What do hydrogeologists do when they interpret pumping test data?

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Overview

Pumping tests are an essential *in situ* technique of hydrogeologic site investigation. Pumping tests are conducted to observe how a groundwater system responds to pumping and to support inferences regarding the structure and properties of the subsurface.

With respect to the reporting of the analyses of pumping tests it is important to distinguish between what a hydrogeologist measures and what he/or she infers from the measurements. This distinction leads to the realization that pumping test analysts do not determine anything and that the parameter values they infer are not facts. The outcomes of pumping test analyses are contingent on the model that has been invoked in their interpretation, and the interpretations must always be regarded as provisional.

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1. Pumping test data

During a pumping test, water is extracted from or injected into a pumping well at a controlled rate. The pumping rates and the water levels in the pumping well and adjacent observation wells are recorded. These are the *data*. In Figure 1 the blue line denotes the water level in the pumping well (left axis) and the red line denotes the variations in the pumping rate, Q (right axis).
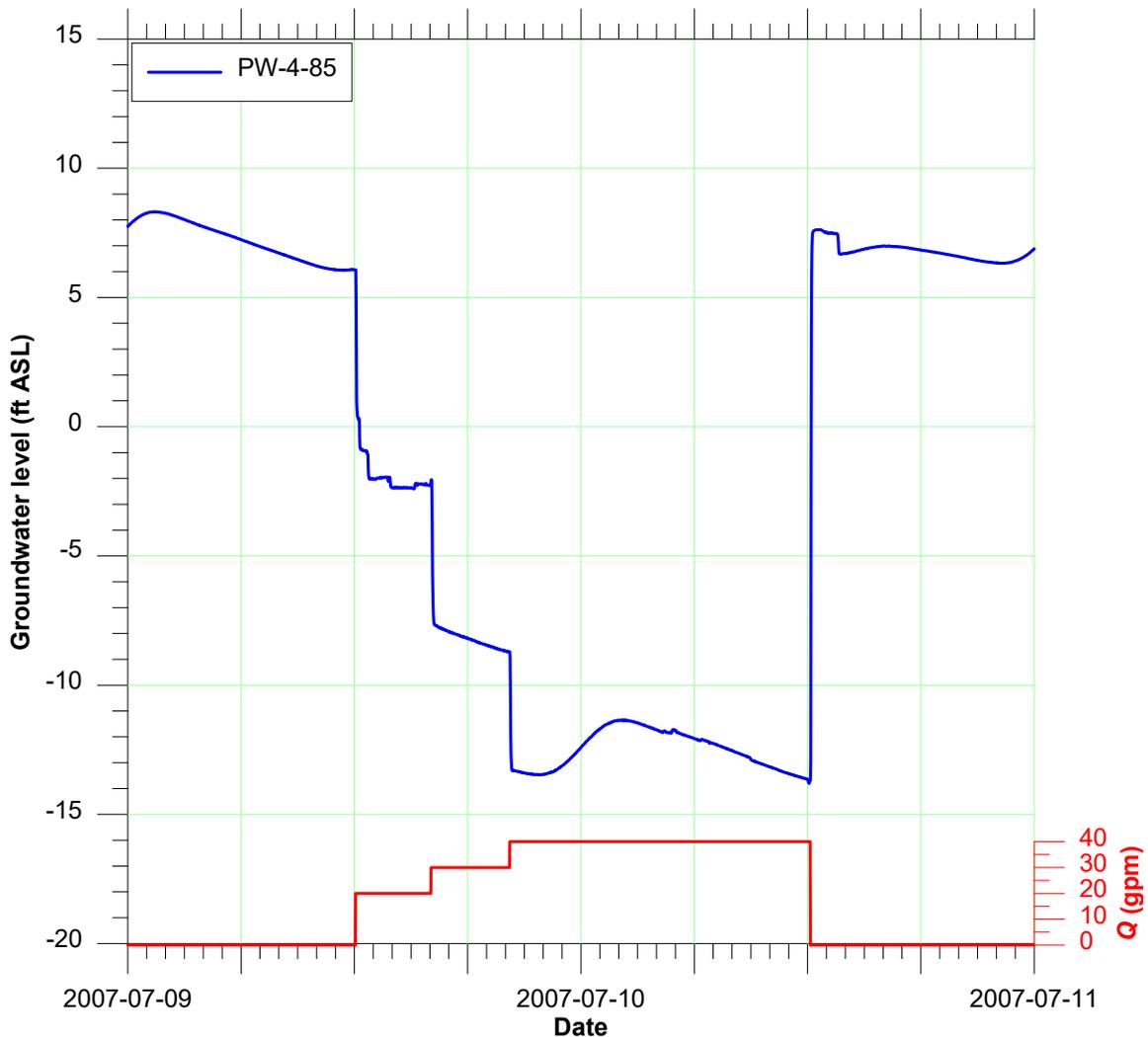
Figure 1. Data collected during a pumping test

