Using Excel for Aquifer Test

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Introduction

Entry level undergraduate students who use commercial software packages for aquifer test often feel frustrated and distant from real field test. This session introduces a method of aquifer test using Excel spreadsheet. Students are generally more interested in creating interactive tools to process aquifer test data to help them better understand aquifer response to pumping.

Creating a Scroll Bar in an Excel Worksheet

The key to create an interactive environment is the ability to change an aquifer parameter (for example, transmissivity) and to view the effect of this change on the type curve(s). A "scroll bar" can be used to vary parameter values in Excel. A scroll bar is created using the "Control Toolbox". This toolbox is shown in Figure 1. (Note: The Control Toolbox in your Excel program might have a different arrangement. Also, it might be "docked" to the edge of the worksheet, or "floating" on the worksheet.) If this toolbox is not visible, it can be displayed by clicking the "View" menu, then selecting "Toolbars", and then selecting "Control Toolbox".

To create a scroll bar on a worksheet, click the Scroll Bar button on the Control Toolbox, then draw (press left mouse button and drag) a long skinny rectangle on the worksheet to outline the scrollbar. When you are done, your worksheet should look like Figure 1. Note that (1) the small white squares around the scrollbar allows you to reshape the scrollbar, and (2) the Design Mode button in the Control Toolbox is now pressed, indicating that you can change the properties of the scroll bar. (Note that the scroll bar need not be aligned with the worksheet cells.) Next, right click on the scroll bar. A pop-up menu appears. Select "Properties". This displays the Properties window for the scroll bar (Figure 1). In the Properties window, enter a cell to be linked to the scroll bar. In our example, we will use cell H3 as the linked cell. Also, change the "Max" value to 10,000.

