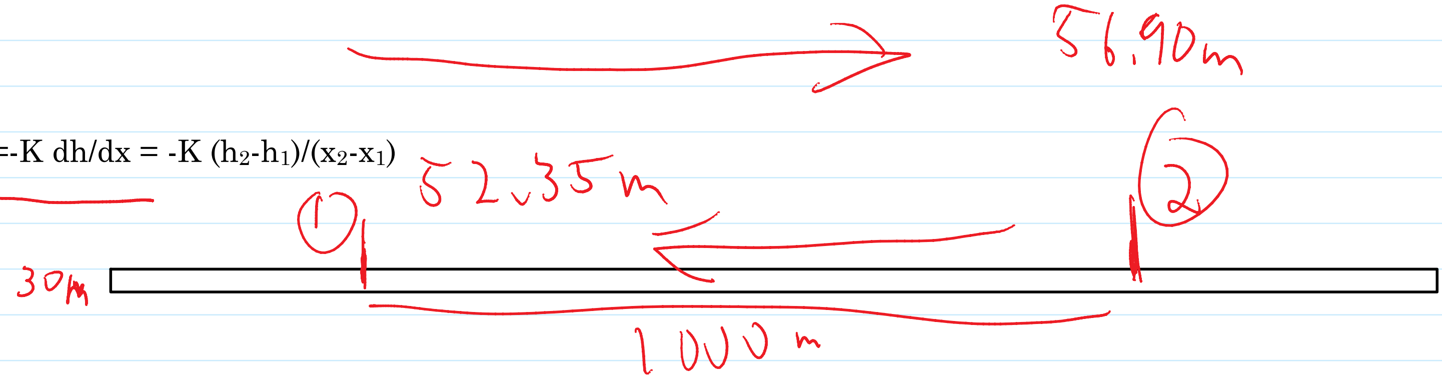
3.1.1 A confined aquifer with a porosity of 0.15 is 30 m thick. The potentiometric surface elevations at two observation wells 1,000 m apart are 52.35 m and 56.90 m. If the horizontal hydraulic conductivity of the aquifer is 25 m/day, determine the flow rate per unit width of the aquifer, specific discharge, and average linear velocity of the flow assuming steady unidirectional flow. How long would it take for a tracer to travel the distance between the obervation wells?

$q=-K\, dh/dx = -K\,(h_2-h_1)/(x_2-x_1)$



$$q = -25\ \frac{m}{day}\left(\frac{(56.9-52.35)\,m}{1000\ m}\right)$$

-25*(56.9-52.35)/1000=-0.1138 $\frac{m^3}{m^2\,day}$

0.1138*30=3.414 $\frac{m^4}{m^2\,day} = \frac{m^2}{day} = \frac{m^3}{m\,day}$

1000/(0.1138/0.15)=1318.1019 days

3.1.1 From Darcy's Law:

$$q = -Kb\frac{dh}{dl} = -(25\ m/day)(30\ m)\left(\frac{(56.90\ m - 52.35\ m)}{1000\ m}\right) = 3.4125\ m^3/day$$

Specific discharge can be found as follows:

$$v = \frac{Q}{A} = \frac{q}{b} = -K\frac{dh}{dl} = -(25\,m/day)\frac{(56.90\,m - 52.35\,m)}{1000\,m} = 0.11375\,m/day = 11.375\,cm/day$$

The seepage velocity, or average linear velocity is calculated as follows:

$$v_p = \frac{v}{n_e} = \frac{0.11375\,m/day}{0.15} = 0.7583\ m/day = 75.83\ cm/day$$

It would take $t = (1000\ m)/(0.7583\ m/day) = 1319\ days \cong 3.6\ years$ for a tracer to travel the distance between the wells.