2. Interpretation step #1: Inference of drawdowns

Analyses of pumping tests are conducted in terms of the changes in water levels caused only by pumping. These changes are referred to as *drawdowns*. The inference of drawdowns is an *interpretation*.

It is clear from Figure 1 that the not all the changes in water levels in PW-4-85 are attributable to pumping. The first step in the analysis must be the inference of the changes in water levels that are caused only by pumping.

The inference of the drawdowns in PW-4-85 requires data from an observation well that responds to outside influences in exactly the same way as PW-4-85 but does not respond to pumping. In typical circumstances, these data are not available and background trends are inferred by examining water levels preceding pumping and following complete recovery. In the case of the PW-4-85 test, water levels from two observation are available to support this step in the interpretation. In this particular case, the background fluctuations in aquifer levels are caused by changes in the levels of an adjacent river. Wells PW4-118 and MW5-100 are located similar distances from the river as PW-4-85, but sufficiently far from PW-4-85 that they are not affected by its pumping. The water level records for the additional wells are shown in Figure 2.

The interpretation of the drawdown in PW-4-85 is illustrated in Figure 2. The drawdown in PW-4-85 at any elapsed time t since the start of pumping is defined as:

$$s_{\text{PW}-4-85}(t) = WL^0_{\text{PW}-4-85}(t) - WL_{\text{PW}-4-85}(t)$$

Here:

- $WL^0_{\text{PW-4-85}}$ (t) denotes the water level in PW-4-85 that would have been observed if there had been no pumping; and
- $WL_{\text{PW-4-85}}$ (t) denotes the water level in PW-4-85 that was actually observed.
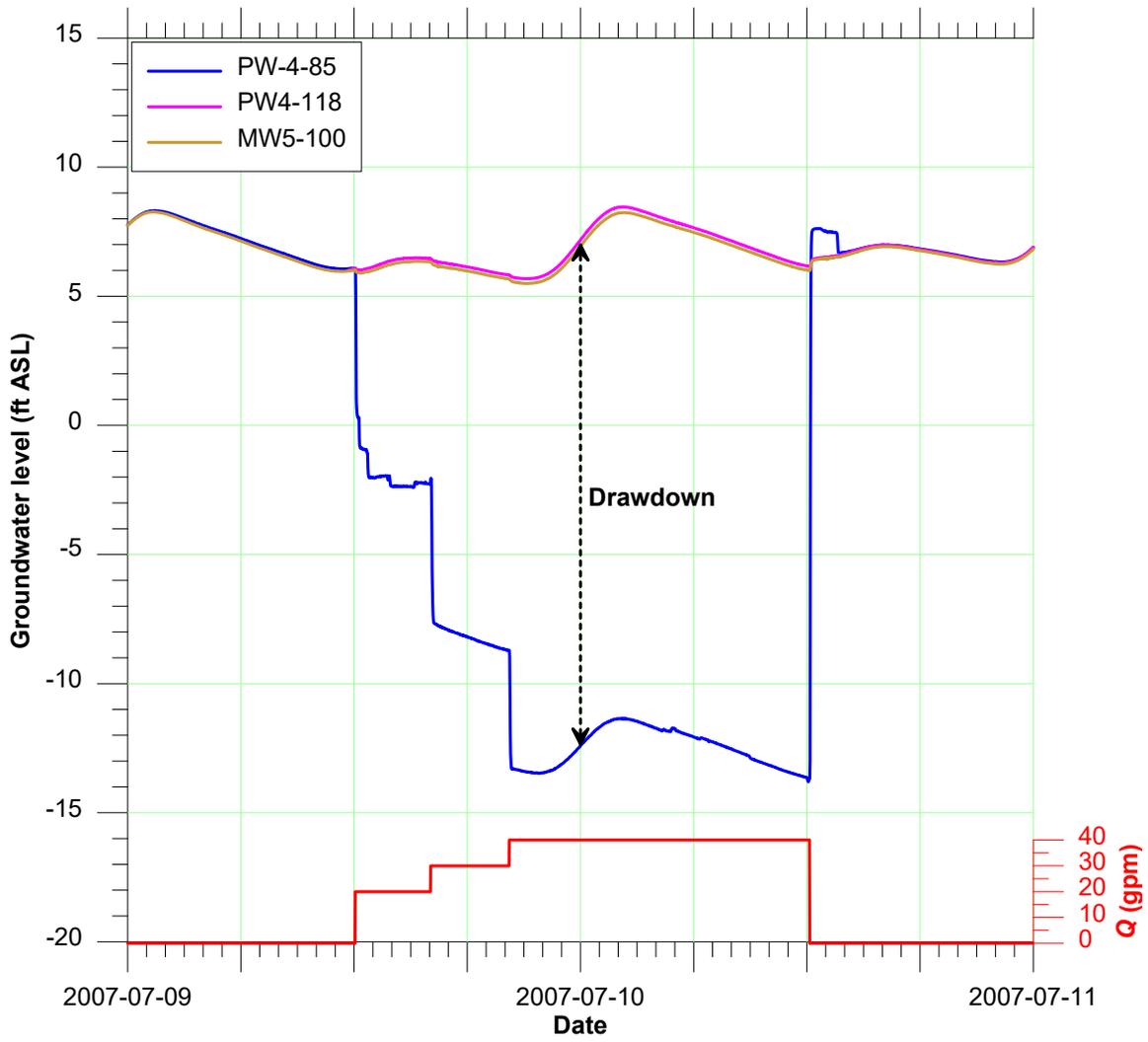
Figure 2. Water level records for the pumping well and adjacent observation wells

