -Errors/variability in permeability code assignment/interpretation.
- Discontinuities caused by the “rules” applied, (e.g. a 5-foot clay next to a 30-foot silt), result in error/variability in the confining layer function.
- The original data set exhibits skewness.

In order to check how much these factors contributed to the ultimate output, a residual analysis was completed to compare the actual data points to the estimated data. These results are listed below in **Tables 3 and 4**. In general, the percent error tends to decrease with increasing total thickness, and the mean error in feet tends to increase with increasing total thickness.

Table 3
Cumulative Thickness Residual Error

Cumulative Thickness	Mean Error in Feet	Mean % Error	Count
0-100 Ft	17	65%	115
100-200 Ft	35	24%	52
200-300 Ft	40	17%	37
300-400 Ft	47	13%	25
400-500 Ft	38	9%	7
500-600 Ft	264	51%	2

Table 4
Maximum Thickness Residual Error

Maximum Thickness	Mean Error in Feet	Mean % Error	Count
0-50	8	36%	137
50-100	17	25%	81
100-150	25	20%	14
150-200	23	13%	5
200-250	123	52%	2

The graduated symbol maps allow the user to view actual data points and to conceptualize alternative depositional scenarios, low permeability layer location, and lateral low permeability layer extent.

These maps should be used in conjunction with other references to draw conclusions about the confining layer. For example, in order to determine a drilling site in hopes of penetrating the confined aquifer, the contour maps and graduated symbol maps should be used to identify potential and preliminary areas of further investigation. Further investigation could consist of referencing other well logs in the areas of high cumulative confinement or large maximum thickness, test hole drilling, aquifer testing, development of cross sections, and so forth. It is important to recognize that these maps make no reference to actual depth of confinement. Therefore, if it is the user's goal to drill a well and screen below confinement, well logs must be referenced to determine the depth of confinement.

Comparison of the low permeability layer maps to the USGS confining layer maps reveals that the general trends are very similar, but there are differences. Differences between the interpretations center on where specific data points are available or unavailable. Clear differences lie in the southwest Bishop area, the Big Pine area, the Thibaut-Sawmill Wellfield, Taboose-Aberdeen Wellfield, and Oak Creek area. Several wells, from well V277 and V278 to V145, define confinement further south and west in the Bishop area than that presented on the USGS maps. Within the Big Pine area, well W341 is west of the USGS confining layer and exhibits low permeability. However, W341 is a single data point with no other data to validate. On the opposite side of the Owens Valley in the Big Pine area, two data points indicate that the alluvial deposits from the Waucoba Canyon area extend further into the Owens Valley than previously mapped. There are no low permeability materials within the two available data points. Within the Thibaut-Sawmill and Taboose-Aberdeen wellfields there are numerous well records than indicate there are no low permeability sediments. This is much different than what was interpreted by the USGS where confinement was assumed across the Owens Valley floor in this area. The final area of significant difference between interpreted low permeability areas and USGS confining layers is the Oak Creek area. This difference is dictated by a single well at the Mt. Whitney fish Hatchery that indicates significant low permeability materials present. Other data points cannot validate this single point; therefore, this data point should be viewed with some caution.

These GIS maps are very sensitive to the location of available data points. Therefore, in locations where data are not available, interpretations were made using the criteria outlined in this Memorandum and may not be accurate. For example, there is one data point available on the east side of the Owens River between the Symmes-Sheperd, Bairs-Georges, and Lone Pine wellfields. The low permeability layer thickness estimate could be greatly improved in this area with the addition of more data points. By comparing where data are available to areas of interest, potential test hole drilling locations can be determined.

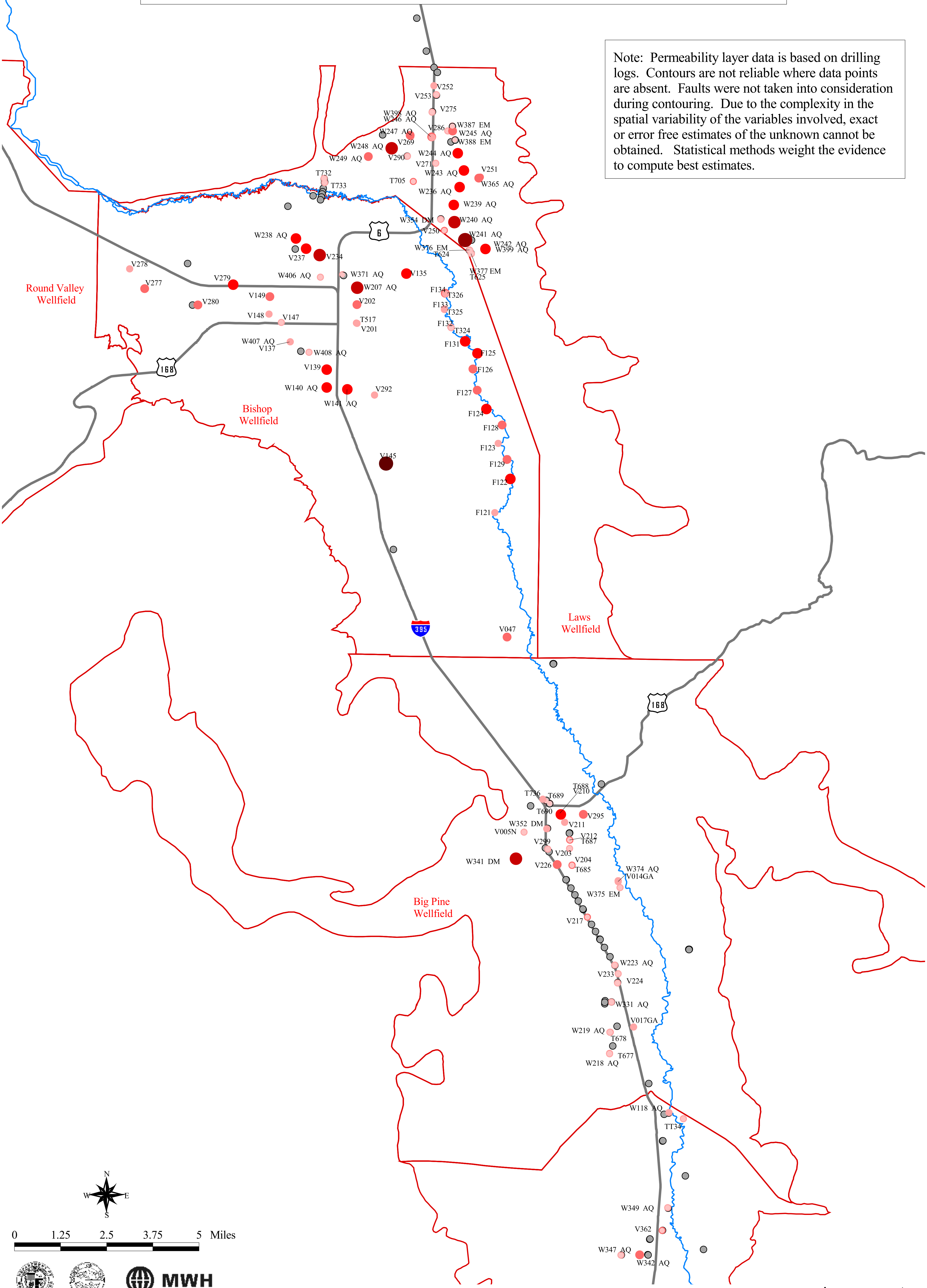
In summary, these maps provide the Cooperative Study Team with a visual aid to conceptualize the confining unit in the Owens Valley. The interpretations presented are one of many possible interpretations that can be made from the data set currently available. In conclusion, the associated GIS layers can be incorporated into both ICWD's and LADWP's GIS databases.