3.1.2

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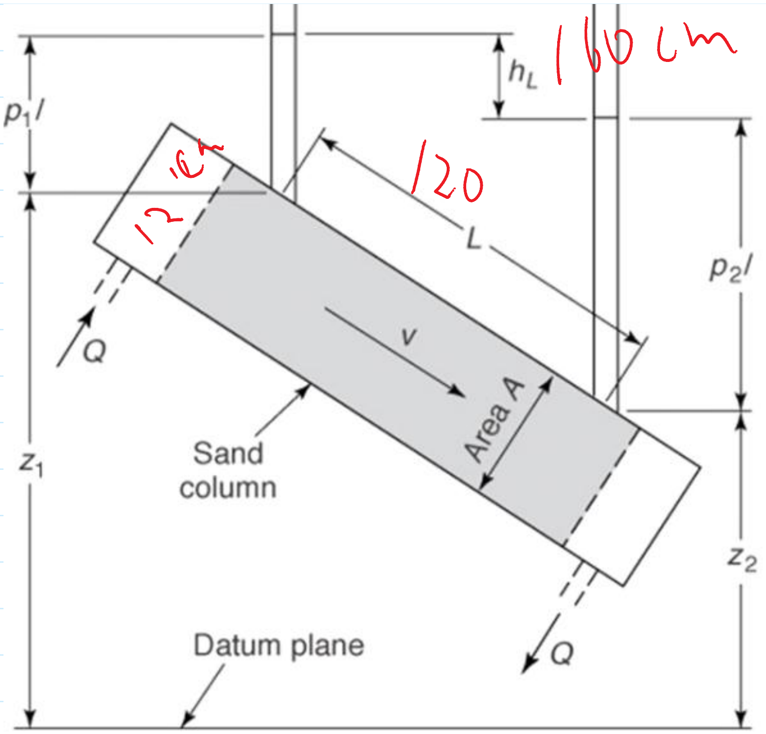
3.1.2 A field sample of an aquifer is packed in a test cylinder (see Figure 3.1.1). The cylinder has a length of 120 cm and a diameter of 12 cm. The field sample with a porosity of 0.24 is tested under a constant head difference of 160 cm with water at 10°C. If the estimated hydraulic conductivity of the sample is 30 m/day, calculate (a) the expected total discharge, (b) the specific discharge, (c) the average flow velocity, and (d) the hydraulic gradient along the cylinder.



$\phi = 0.24$

$K = 30$ m/day

total $= q A_t = KA \frac{h_2 - h_1}{x_2 - x_1}$

30*3.14*0.06^2*(160)/120=0.4522 m^3/day

30*(160)/120=40 m/day

30*(160)/120/0.24=166.6667 m/day

3.1.2 (a) The cross-sectional area of the sample is

$$A = \frac{\pi D^2}{4} = \frac{\pi (0.12\ m)^2}{4} = 0.01131\ m^2$$

The hydraulic gradient, *dh/dl*, is given by

$$\frac{dh}{dl} = \frac{(-160\ cm)}{120\ cm} = -1.333$$

Applying Darcy's Law using Eq. 3.1.4

$$Q = -KA\frac{dh}{dl} = -(30\ m/day)(0.01131\ m^2)(-1.333) = 0.4524\ m^3/day$$

(b) Specific discharge or Darcy velocity is given by equation 3.1.5

$$v = -K\frac{dh}{dl} = -30\ m/day\frac{(-1.6\ m)}{(1.2\ m)} = 40\ m/day = 4.63 \times 10^{-4}\ m/s$$

(c) The porosity of the sample, α, is given as 0.24. Thus, using equation 3.1.6

$$v_a = \frac{Q}{\alpha A} = \frac{v}{\alpha} = \frac{40\ m/day}{0.24} = 166.67\ m/day = 1.929 \times 10^{-3}\ m/s$$

(d) The hydrauic gradient, *dh/dl*, has allready been found as (-1.333)

3.2.1

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Hydraulic conductivity of medium sand, 11.2 m/day at 25C, What is intrinsic permeability? What is the expected in-situ hydraulic conductivity if the natural groundwater temperature is 10C?

