Module 5: Groundwater Flow Basics & Applications

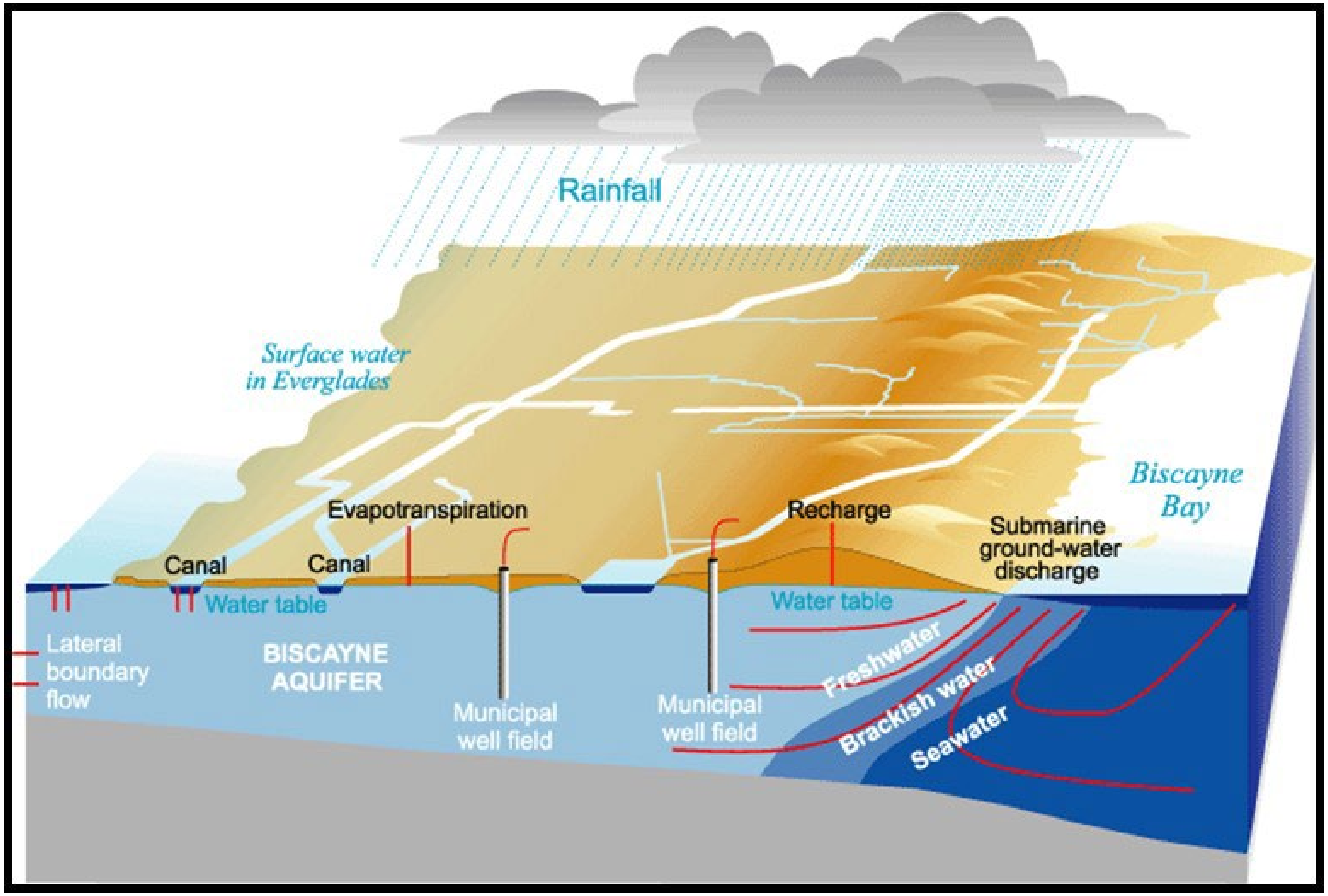
CWR 3540: Water Resources Engineering

FIU Department of Civil & Environmental Engineering

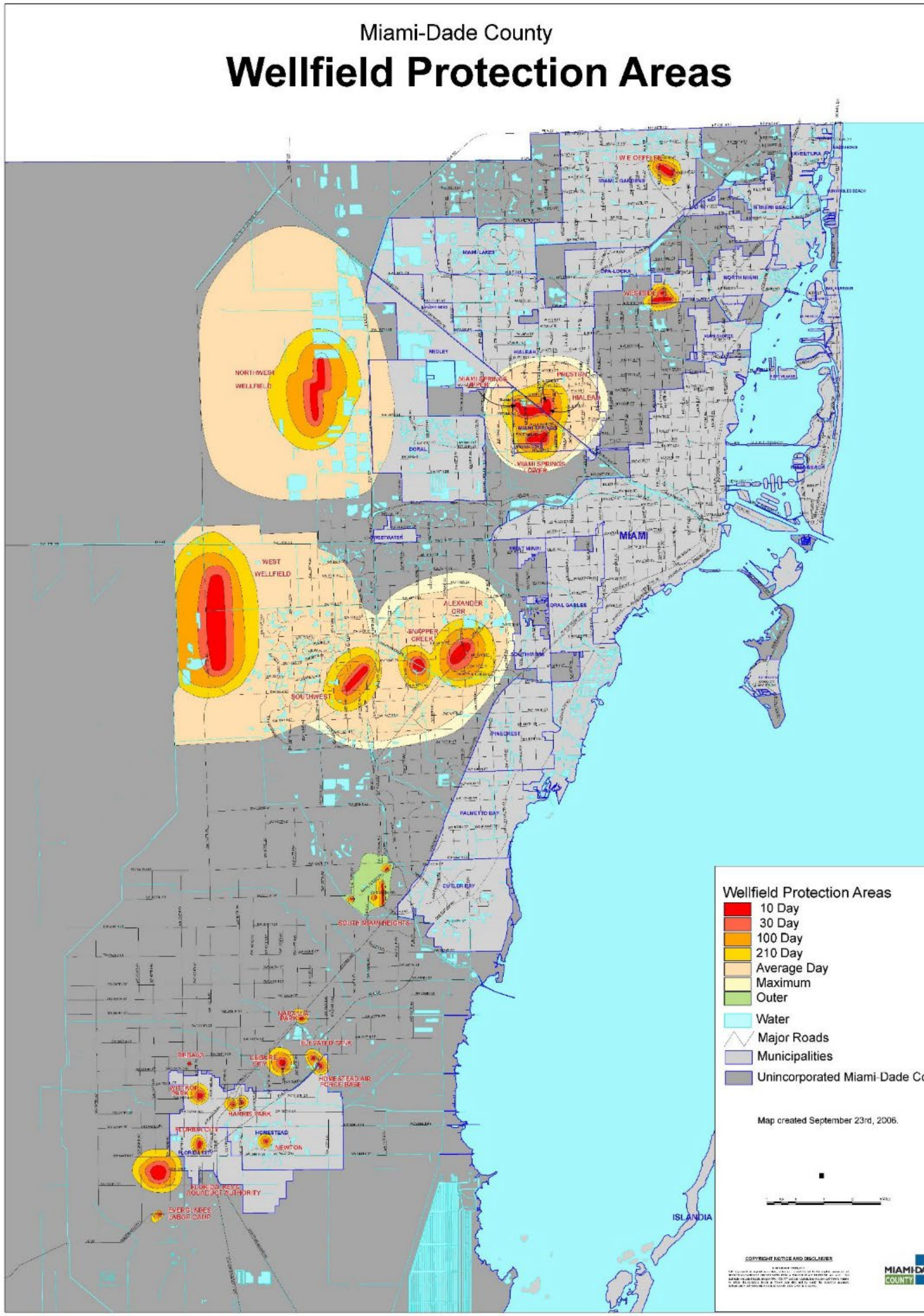
Summary by Professor Fuentes

Required Text: R. S. Gupta, 4th Edition, ISBN: 1-4786-3091-4