The interpreted drawdowns in PW-4-85 are plotted in Figure 3. Referring to Figure 2, after 12 hours of pumping (720 minutes), the drawdown is calculated as:

$$s_{\text{PW}-4-85}(720 \text{ min}) = (7.228 \text{ ft}) - (-12.369 \text{ ft}) = 19.597 \text{ ft}$$

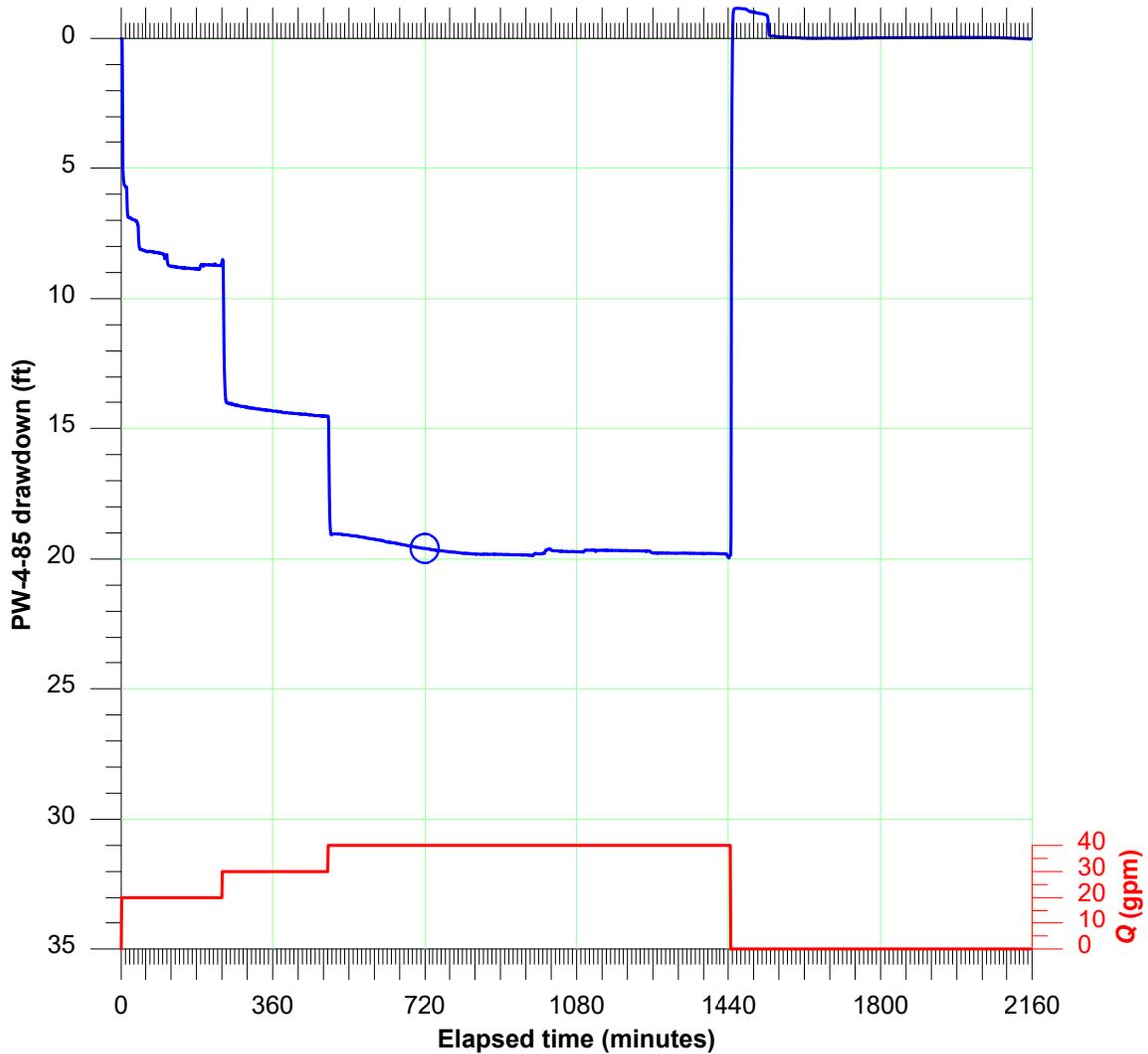The circle in Figure 3 indicates the results of the example calculation.