$k = K\,\mu/(\rho g) = K\,\nu/g$

Calculate k, then K at other temperature

TABLE 1.3 Viscosities of Water and Air

Temperature (°C)	Water Viscosity (μ) N·sec/m²	Water Kinematic Viscosity (ν) m²/sec	Air Viscosity (μ) N·sec/m²	Air Kinematic Viscosity (ν) m²/sec
0	1.781×10^{-3}	1.785×10^{-6}	1.717×10^{-5}	1.329×10^{-5}
5	1.518×10^{-3}	1.519×10^{-6}	1.741×10^{-5}	1.371×10^{-5}
10	1.307×10^{-3}	1.306×10^{-6}	1.767×10^{-5}	1.417×10^{-5}
15	1.139×10^{-3}	1.139×10^{-6}	1.793×10^{-5}	1.463×10^{-5}
20	1.002×10^{-3}	1.003×10^{-6}	1.817×10^{-5}	1.509×10^{-5}
25	0.890×10^{-3}	0.893×10^{-6}	1.840×10^{-5}	1.555×10^{-5}
30	0.798×10^{-3}	0.800×10^{-6}	1.864×10^{-5}	1.601×10^{-5}
40	0.653×10^{-3}	0.658×10^{-6}	1.910×10^{-5}	1.695×10^{-5}
50	0.547×10^{-3}	0.553×10^{-6}	1.954×10^{-5}	1.794×10^{-5}
60	0.466×10^{-3}	0.474×10^{-6}	2.001×10^{-5}	1.886×10^{-5}
70	0.404×10^{-3}	0.413×10^{-6}	2.044×10^{-5}	1.986×10^{-5}
80	0.354×10^{-3}	0.364×10^{-6}	2.088×10^{-5}	2.087×10^{-5}
90	0.315×10^{-3}	0.326×10^{-6}	2.131×10^{-5}	2.193×10^{-5}
100	0.282×10^{-3}	0.294×10^{-6}	2.174×10^{-5}	2.302×10^{-5}

TABLE 1.2 Density and Specific Weight of Water

Temperature (°C)	Density (ρ, kg/m³)	Specific Weight (γ, N/m³)
0° (ice)	917	8,996
0° (water)	999	9,800
4°	1,000	9,810
10°	999	9,800
20°	998	9,790
30°	996	9,771
40°	992	9,732
50°	988	9,692
60°	983	9,643
70°	978	9,594
80°	972	9,535
90°	965	9,467
100°	958	9,398

$k = K\,\mu/(\rho g) = K\,\nu/g$

11.2*0.893*10^-6/9.81=0.0

1.18e-11

$$\frac{m}{s}\,\frac{m^2 s^2}{s\; m} = m^2$$

1.18e-11*9.81/1.306e-6=
0.0001

$$K = \frac{k g}{\nu} =$$

7.81

30 to 7.65 m/day

11.2
*0.893/1.306=7.6582

3.2.1 (a) The relationship between intrinsic permeability and hydraulic conductivity is given by equation 3.2.1

$$k = \frac{K\mu}{\rho g}$$

For water at 25°C, $\rho = 997.044$ kg/m^3, $\mu = 8.937 \times 10^{-4}\ kg/s.m$

and the acceleration of gravity is given as

$$g = 9.81\, m/s^2$$

$K = 11.2\ m/day = 1.2963 \times 10^{-4}\ m/s$

$$k = \frac{K\mu}{\rho g} = \frac{(1.2963 \times 10^{-4}\ m/s)(8.937 \times 10^{-4}\ kg/s.m)}{(997.044\ kg/m^3)(9.81\ m/s^2)} = 1.184 \times 10^{-11}\ m^2$$

or

$k = 11.84\ (\mu m)^2$

(b) For water at 25°C, $\rho = 999.700$ kg/m^3, $\mu = 1.3077 \times 10^{-3}\ kg/s.m$