References

Hollett, K.J., W.R. Danskin, W.F. McCaffrey, and C. L., 1991, Walti, Geology and Water Resources of the Owens Valley, California, USGS Water-Supply Paper 2370-B.

CUMULATIVE LOW PERMEABILITY LAYER THICKNESS MAP (GRADUATED SYMBOL)
NORTH OWENS VALLEY
MAP No. 1

Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.



MWH

cl_max_post.apr

Cumulative Interpreted Low Permeability Thickness Layer

- 0
- 1 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 600
- 601 - 700

Highways

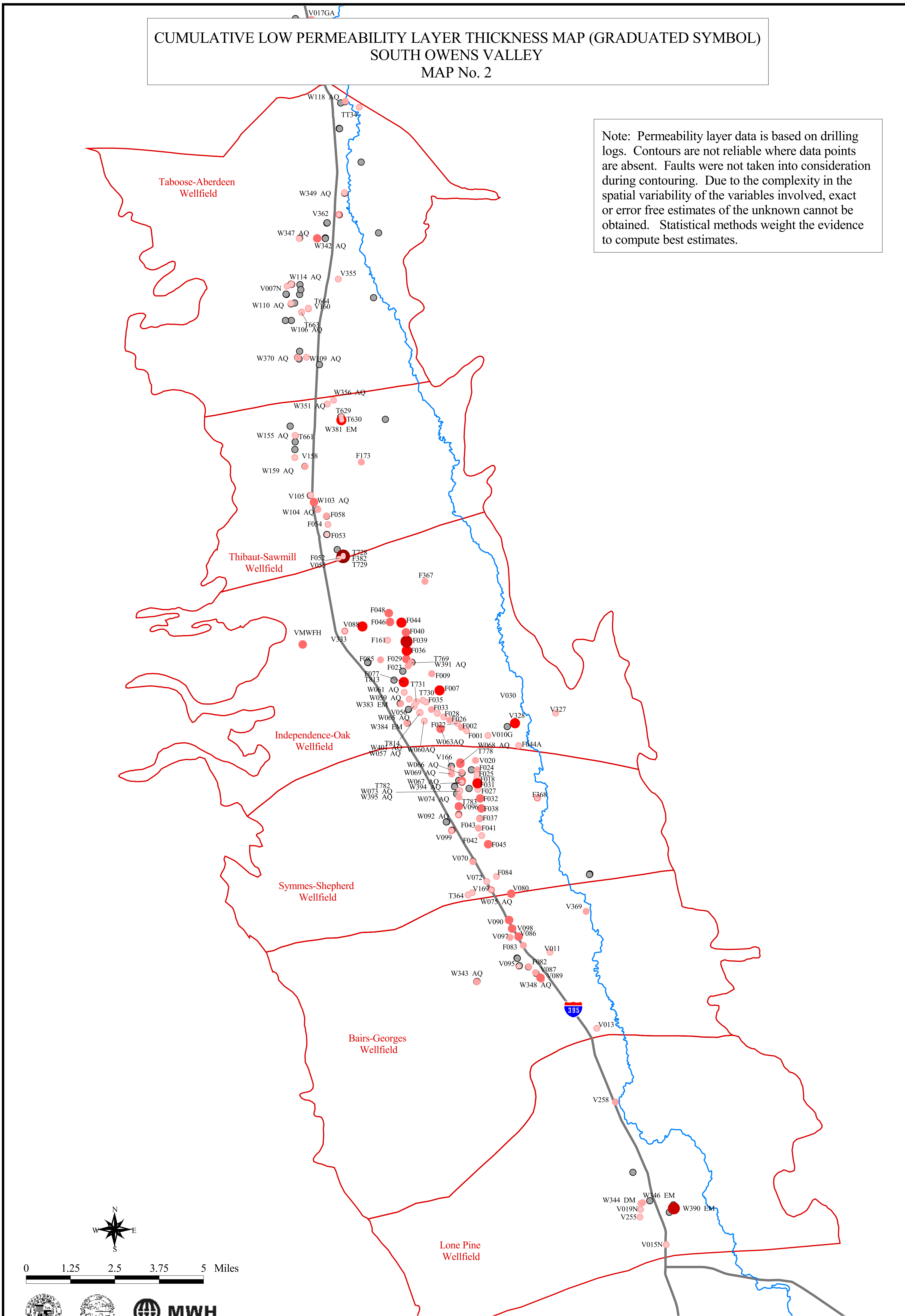
Owens River

Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

CUMULATIVE LOW PERMEABILITY LAYER THICKNESS MAP (GRADUATED SYMBOL)
SOUTH OWENS VALLEY
MAP No. 2



Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.