Figure 3. Interpreted drawdowns

3. Interpretation step #2: Estimation of aquifer properties

The inference of the values of properties of the subsurface requires selecting an idealized mathematical model of the subsurface and adjusting the parameters of the model until an acceptable match to the inferred drawdowns is obtained. This is referred to as *inverse analysis*. Although inverse analyses may now be conducted with "automatic" curve-matching techniques, the interpreter must still select an appropriate model. Inferences regarding the structure of the subsurface are *interpretations* and the transmissivities and/or hydraulic conductivities developed from pumping test analyses must always be regarded as estimates and <u>never</u> as facts.

As a first interpretation, it is assumed that all of the drawdowns are due to head losses in the formation. The drawdowns are matched with the Theis (1935) solution. The results of the match are shown in Figure 4. A transmissivity of 4,100 ft^2/day and a storativity of 0.17 are estimated through nonlinear least-squares regression. Implicit in this analysis are the assumptions that the formation responds as an ideal confined aquifer that is homogeneous, isotropic and infinite in areally extent. It is also assumed that the pumping well is screened across the entire thickness of the formation.

<u>Initial assessment: Critical thinking</u>

As shown in Figure 4, with the exception of the first pumping step, the fitted Theis solution matches closely the inferred drawdowns. However, there are at least two problems with the match. First, the well is observed to recover more quickly than is calculated with the Theis solution. Second, the storage coefficient is unrealistically large for a confined aquifer. Obtaining an unrealistic parameter value from an analysis is usually an indicator that something is missing in the analysis. In the case of a pumping well, it may not be appropriate to assume that all the drawdowns in the well are due solely to head losses in the formation.
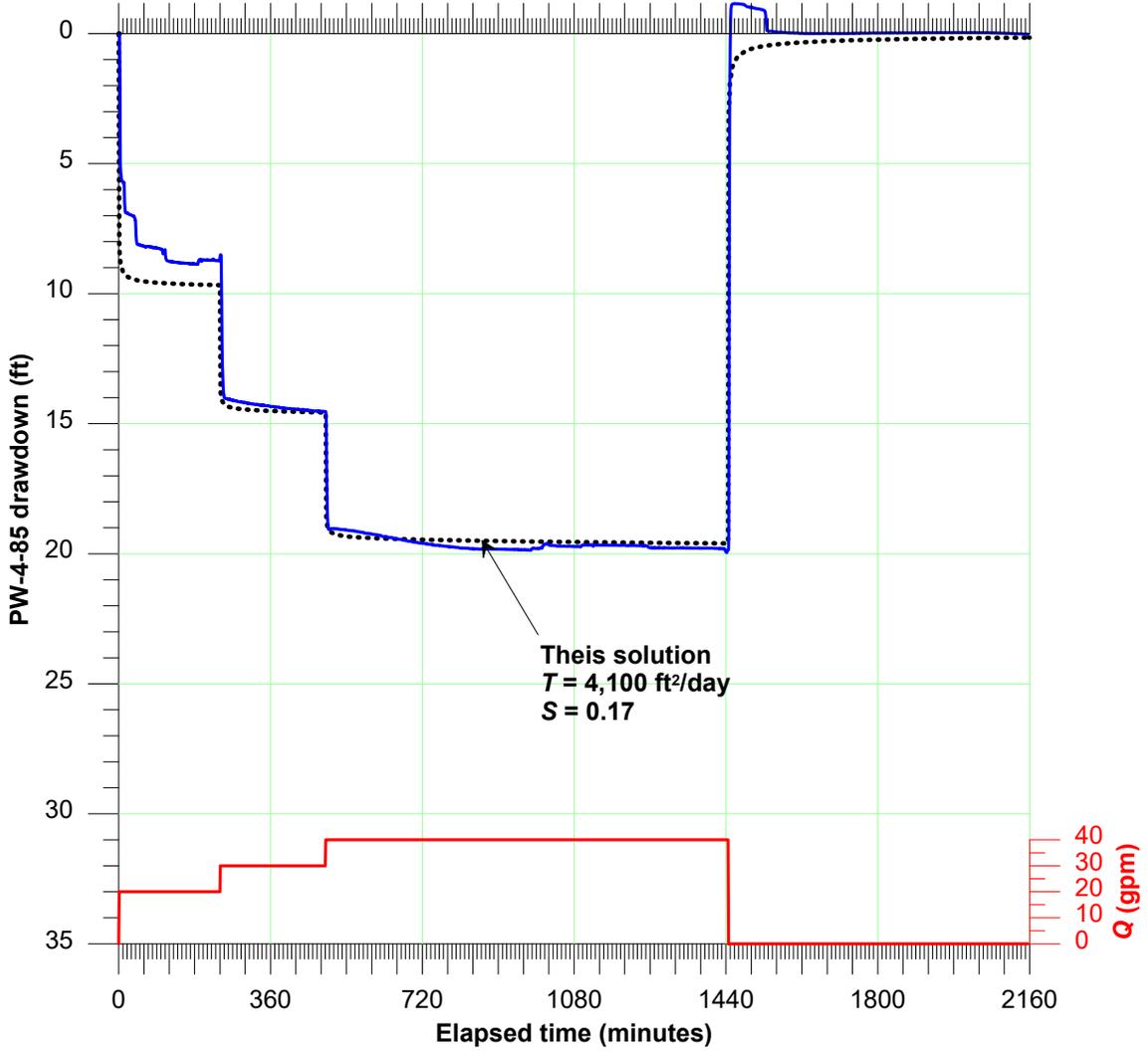
Figure 4. Match to the drawdowns with the Theis solution