Rearrange equation 3.2.1 to obtain the hydraulic conductivity in the field.

$$K = \frac{k\rho g}{\mu} = \frac{(1.184 \times 10^{-11}\ m^2)(999.700\ kg/m^3)(9.81\ m/s^2)}{(1.3077 \times 10^{-3}\ kg/s.m)} = 8.879 \times 10^{-5}\ m/s$$

or

$K = 7.67\ m/day$

3.3.3

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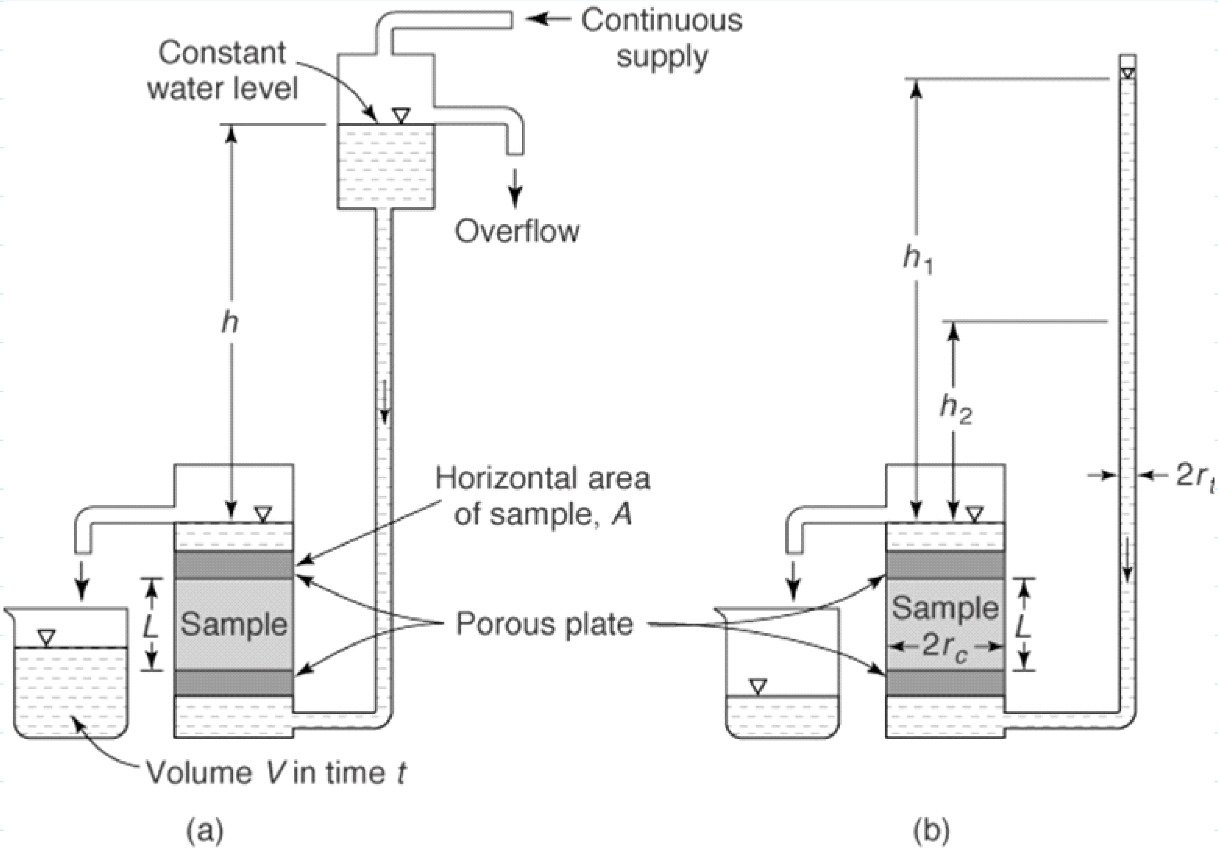
30 cm long sample tested in falling head permeameter with 10 cm diameter cylinder. Diameter of tube is 10 mm. Water level begins at 35 cm above outlet level, drops to 22 cm after 11 hours of operation; find K