To return the worksheet to its normal operating mode, click the Design Mode button so it is no longer pressed. Test the scroll bar by dragging the slider. You should see the value in cell H3 change as you drag the slider. When the slider is at the left end of the scrollbar, the value in cell H3 should be 0. When the slider is at the right end of the scrollbar, the value in cell H3 should be 10000. **Note:** If you want to modify the toolbar at a later time, just click the Design Mode button and then click on the toolbar. Next, convert the value in cell H3 into a transmissivity value, which we will put in cell F3. If you want the transmissivity value to vary from 10^{-10} to 10^{0}, The formula for cell F3 is =10^((H3/1000)-10). Now if you drag the slider, the value in cell F3 should change from 10^{-10} to 10^{0} (Figure 2). The final step is to repeat the above procedure to create another scroll bar to change the storage coefficient. The storage coefficient value will be put in cell L3.
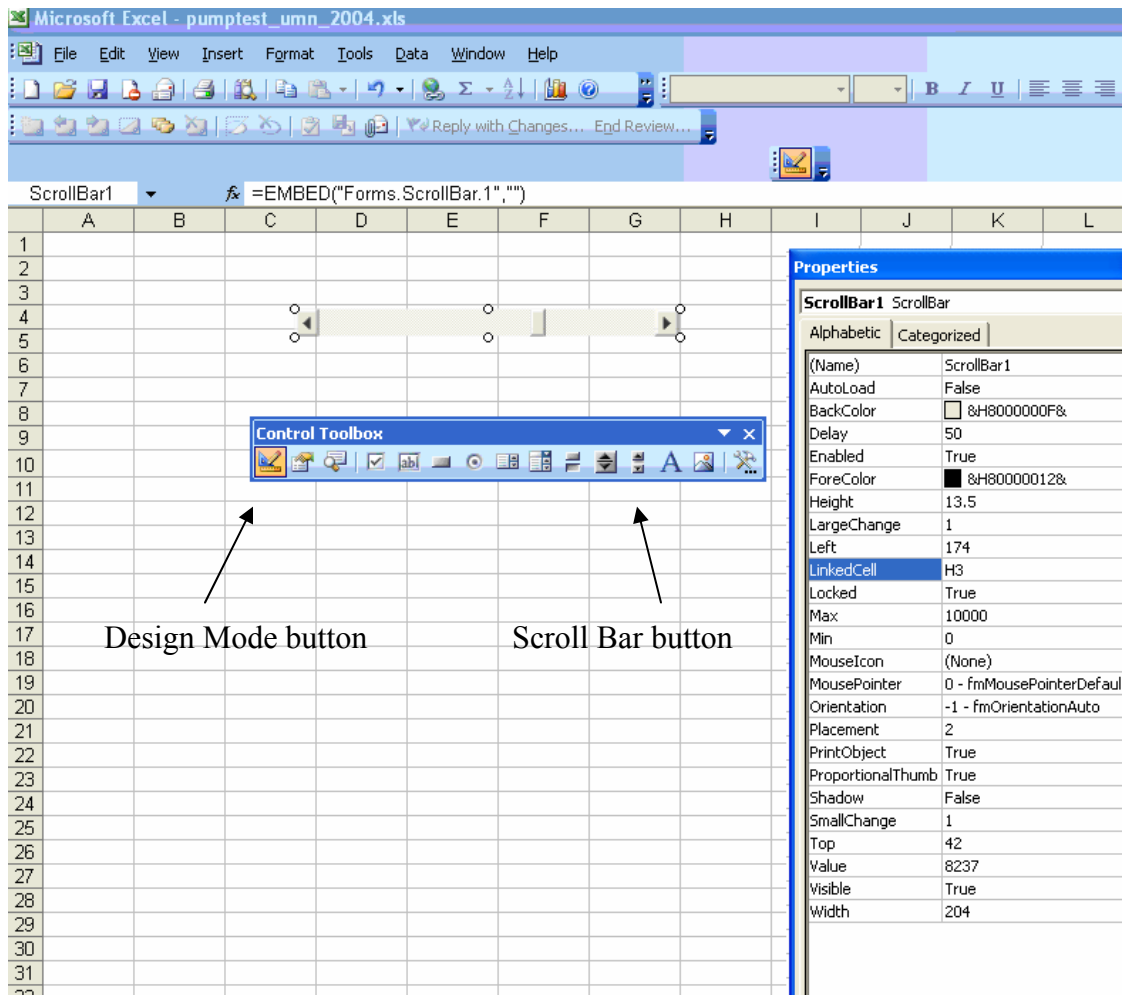
Figure 1. Control Toolbox in Excel (Notice that the "Scroll Bar" button is used to create a scroll bar. "Design Mode" button is pressed to edit the properties of the scroll bar. Here we entered "H3" as linked cell and "10000" as Max value).
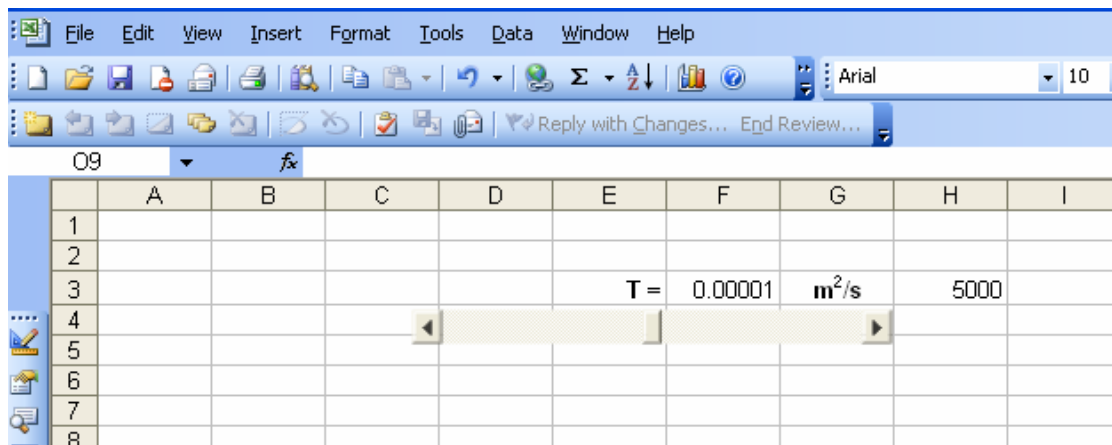

Figure 2. Using a scroll bar to change transmissivity value in cell F3.