4. Interpretation step #3: Refined analysis

To refine our interpretation, we try to identify whether nonlinear well losses might be a significant component of the drawdown in PW-4-85. This is done through what is referred to as a Hantush-Bierschenk analysis. The results of the analysis are shown in Figure 5. The results suggest that there are nonlinear well losses, with an estimated nonlinear well loss coefficient, C, of 0.029 ft/gpm^2. As shown in the Figure 6, the interpreted nonlinear well losses comprise an appreciable fraction of the total drawdowns.
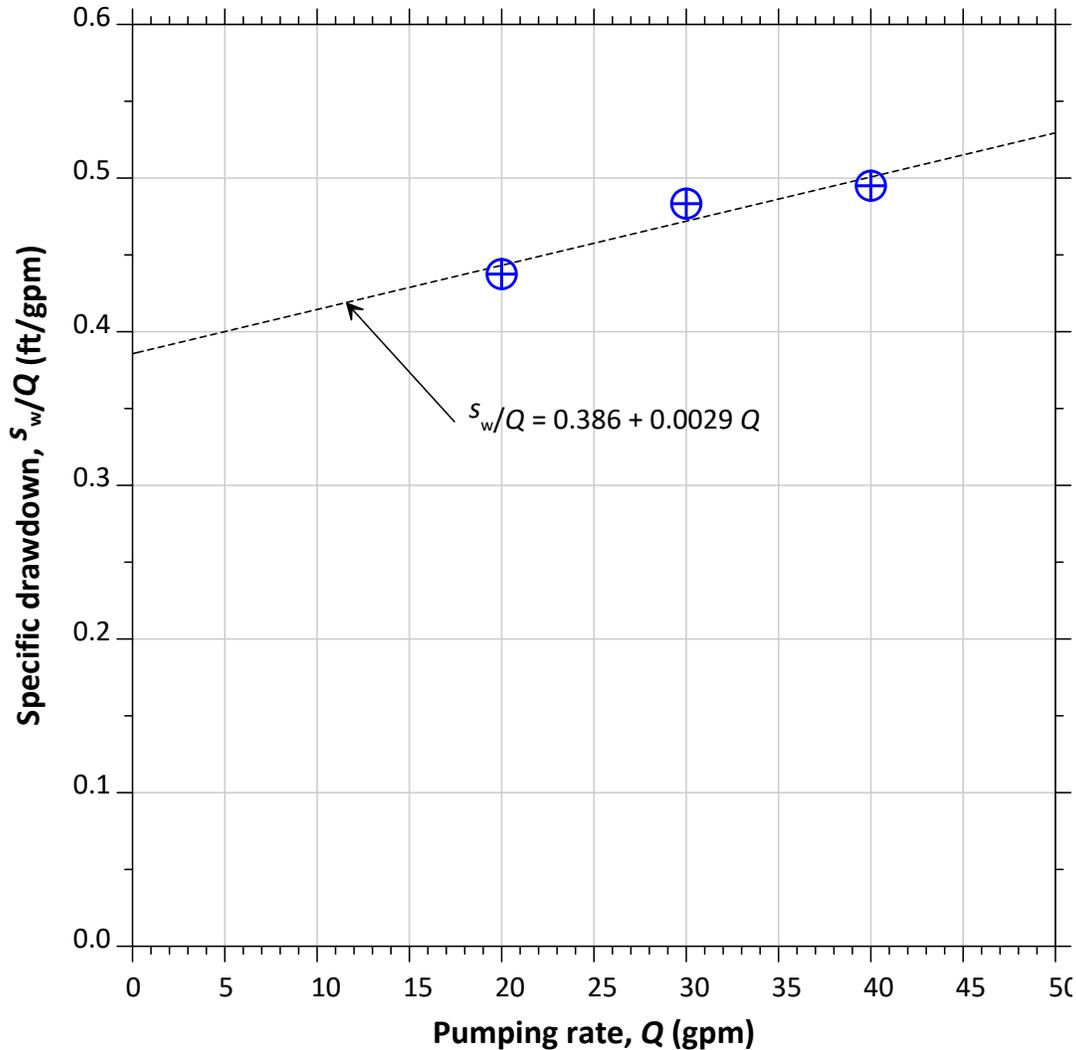

The figure shows a plot with y-axis labeled "Specific drawdown, s_w/Q (ft/gpm)" ranging from 0.0 to 0.6, and x-axis labeled "Pumping rate, Q (gpm)" ranging from 0 to 50. The fitted line equation is shown as $s_w/Q = 0.386 + 0.0029\,Q$.