$K = r_t^2/r_c^2 \ L/t \ \mathrm{Ln}(h_1/h_2)$

3.3.3 Equation 3.3.6 is used to determine the hydraulic conductivity in a falling-head permeameter test

$$K = \frac{r_t^2 L}{r_c^2 t} \ln \frac{h_1}{h_2} = \frac{(0.5\ cm)^2 (30\ cm)}{(5.0\ cm)^2 (11 \times 3600\ \text{sec})} \ln \frac{35\ cm}{22\ cm} = 3.517 \times 10^{-6}\ cm/s$$

or

$$K = 3.04 \times 10^{-3}\ m/day$$

3.4.2

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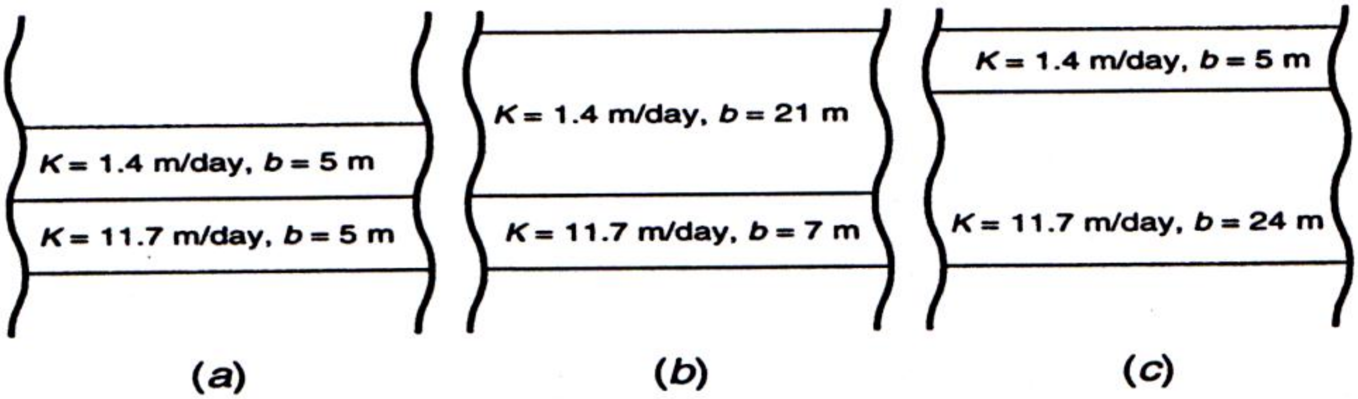
3.4.2 The stratification of a confined aquifer with a horizontal bed varies as follows. Calculate the equivalent horizontal and vertical hydraulic conductivities in each case. What happens to the degree of anisotropy?



3.4.2 Eq. 3.4.5 can be used to determine the equivalent horizontal hydraulic conductivities:

$$K_{xA} = \frac{K_1 z_1 + K_2 z_2}{z_1 + z_2}$$

$$= \frac{(1.4\ m/day)(5\ m) + (11.7\ m/day)(5\ m)}{(5\ m + 5\ m)} = 6.55\ m/day$$

$$K_{xB} = \frac{(1.4\ m/day)(21\ m) + (11.7\ m/day)(7\ m)}{(21\ m + 7\ m)} = 3.975\ m/day$$

$$K_{xC} = \frac{(1.4\ m/day)(5\ m) + (11.7\ m/day)(24\ m)}{(5\ m + 24\ m)} = 9.92\ m/day$$

and the equivalent vertical hydraulic conductivities can be found using Eq. 3.4.12:

$$K_{zA} = \frac{z_1 + z_2}{\frac{z_1}{K_1} + \frac{z_2}{K_2}}$$

$$= \frac{(5\ m) + (5\ m)}{\frac{5\ m}{1.4\ m/day} + \frac{5\ m}{11.7\ m/day}} = 2.5\ m/day$$

$$K_{zB} = \frac{(21\ m) + (7\ m)}{\frac{21\ m}{1.4\ m/day} + \frac{7\ m}{11.7\ m/day}} = 1.795\ m/day$$

$$K_{zC} = \frac{(5\ m) + (24\ m)}{\frac{5\ m}{1.4\ m/day} + \frac{24\ m}{11.7\ m/day}} = 5.16\ m/day$$

and the degree of anisotropy for each location is given by

$$\frac{K_{xA}}{K_{zA}} = \frac{6.55\ m/day}{2.50\ m/day} = 2.62$$

$$\frac{K_{xB}}{K_{zB}} = \frac{3.975\ m/day}{1.795\ m/day} = 2.21$$

$$\frac{K_{xC}}{K_{zC}} = \frac{9.92\ m/day}{5.16\ m/day} = 1.92$$

3.5.1

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3.5.1 The groundwater temperatures in the United States vary from about 4°C in the northern part to approximately 20°C in the southern part. Assuming a productive alluvial aquifer with an intrinsic

Permeability of 100 Darcys and a hydraulic gradient of 0.01. How much would the production of the same aquifer change between a northern and southern state?

TABLE 1.3 Viscosities of Water and Air

	Water		Air	
Temperature (°C)	Viscosity (μ) $N \cdot sec/m^2$	Kinematic Viscosity (ν) m^2/sec	Viscosity (μ) $N \cdot sec/m^2$	Kinematic Viscosity (ν) m^2/sec
0	1.781×10^{-3}	1.785×10^{-6}	1.717×10^{-5}	1.329×10^{-5}
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20	1.002×10^{-3}	1.003×10^{-6}	1.817×10^{-5}	1.509×10^{-5}
25	0.890×10^{-3}	0.893×10^{-6}	1.840×10^{-5}	1.555×10^{-5}
30	0.798×10^{-3}	0.800×10^{-6}	1.864×10^{-5}	1.601×10^{-5}
40	0.653×10^{-3}	0.658×10^{-6}	1.910×10^{-5}	1.695×10^{-5}
50	0.547×10^{-3}	0.553×10^{-6}	1.954×10^{-5}	1.794×10^{-5}
60	0.466×10^{-3}	0.474×10^{-6}	2.001×10^{-5}	1.886×10^{-5}
70	0.404×10^{-3}	0.413×10^{-6}	2.044×10^{-5}	1.986×10^{-5}
80	0.354×10^{-3}	0.364×10^{-6}	2.088×10^{-5}	2.087×10^{-5}
90	0.315×10^{-3}	0.326×10^{-6}	2.131×10^{-5}	2.193×10^{-5}
100	0.282×10^{-3}	0.294×10^{-6}	2.174×10^{-5}	2.302×10^{-5}

1.519/1.003=1.5145

TABLE 1.2 Density and Specific Weight of Water

Temperature (℃)	Density (ρ, kg/m^3)	Specific Weight (γ, N/m^3)
0° (ice)	917	8,996
0° (water)	999	9,800
4°	1,000	9,810
10°	999	9,800
20°	998	9,790
30°	996	9,771
40°	992	9,732
50°	988	9,692
60°	983	9,643
70°	978	9,594
80°	972	9,535
90°	965	9,467
100°	958	9,398

3.5.1 For water at 4°C, $\rho = 999.973 \text{ kg/m}^3$, $\mu = 1.5674 \times 10^{-3} \; kg/s.m$

For water at 20°C, $\rho = 998.203 \text{ kg/m}^3$, $\mu = 1.005 \times 10^{-3} \; kg/s.m$

$$k = 100 \; darcys = 100 \times 0.987 \; (\mu m)^2 = 98.7 \; (\mu m)^2 = 9.87 \times 10^{-11} \; m^2$$