Cumulative Interpreted Low Permeability Thickness Layer

- 0
- 1 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 600
- 601 - 700

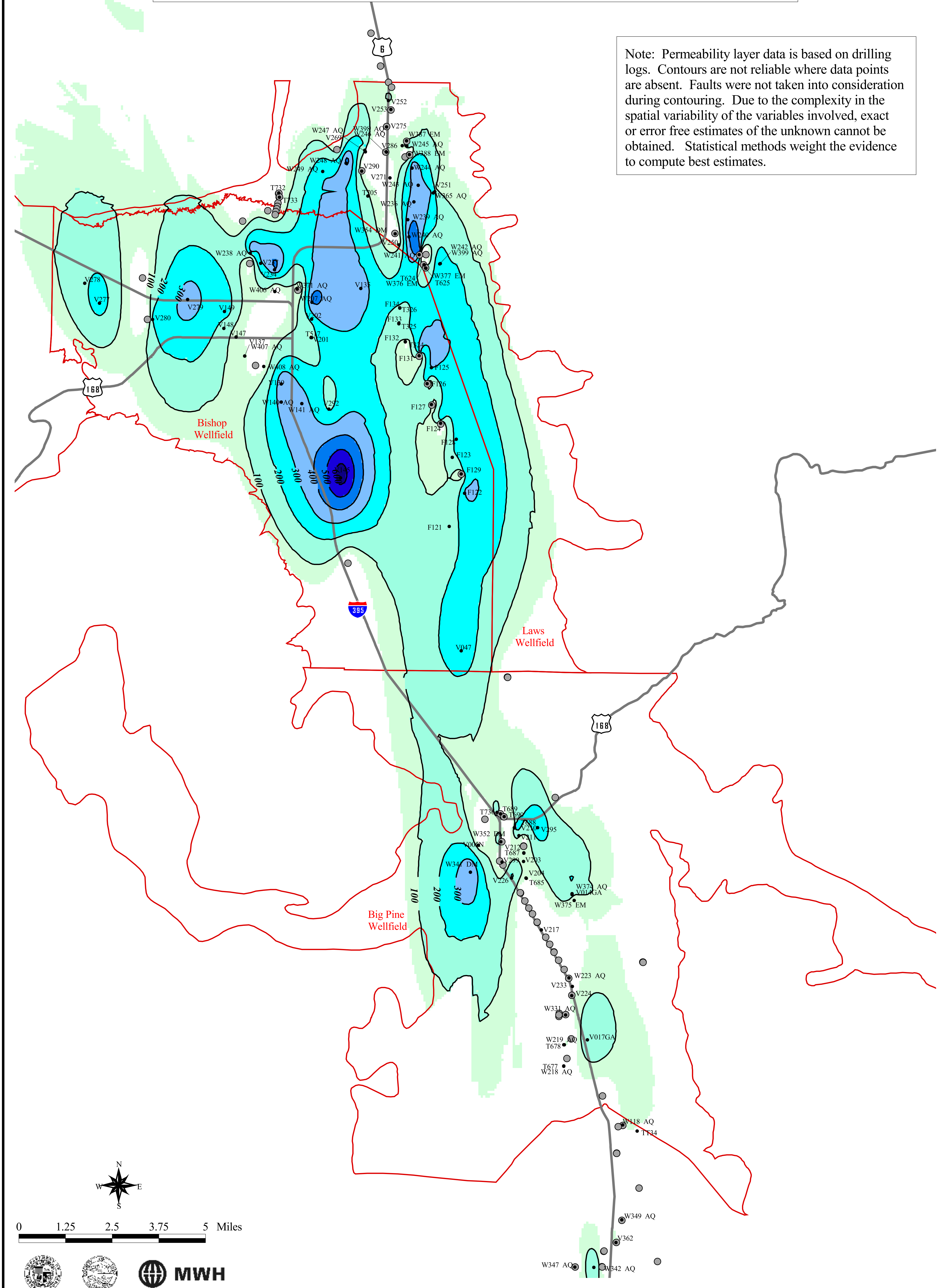
- Highways
- Owens River
- Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

CUMULATIVE LOW PERMEABILITY LAYER THICKNESS MAP (CONTOUR)
NORTH OWENS VALLEY
MAP No. 3

Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.