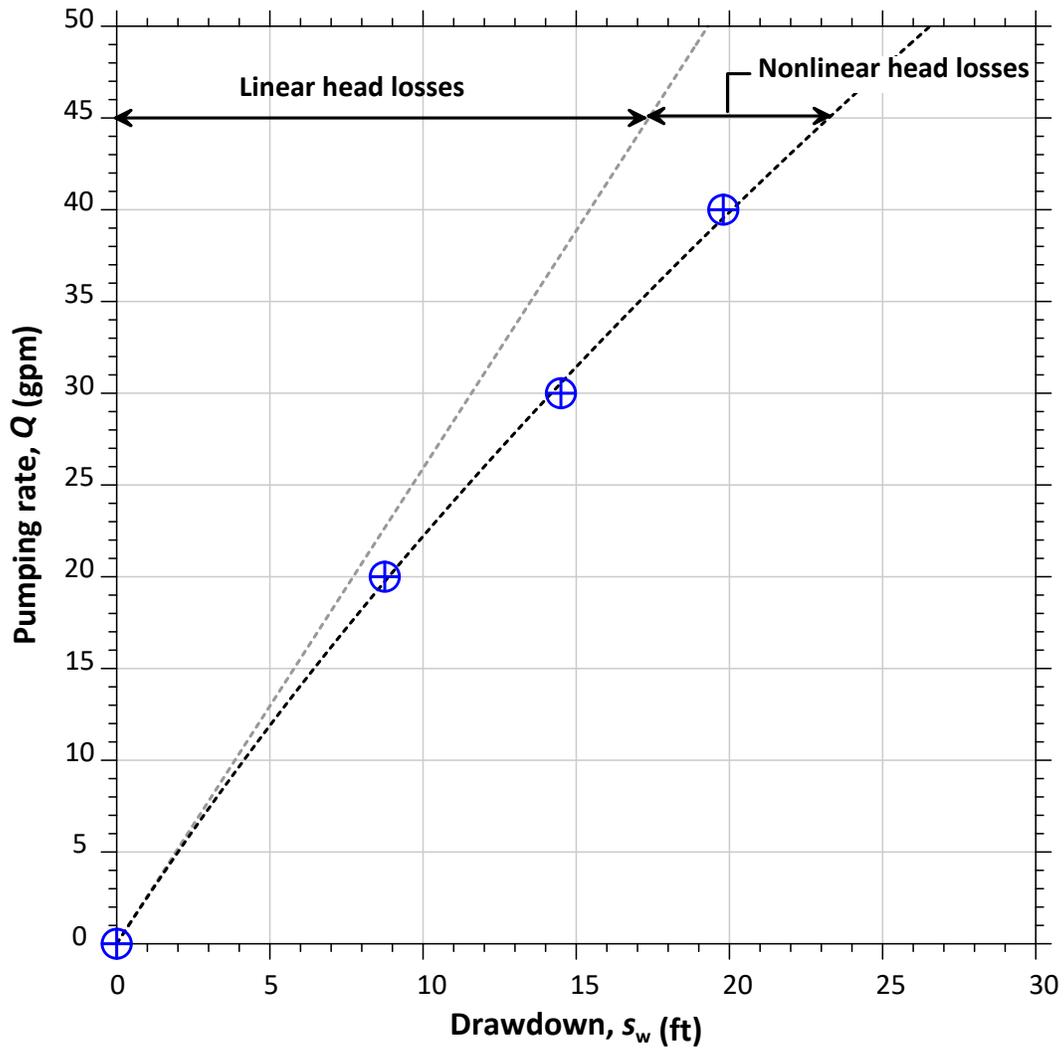**Figure 5. Hantush-Bierschenk analysis of PW-4-85 drawdowns**