Creating an Interactive Theis Type Curve

We now create a Theis type curve that can be controlled by the transmissivity and storage coefficient scroll bars. The Theis (1935) solution can be expressed as:

$$s(r,t) = \frac{Q}{4\pi T} E_1(u) = \frac{Q}{4\pi T} W(u)$$

$$u = \frac{r^2 S}{4Tt}$$

The function $E_1(u)$ is known as the exponential integral. It can be evaluated by polynomial and rational approximations given by Abramowitz and Stegun (1970, p. 231, eq. 5.1.53 and 5.1.56).

For $0 \leq x \leq 1$

$$E_1(x) + \ln(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3$$
$$+ a_4 x^4 + a_5 x^5 + \varepsilon(x)$$

$$|\varepsilon(x)| < 2 \times 10^{-7}$$

where

$a_0 = -0.57721566$ $a_1 = 0.99999193$
$a_2 = -0.24991055$ $a_3 = 0.05519968$
$a_4 = -0.00976004$ $a_5 = 0.00107857$

For $1 \leq x < \infty$

$$xe^x E_1(x) = \frac{x^4 + a_1 x^3 + a_2 x^2 + a_3 x + a_4}{x^4 + b_1 x^3 + b_2 x^2 + b_3 x + b_4} + \varepsilon(x)$$

$$|\varepsilon(x)| < 10^{-7}$$

where

$a_1 = 8.57332\ 87401$ $b_1 = 9.57332\ 23454$
$a_2 = 18.05901\ 69730$ $b_2 = 25.63295\ 61486$
$a_3 = 8.63476\ 08925$ $b_3 = 21.09965\ 30827$
$a_4 = 0.26777\ 37343$ $b_4 = 3.95849\ 69228$

In the ground-water field, the exponential integral $E_1(u)$ is known as the Theis well function and is denoted by $W(u)$.

Visual Basic is used to create a user-defined function to evaluate the exponential integral $E_1(u)$. The steps for creating the user defined function are as follows (Use the 2004 test data at University of Minnesota's hydrogeology field course, pumptest_umn_2004.xls as an example):

1. Clicking the "Tools" menu, then select "Macro", and then select "Visual Basic Editor". The Microsoft Visual Basic editor window appears. We will now work in this window (which contains several sub windows).

2. On the left is the "Project" sub window. This contains a "project tree" with main headings and subheadings. Select "VBAProject (pumptest_umn_2004.xls)".

3. Click the "Insert" menu and select "Module". A new sub window opens up. The title of this sub window is " VBAProject (pumptest_umn_2004.xls)". Note that back in the Project sub window, an extra item named "Modules" is added under the project "VBAProject (VBAProject (pumptest_umn_2004.xls)".

4. Copy the following code into the module sub window.

```
Public Function expint1(u As Double)
' Computes the exponential integral E1(u)
' Make sure u is not negative
If u < 0 Then
expint1 = "#NUM!"
ElseIf u <= 1 Then
expint1 = -0.57721566 + 0.99999193 * u _
- 0.24991055 * u ^ 2 + 0.05519968 * u ^ 3 _
- 0.00976004 * u ^ 4 + 0.00107857 * u ^ 5 - Log(u)
Else
expint1 = Exp(-u) * (u ^ 4 + 8.5773287401 * u ^ 3 _
+ 18.059016973 * u ^ 2 + 8.6347608925 * u + 0.2677737343) _
/ (u ^ 4 + 9.5733223454 * u ^ 3 + 25.6329561486 * u ^ 2 _
+ 21.0996530827 * u + 3.9584969228) / u
End If
If expint1 < 1E-100 Then
' We avoid returning 0 to prevent triggering
' an error message if we plot with log-log axes.
expint1 = 1E-100
End If
End Function
```

Note that the exponential function is called expint1 instead of E_1 because we don't want to fool Excel into thinking that we are referring to a cell. Also note that the underscore character (_) is the line continuation symbol in Visual Basic. A line that begins with a single quote is a comment line.