Cumulative Interpreted Low Permeability Layer Thickness

- 50 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 600
- 601 - 700

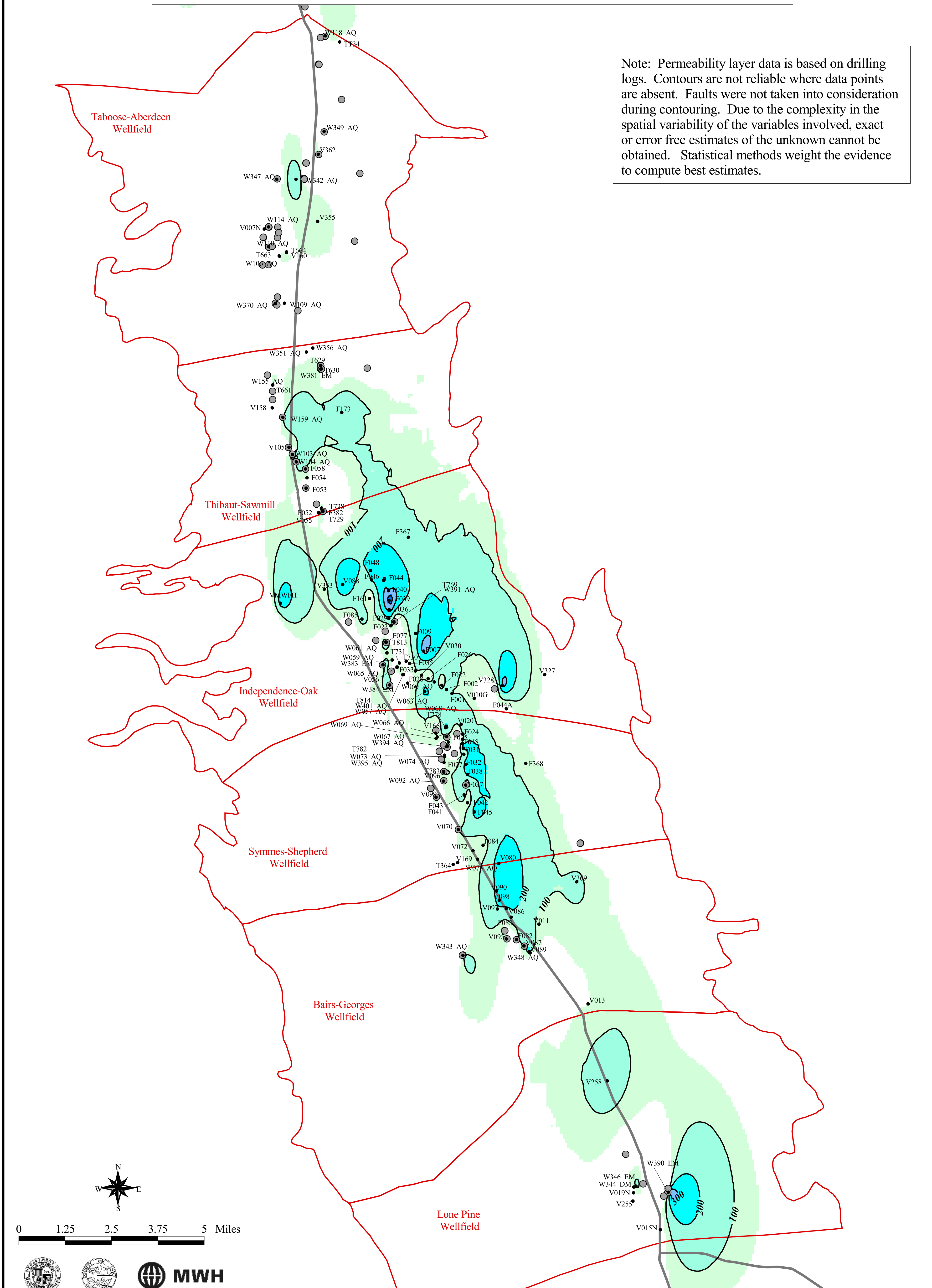
- Low Permeability
- No Low Permeability
- Contour (Interval =100 ft)
- Owens River
- Highways
- Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

CUMULATIVE LOW PERMEABILITY LAYER THICKNESS MAP (CONTOUR)
SOUTH OWENS VALLEY
MAP No. 4

Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.



Cumulative Interpreted Low Permeability Layer Thickness

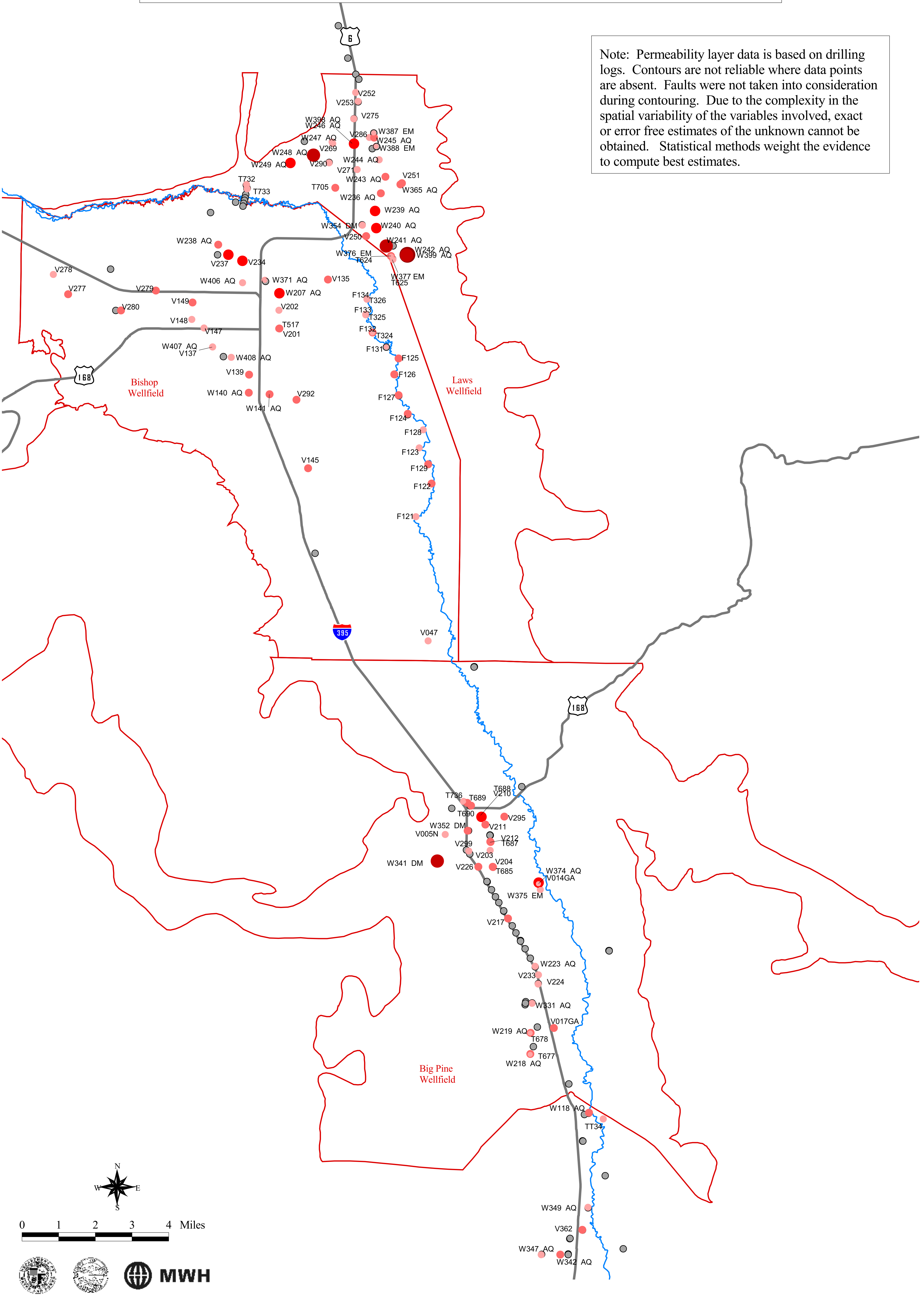
- 50 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500

