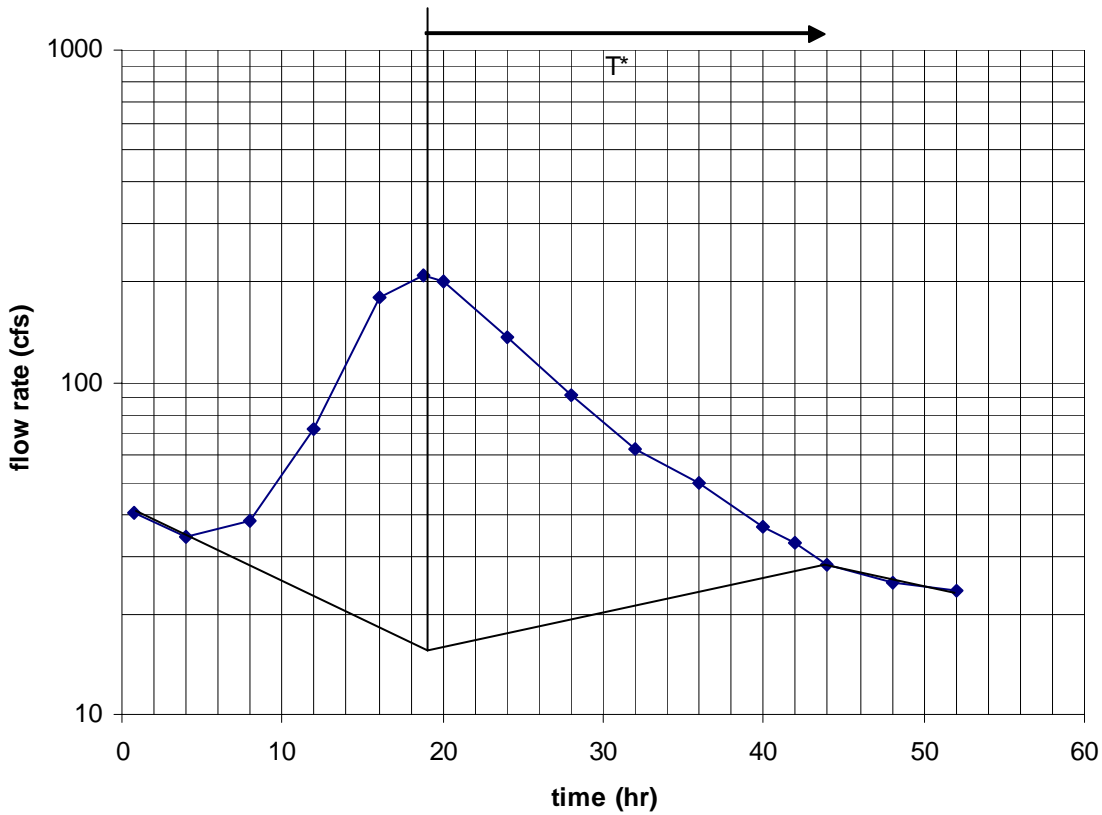


1. Hydrograph separation

Using the observations of storm runoff in the river, one may plot the hydrograph as follows:



where $T^* = 1.04$ days or 25 hours is calculated using the relationship $T^* = A^2$, where A is the drainage area of the jurisdictions. To determine the total groundwater recharge, we use the following equations:

$$V_r = Q_0'/k_2 - Q_0/k_1 e^{(-k_1 t)}, \quad Q = Q_0 e^{(-k t)}$$

where Q_0 and Q_0' are the initial flow rate of the recession curves before the ascending and after the descending limbs of the hydrograph and Q is the final value of the recession curves. One reads from the hydrograph the following values:

```
> Q[0,1,cfs] := 40.63; Q[1,cfs] := 15.5; t[1,sec] := (19 - 0.8)*60*60; k[1,1/sec] := -ln(Q[1,cfs]/Q[0,1,cfs])/t[1,sec];
Q[0,2,cfs] := 28.13; Q[2,cfs] := 23.44; t[2,sec] := (52 - 44)*60*60; k[2,1/sec] := -ln(Q[2,cfs]/Q[0,2,cfs])/t[2,sec];
```

$$Q_{0,1,cfs} := 40.63$$

$$Q_{1,cfs} := 15.5$$

$$t_{1,sec} := 65520.0$$

$$k_{1, \frac{1}{sec}} := 0.00001470797751$$

$$Q_{0,2,cfs} := 28.13$$

$$Q_{2,cfs} := 23.44$$

$$t_{2,sec} := 28800$$

$$k_{2,\frac{1}{sec}} := 0.6333078396 \cdot 10^{-5}$$

```
> V[r,ft^3] := Q[0,2,cfs]/k[2,1/sec] -
Q[0,1,cfs]/k[1,1/sec]*exp(-1*k[1,1/sec]*t[1,sec]);
```

$$V_{r,ft^3} := 0.3387907886 \cdot 10^7$$

Groundwater recharge occurs over a period of four weeks. Therefore, a representative average recharge rate will be:

```
> Q[r,ft^3/hr] := V[r,ft^3]/(4*7*24);
```