5. Click the "File" menu and select "Save pumptest_umn_2004.xls ". This saves the macro with the workbook.

To create the interactive Theis type curve, use the following procedure:

1. Put the pumping rate (Q) into cell B2. In this example, use a pumping rate of 0.008 m^3/s (128 gal/min). This is the pumping rate for the multiple well aquifer test in 2004 at University of Minnesota's hydrogeology field site.

2. In column A, starting at row 5, create a column of values for t/r^2. The first row starts at 0.001 and for each successive row, multiply the value in the previous row by 1.2, proceed down to row 95, where the value is 13376.

3. In column B, starting at row 5, use the Theis equation to compute the drawdown for the t/r^2 value in column A. For example, the formula for cell B5 is

$$=(\$B\$2/4/PI()/\$F\$3)*expint1(\$L\$3/4/\$F\$3/A5)$$

Q   T   S   T t/r^2

Note the absolute reference (indicated by the $ symbol) to the cells containing Q, T, and S.

4. Create a log-log plot of drawdown versus time, using data in the cell range A5:B95. The resultant worksheet should look like Figure 3. When you drag the slider of the T or S scrollbar, the computed drawdowns in column B should change, and the type curve should also change in the plot. The behavior of the Theis solution (on log-log plot) can be readily demonstrated by varying the T and S values using the scroll bar. As the S value is changed, the type curve is translated horizontally to the left or right. As the T value is changed, the type curve is translated diagonally. However, the shape of the type curve is always the same.