Figure 6. Identification of linear and nonlinear components of PW-4-85 drawdown

As a second refinement of the interpretation, the storativity is fixed at a more realistic value for a confined aquifer ($S = 1{\times}10^{-4}$). The match to the drawdowns with the Theis solution incorporating the nonlinear well losses and a realistic storativity is shown in Figure 7. Comparing the matches shown in Figures 4 and 7, it is not possible to say that one match to the drawdowns is obviously superior. But there is an important difference between the results of the two analyses: the estimated transmissivity is increased significantly from 4,100 ft^2/day to 5,600 ft^2/day. The example presented here highlights the fact that the results of pumping tests analyses are contingent on the model that has been invoked in the interpretation.
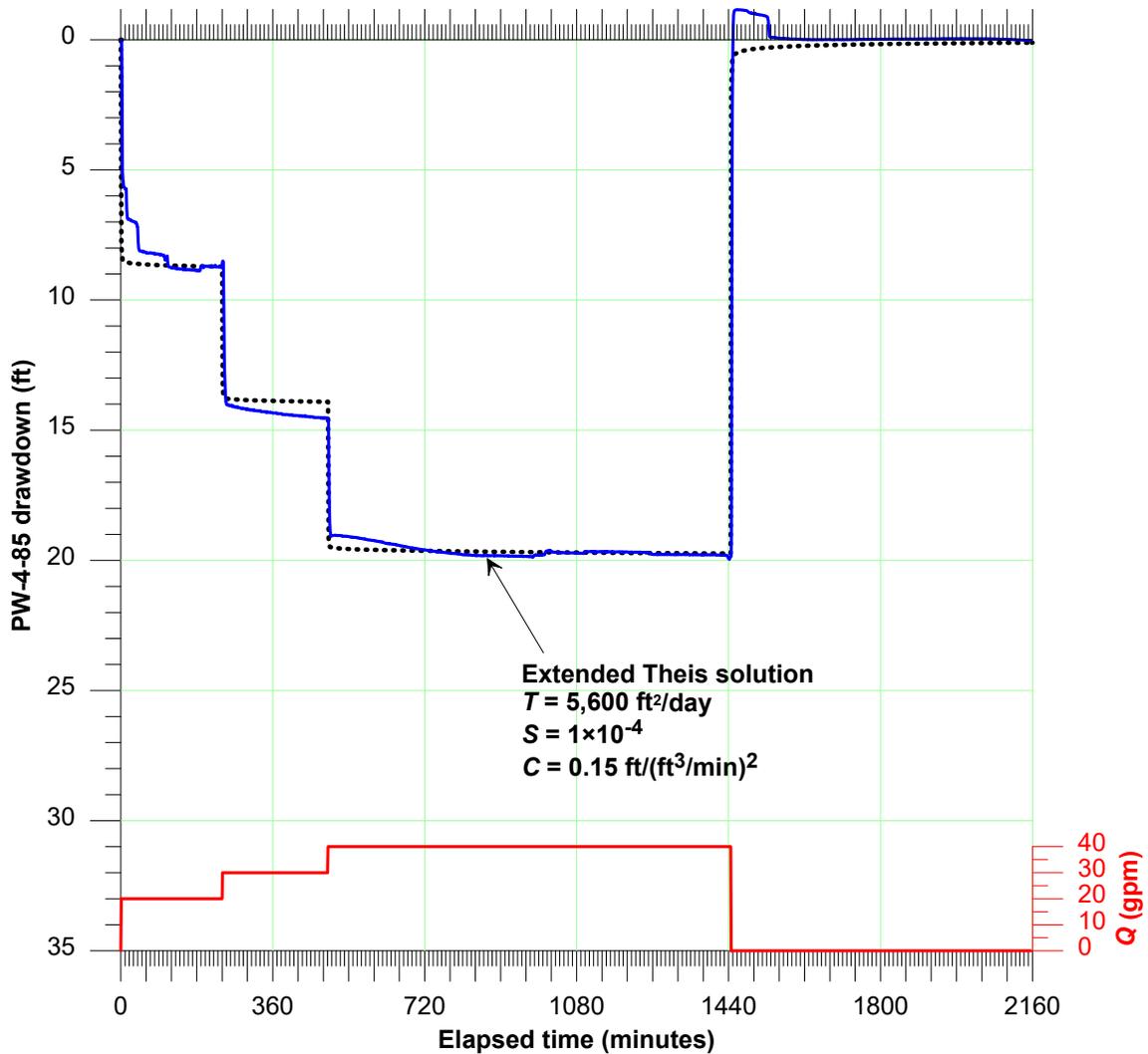

Extended Theis solution
$T = 5{,}600$ ft²/day
$S = 1{\times}10^{-4}$
$C = 0.15$ ft/(ft^3/min)^2

Figure 7. Alternative match to the drawdowns with the extended Theis solution

5. Perspective on the interpretation of pumping tests

1. Pumping rates and the water levels in the pumping well and adjacent observation wells are *data*. Everything else in the analysis of a pumping test is *interpretation*.

2. Analyses of pumping tests are conducted in terms of the changes in water levels caused only by pumping. These changes are referred to as *drawdowns*. The first step in the analysis must be the inference of the changes in water levels that are caused only by pumping.

3. Estimation of the values of properties of the subsurface requires selecting an idealized mathematical model of the subsurface and adjusting the parameters of the model until an acceptable match to the inferred drawdowns is obtained. Although inverse analyses may now be conducted with "automatic" curve-matching techniques, the interpreter must still select an appropriate model. Inferences regarding the structure of the subsurface are *interpretations* and the transmissivities and/or hydraulic conductivities developed from pumping test analyses must always be regarded as estimates and <u>never</u> as facts.