$$Q_{r,\frac{ft^3}{hr}} := 5041.529592$$

2. Permeameter and equivalent hydraulic conductivity

Given the specification of the permeameter, one may calculate the hydraulic conductivities of the rock layers using the following equation:

$$K = \frac{2.3 a L}{A (t_1 - t_0)} \log_{10} \left(\frac{h_0}{h_1} \right).$$

For the first layer, one has:

```
> A := 3.14159*(1/12)^2; a := 3.14159*(0.25/12)^2; h[0] := 5;
t[1] := 30/60; L := 6/12; h[1,1] := 1.61; K[1,ft/hr] :=
2.3*a*L/(A*t[1])*log10(h[0]/h[1,1]);
```

$$A := 0.02181659722$$

$$a := 0.001363537326$$

$$h_0 := 5$$

$$t_1 := \frac{1}{2}$$

$$L := \frac{1}{2}$$

$$h_{1,1} := 1.61$$

$$K_{1,\frac{ft}{hr}} := 0.07074571842$$

and for the second and third layer:

```
> h[1,2] := 4.14; K[2,ft/hr] :=
2.3*a*L/(A*t[1])*log10(h[0]/h[1,2]); h[1,3] := 0.75; K[3,ft/hr]
:= 2.3*a*L/(A*t[1])*log10(h[0]/h[1,3]);
```

$$h_{1,2} := 4.14$$

$$K_{2, \frac{ft}{hr}} := 0.01178313910$$

$$h_{1,3} := 0.75$$

$$K_{3, \frac{ft}{hr}} := 0.1184368815$$

Assuming the aquifers are homogeneous and isotropic, one may calculate the equivalent hydraulic conductivities parallel and perpendicular to the general direction of the confined aquifer using the following equations:

$$K_x = \frac{\sum m_i K_i}{\sum m_i} \text{ and } K_z = \frac{\sum m_i}{\sum \frac{m_i}{K_i}}. \text{ Numerically, they are:}$$

```
> K[x] := (75*K[1,ft/hr]+50*K[2,ft/hr]+25*K[3,ft/hr])/(75+50+25);
K[z] := (75+50+25)/(75/K[1,ft/hr]+50/K[2,ft/hr]+25/K[3,ft/hr]);
```

$$K_x := 0.05904005249$$

$$K_z := 0.02720067446$$

Transmissivity of the entire confined aquifer may thus be calculated as:

```
> T := K[x]*(75+50+25);
```

$$T := 8.856007874$$

with a unit of ft^2/hr .

Design a well

To solve the problem, one needs to use the workbook Theis.xls and the principle of superposition by placing an image well 100 ft across the river. The following table summarizes the calculations:

r_w	Q	C	s_w	s_p	s_i	s_t	E_p	Q_r
1	632	0.00015	59.91	78.43	-18.43	60.00	0.50	-127.85
0.50	537	0.0002	57.67	73.33	-15.64	57.69	0.50	-32.85
0.25	479	0.0003	57.36	71.37	-13.94	57.43	0.50	25.15

In the above table, r_w is the well radius (ft), Q is maximum allowable pumping rate (ft^3/hr), C is well loss constant, s_w is well loss (ft), s_p is the drawdown (ft) as a result of the pumping well before the image well drawdown, s_i (ft), is added to obtain the theoretical drawdown s_t (ft). The well efficiency

is calculated using the relation $E_p = \frac{s_t}{s_w + s_t}$. Given that 10% of the annual groundwater recharge is

received by the confined aquifer, one may calculate the amount of water in $\frac{ft^3}{hr}$ that the well is to withdraw from the river. In the above table, the column under Q_r indicates this amount of water from the river if the balance is negative. The calculations for the 6 in well is contained in [this workbook](http://research.umbc.edu/~jgwo/Courses/IntroductionToSubsurfaceHydrology/final.xls) at <http://research.umbc.edu/~jgwo/Courses/IntroductionToSubsurfaceHydrology/final.xls>. The general solution procedure is:

- 1. Use the efficiency requirement and the well diameter to determine the drawdown at the well. One needs to do this by trial and error by adjusting the pumping rate or Q in the EXCEL workbook. In the case of the 6 in well and in the EXCEL workbook, the efficiency requirement was satisfied by setting well pumping rate at $479 \text{ ft}^3/\text{hr}$. In the spreadsheet Type Curve, cell F2 is the drawdown due to the well itself and cell F66 is the drawdown due to the image well. Because the image well is an injection well, one must subtract F66 from F2. The result was placed in cell G2. Because Q, the pumping rate, does not enter the calculation of Type Curve, one needs to do the type curve calculation only once for each type of well. Drawdowns then change linearly with the pumping rate. The calculation of well efficiency is set up in the spreadsheet Parameters.**
- 2. From results in Problem 1, we know 10% of groundwater recharge is about $504.15 \text{ ft}^3/\text{hr}$, the water required from the river is thus the difference between the pumping and this value. If the balance is due to the river (negative in the spreadsheet shown here), then we draw water from the river. Otherwise, the groundwater recharge is enough to supply the pumpage. The calculation shown above suggest that with the 6 in well, one does not need to pull water from the river. For the 12 and 24 in wells, we do need recharge from the river.**