In another worksheet, repeat the above procedure (or use copy and paste) to create another Theis type curve on semi-log plot. This is shown in Figure 4. The behavior of the Theis solution (on semi-log plot) can again be readily demonstrated. As the S value is changed, the type curve is translated horizontally to the left or right. As the T value is changed, the slope of the straight-line portion is increased or decreased.
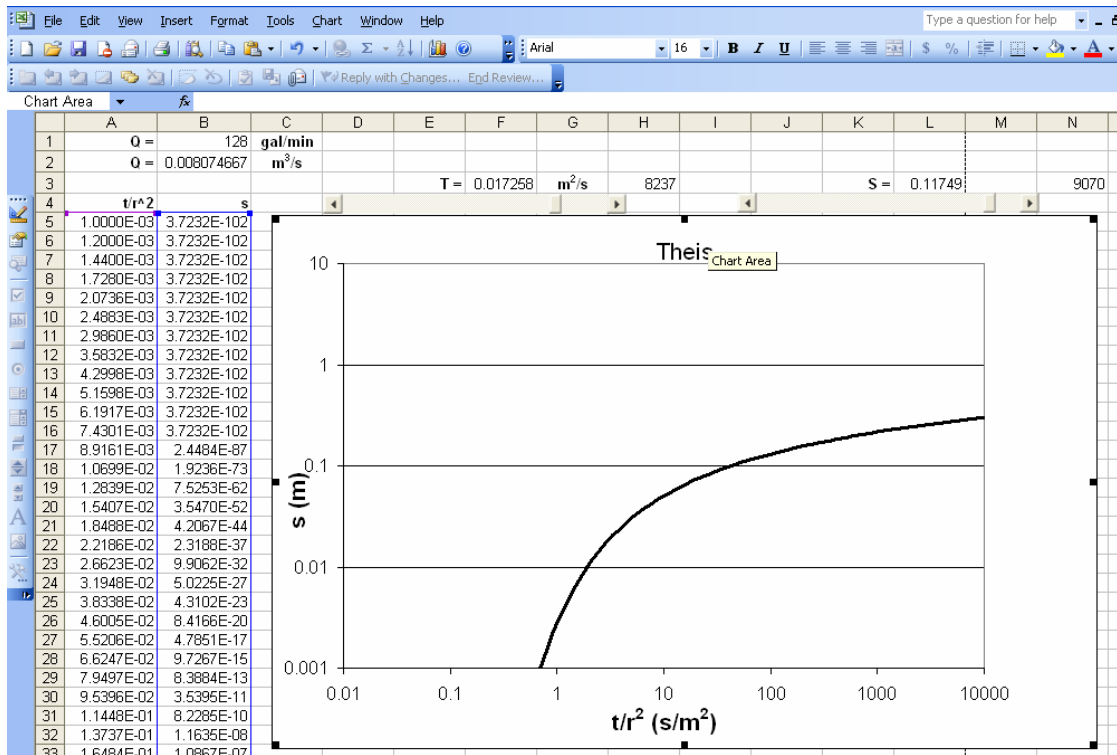
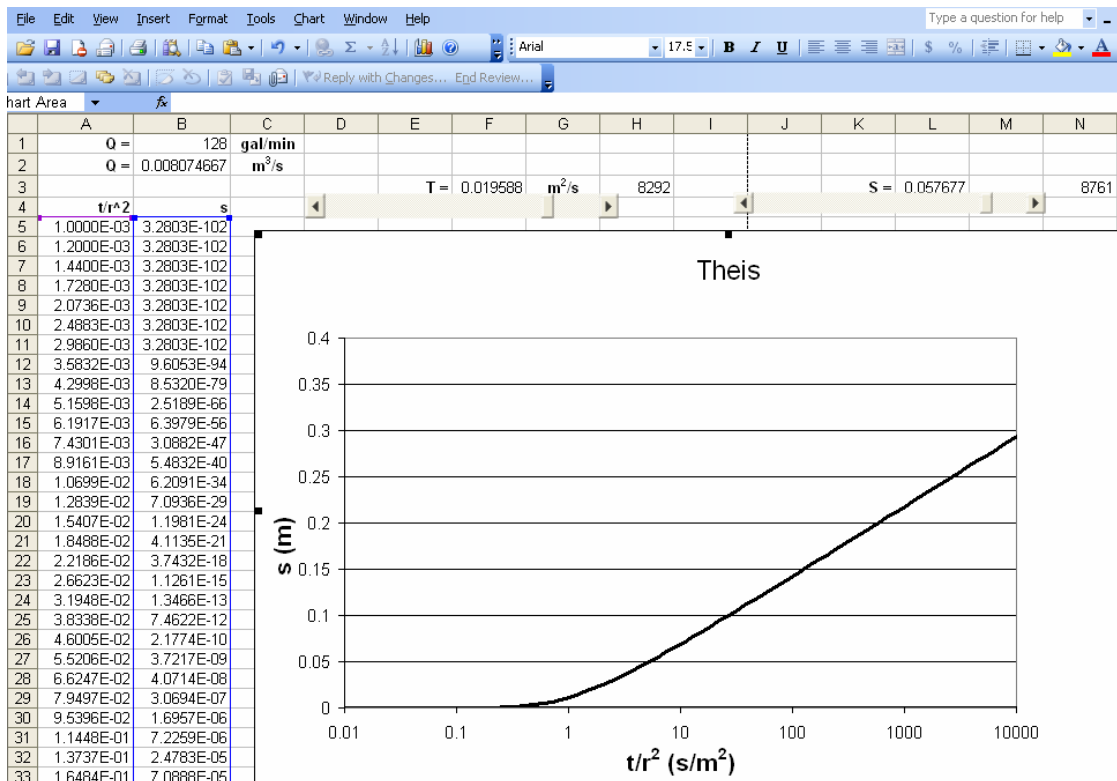Figure 3. Excel worksheet showing interactive Theis type curve (log-log plot).

Figure 4. Excel worksheet showing interactive Theis type curve (semi-log plot).