- Low Permeability
- No Low Permeability
- Contour (Interval =100 ft)
- Owens River
- Highways
- Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

MAXIMUM LOW PERMEABILITY LAYER THICKNESS MAP (GRADUATED SYMBOL)
NORTH OWENS VALLEY
MAP No. 5



Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.

Maximum Interpreted Low Permeability Layer Thickness

- 0
- 1 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 600
- 601 - 700

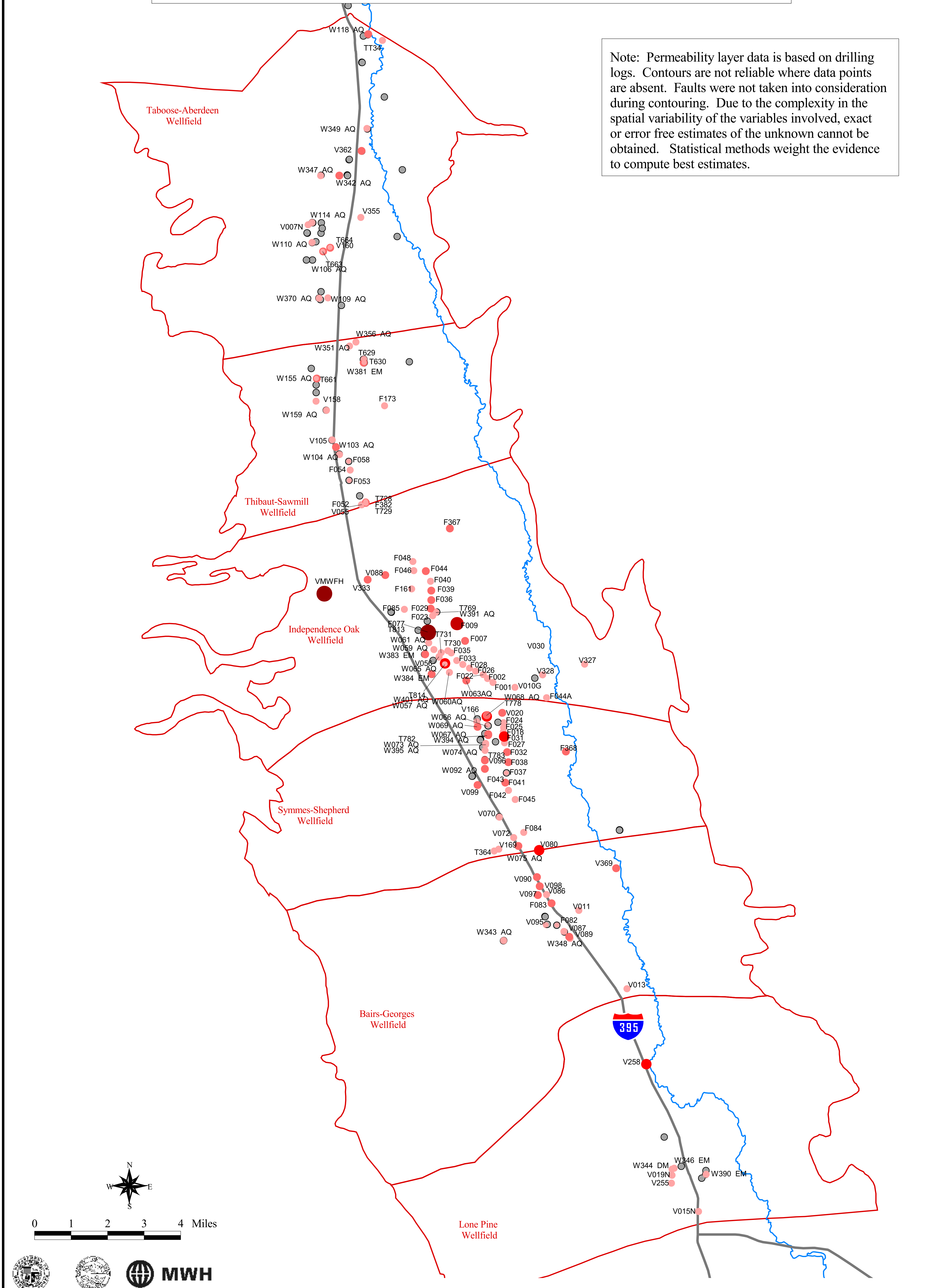
- Highways
- Owens River
- Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

MAXIMUM LOW PERMEABILITY LAYER THICKNESS MAP (GRADUATED SYMBOL)
SOUTH OWENS VALLEY
MAP No. 6

Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.