The hydraulic conductivity values can be determined using equation 3.2.1

$$K_N = \frac{k\rho g}{\mu} = \frac{(9.87 \times 10^{-11} \; m^2)(999.973 \; kg/m^3)(9.81 \; m/s^2)}{(1.5674 \times 10^{-3} \; kg/s.m)} = 6.177 \times 10^{-4} \; m/s$$

or

$$K_N = 53.37 \; m/day$$

and

$$K_s = \frac{k\rho g}{\mu} = \frac{(9.87\times10^{-11}\ m^2)(998.203\ kg/m^3)(9.81\ m/s^2)}{(1.005\times10^{-3}\ kg/s.m)} = 9.617\times10^{-4}\ m/s$$

or

$$K_s = 83.09\ m/day$$

Thus, the total flow rate of the unconfined aquifer shown in figure 3.5.1 would be

$$Q = KiA = (53.37\ m/day)(0.01)(50\ m\times1000\ m) = 26{,}685\ m^3/day$$

in the northern part, while the same aquifer under the same conditions except for the temperature of groundwater would produce

$$Q = KiA = (83.09\ m/day)(0.01)(50\ m\times1000\ m) = 41{,}545\ m^3/day$$

in the southern part of the country. This means a 56% increase in the productivity.

3.12.4

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Compute the ponding time and cumulative infiltration at ponding for a sandy clay loam soil with a 30 percent initial effective saturation, subject to a rainfall intensity of 2 cm/hr.

3.11.4 For sandy clay loom soil, $\eta = 0.398$, $K = 0.15$ cm/hr, $\psi = 21.85$ cm, $\theta_e = 0.330$.

$S_e = 0.3$, $i = 2$ cm/hr (given).

$\Delta\theta = (1 - S_e)\theta_e = (1 - 0.3)(0.33) = 0.231.$

$$t_p = \frac{K\psi\Delta\theta}{i(i - K)} = \frac{0.15(21.85)(0.231)}{2(2 - 0.15)} = 0.205 \text{ hr} = 12.3 \text{ min.}$$

$F = it_p = 2(0.205) = 0.41$ cm $= 4.1$ mm.

3.12.8

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Use Green-Ampt to compute infiltration rate and cumulative infiltration for silty clay soil (n=0.479), psi=29.22 cm K=0.05 cm/hr) at 0.25 hour increments up to hours from beginning of infiltration. Assume initial effective saturation of 30% and continuous ponding.

3.11.8 For silty-clay soil, $\eta = 0.479$, $K = 0.05$ cm/hr, $\psi = 29.22$ cm, $\theta_e = 0.423$.

$S_e = 0.3$, (given).

$\Delta\theta = (1 - S_e)\theta_e = (1 - 0.3)(0.423) = 0.296.$

$F = Kt + \psi\Delta\theta \ln[1 + F/(\psi\Delta\theta)] = 0.05t + 29.22(0.296) \ln[1 + F/(29.22 \times 0.296)$

$= 0.05t + 8.65 \ln[1 + F/8.65]$

$f = K(1 + \psi\Delta\theta/F) = 0.05(1 + 8.65/F)$

Values of F and f can be determined by successive substitution using these two equations. The result is given in the following table.

Time t (hr)	Infiltration depth, F (cm)	Infiltration rate, f (cm/hr)
0	0	0
0.25	0.476	0.959
0.50	0.677	0.689
0.75	0.834	0.569
1.00	0.964	0.499
1.25	1.081	0.450
1.50	1.191	0.413
1.75	1.290	0.385
2.00	1.383	0.363
2.25	1.471	0.344
2.50	1.555	0.328
2.75	1.636	0.314
3.00	1.713	0.302
3.25	1.787	0.292
3.50	1.859	0.283
3.75	1.928	0.274
4.00	1.996	0.267