Using the Interactive Theis Type Curve for Data Analysis

To illustrate the use of the interactive Theis curve, we analyze the aquifer test data from University of Minnesota's hydrogeology field site in 2004. We can import the drawdown data from observation wells 1, 2, 4, 5 and 7 into a separate work sheet, and then compute $t/r2$ for each data point. Then we can add the observed data on the log-log and semi-log plots with the interactive type curve. It is easy to adjust the scrollbars for T and S until the type curve fits the data (to the extent that the type curve can fit the data), as illustrated by Figure 5. The Excel workbook (pumptest_umn_2004.xls) and water well distribution (wellfield2003.xls) for this exercise can be downloaded from the "Teaching Hydrogeology in the 21st Century" web site (http://serc.carleton.edu/NAGTWorkshops/hydrogeo/activities.html).
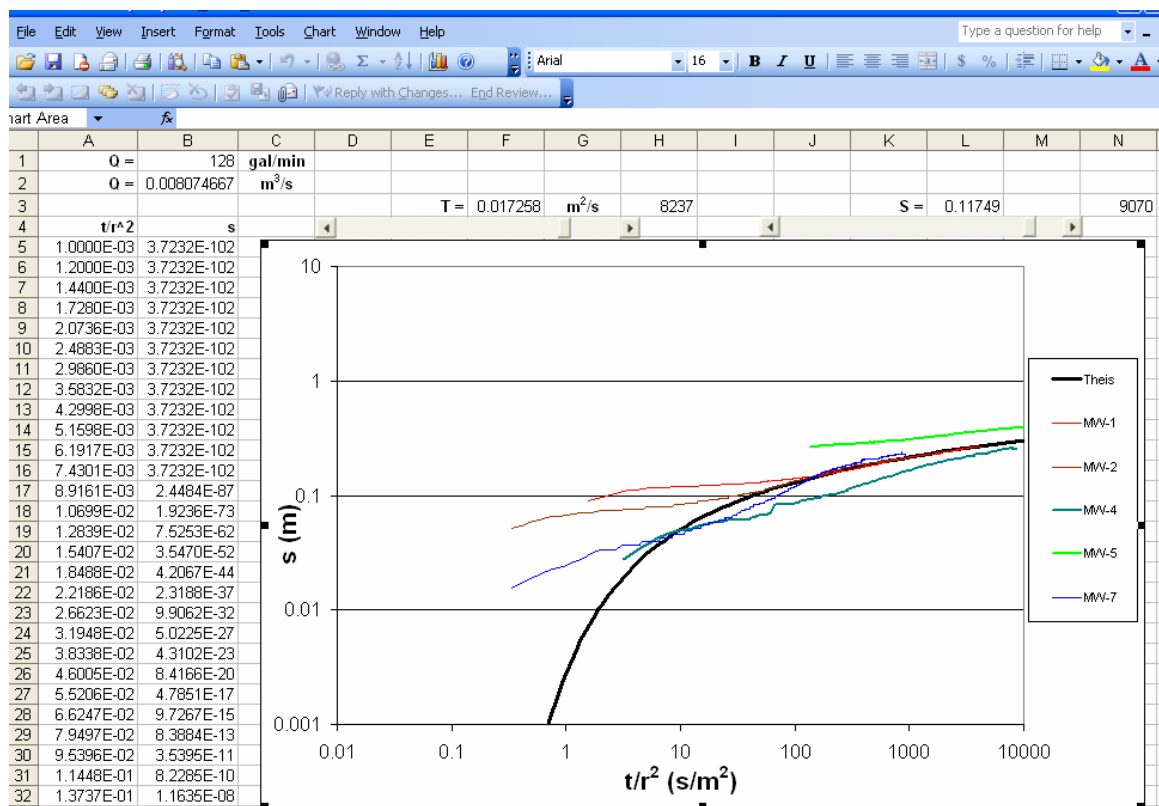

Figure 5. Matching the Theis type curve to observed drawdown on log-log plot

References

Abramowitz, M., and Stegun, I.A., eds., 1970, Handbook of Mathematical Functions, National Bureau of Standards Applied Mathematics Series 55, Washington, D.C., 1046 p.

Theis, C. V., 1935, The relationship between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage, Transactions American Geophysical Union, v. 16, p. 519-524.