Maximum Interpreted Low Permeability Layer Thickness

- 0
- 1 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 600
- 601 - 700

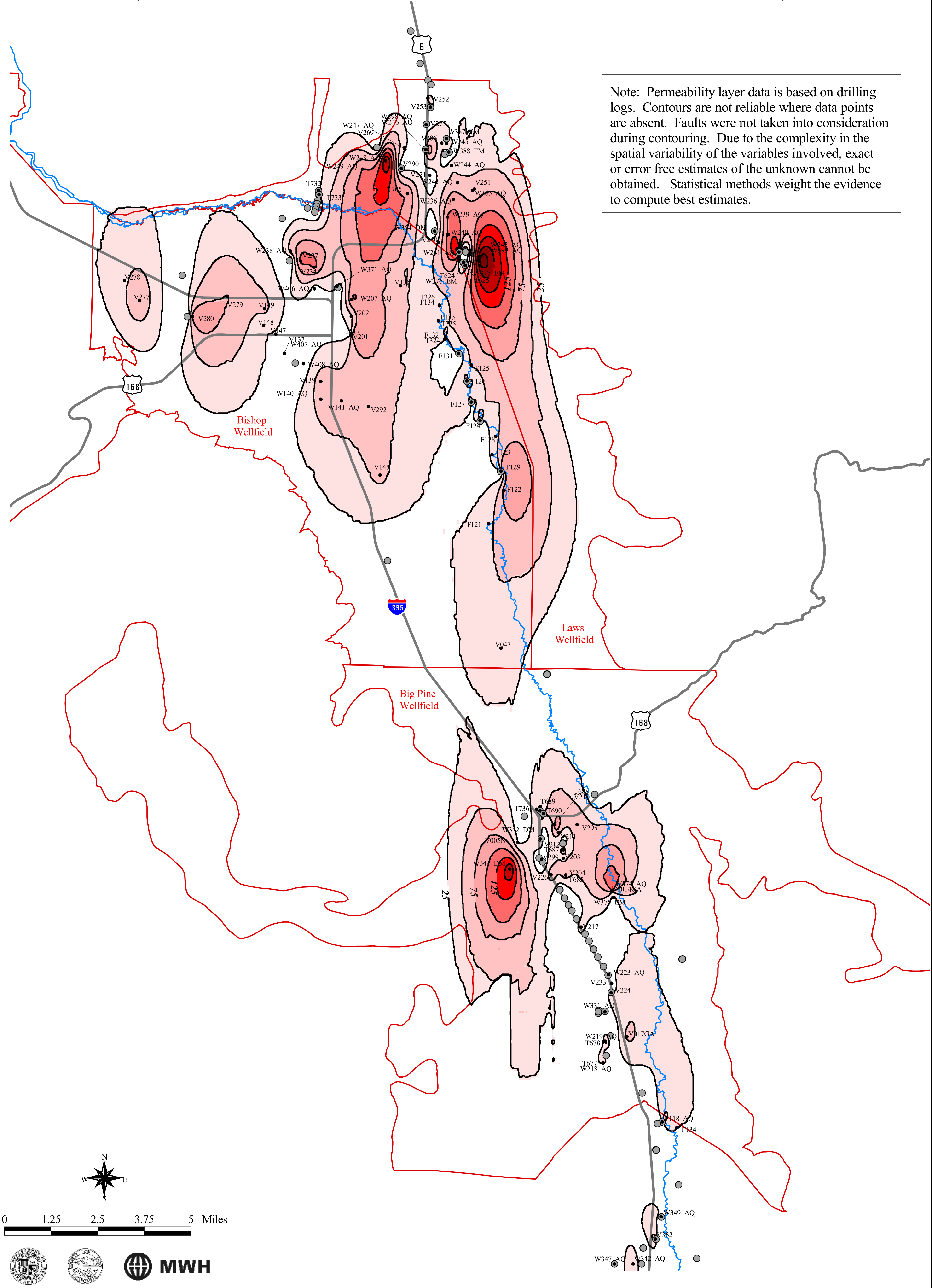
Highways
Owens River
Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

MAXIMUM LOW PERMEABILITY LAYER THICKNESS MAP (CONTOUR)
NORTH OWENS VALLEY
MAP No. 7

Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.



Maximum Interpreted Permeability Layer Thickness

- 25 - 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250

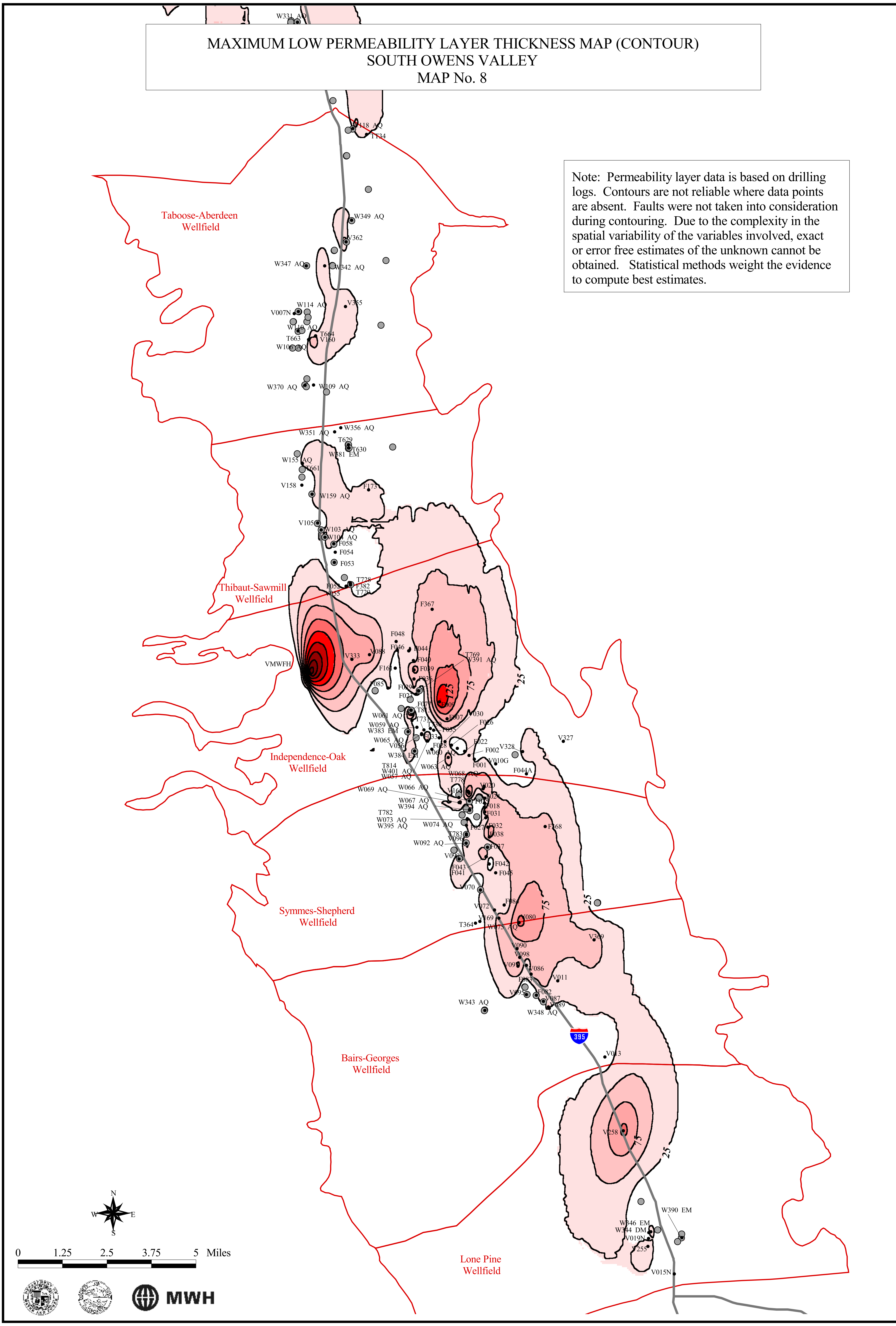
- Low Permeability
- No Low Permeability
- Contour (Interval = 25 ft)
- Owens River
- Highways
- Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

MAXIMUM LOW PERMEABILITY LAYER THICKNESS MAP (CONTOUR)
SOUTH OWENS VALLEY
MAP No. 8

Note: Permeability layer data is based on drilling logs. Contours are not reliable where data points are absent. Faults were not taken into consideration during contouring. Due to the complexity in the spatial variability of the variables involved, exact or error free estimates of the unknown cannot be obtained. Statistical methods weight the evidence to compute best estimates.



Maximum Interpreted Low Permeability Layer Thickness

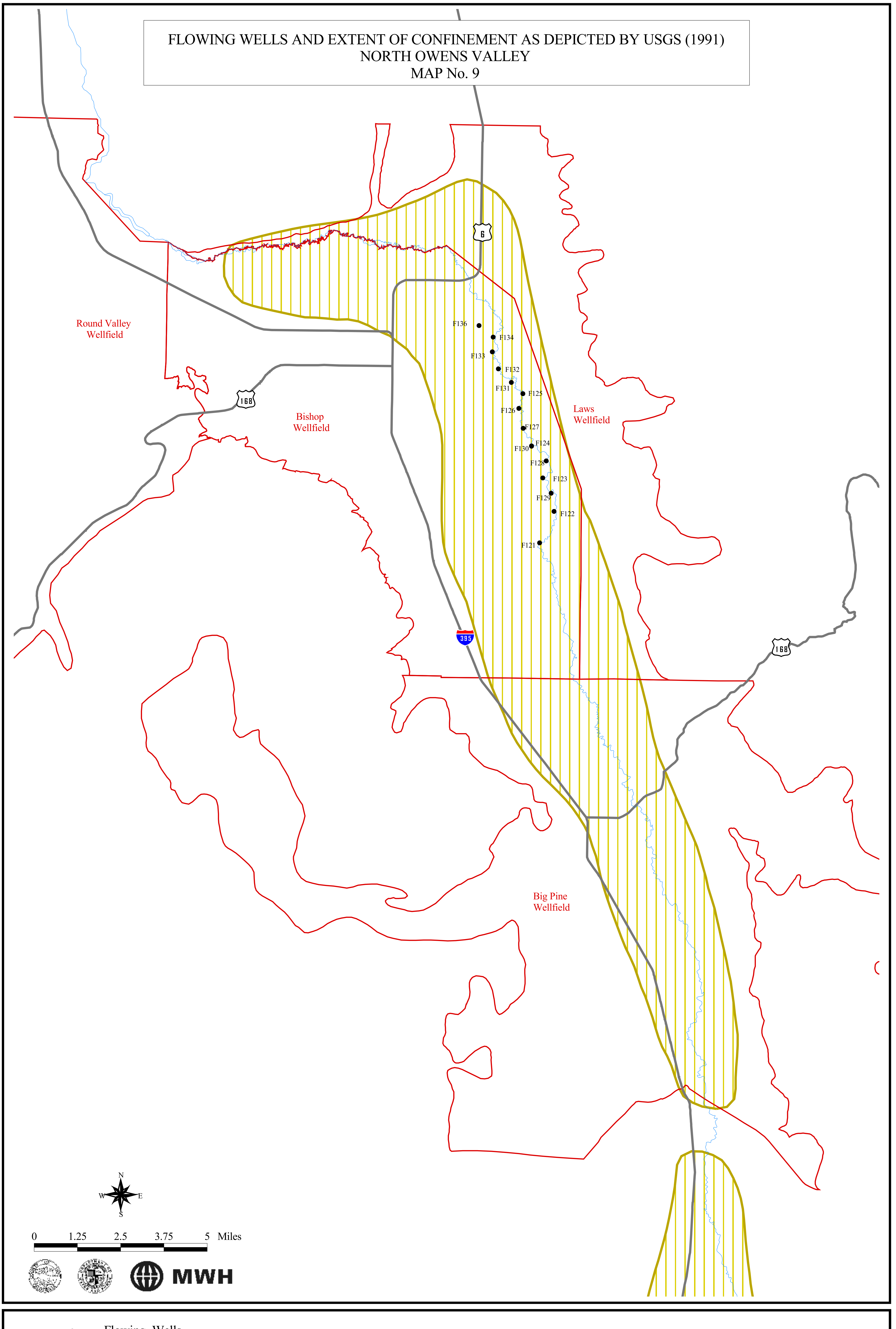
- 25 - 50
- 51 - 75
- 76 - 100
- 101 - 125
- 126 - 150
- 151 - 175
- 176 - 200
- 201 - 225
- 226 - 250

- Low Permeability
- No Low Permeability
- Contour (Interval = 25 ft)
- Owens River
- Highways
- Management Area Boundaries

A low permeability layer is defined as a layer with an ending depth greater than 50 feet below the ground surface and:
A permeability code of 1, that is at least 5 feet thick or;
A permeability code of 2, that is at least 10 feet thick or;
A permeability code of 3, that is at least 30 feet thick.

Code	Description	Layer
1	Relatively Impermeable	Clay, "Gumbo", mostly clay with some sand, clay and silt
2	Low Permeability	Silt, Clayey -cemented (includes tufa), clay/gravel mixtures
3	Moderate Permeability	Silty Sand, sandy silt, clay/sand/gravel mixtures

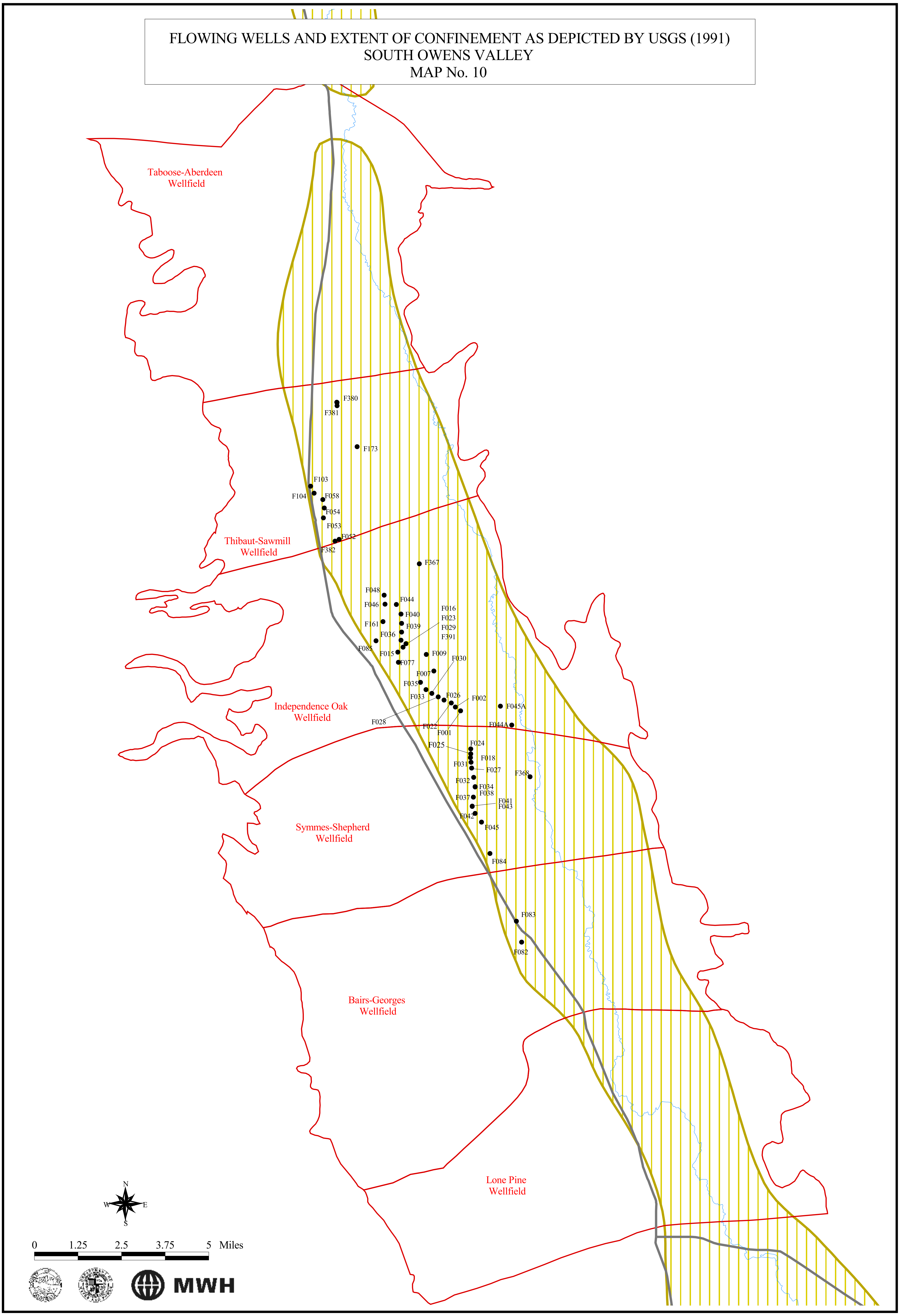
FLOWING WELLS AND EXTENT OF CONFINEMENT AS DEPICTED BY USGS (1991)
NORTH OWENS VALLEY
MAP No. 9



- Flowing Wells
- Owens River
- Highways
- USGS Confining Layer[1]
- Wellfield

[1] 1. Representation of Hydrostratigraphic Unit 2, Hollett 1991, USGS Water Supply Paper 2370-B, Geology and Water Resources of Owens Valley, California, Figure 17.

FLOWING WELLS AND EXTENT OF CONFINEMENT AS DEPICTED BY USGS (1991)
SOUTH OWENS VALLEY
MAP No. 10



- Flowing Wells
- Owens River
- Highways
- USGS Confining Layer [1]
- Wellfield

1. Representation of Hydrostratigraphic Unit 2, Hollett 1991, USGS Water Supply Paper 2370-B, Geology and Water Resources of Owens Valley, California, Figure 17.