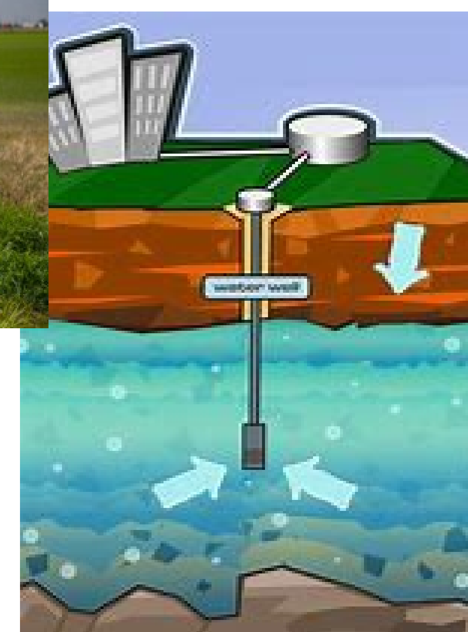
Sketch of the Biscayne Aquifer



Miami-Dade County Water Supply: Well Fields



Groundwater Wells

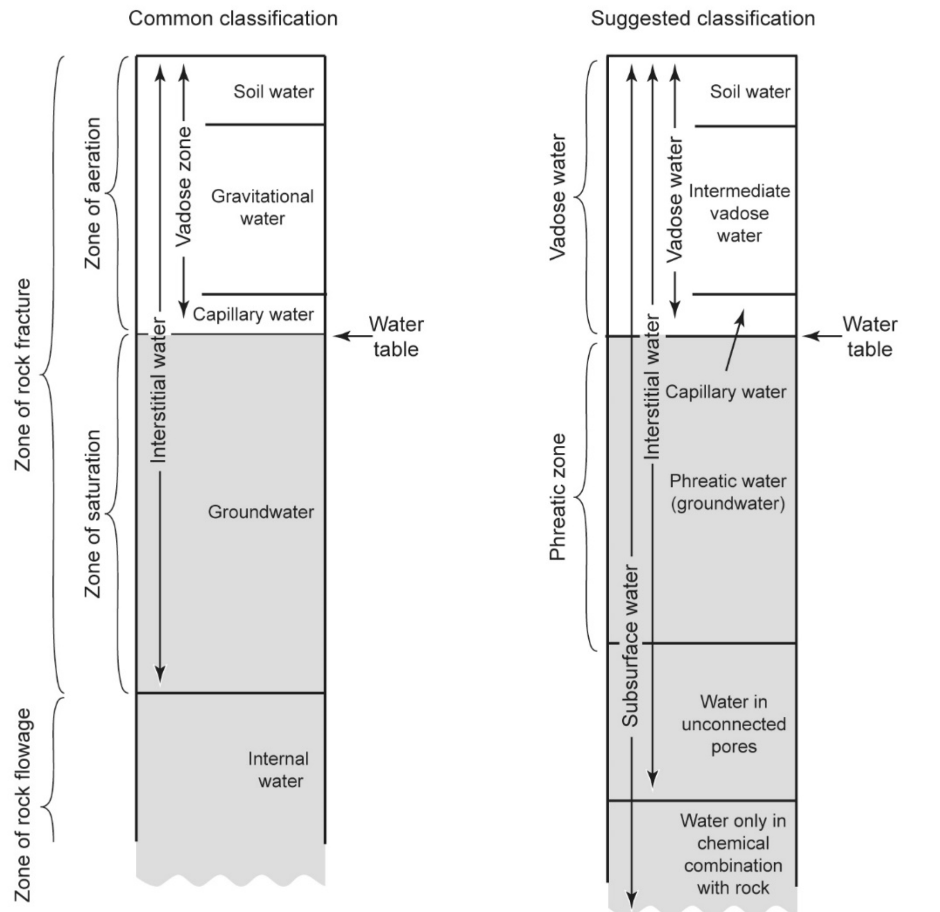


Scope

- Subsurface water = all waters that occur below the earth's surface
- Groundwater = water in the saturated zone
- Civil engineering focus:
  - Its movement and distribution and
  - Either its extraction or injection mostly for supply

Subsurface Water Classification

Figure 5.1 Meinzer's classification and modification suggested by Davis and DeWiest (1966).



Groundwater Classification: By Manner of Formation

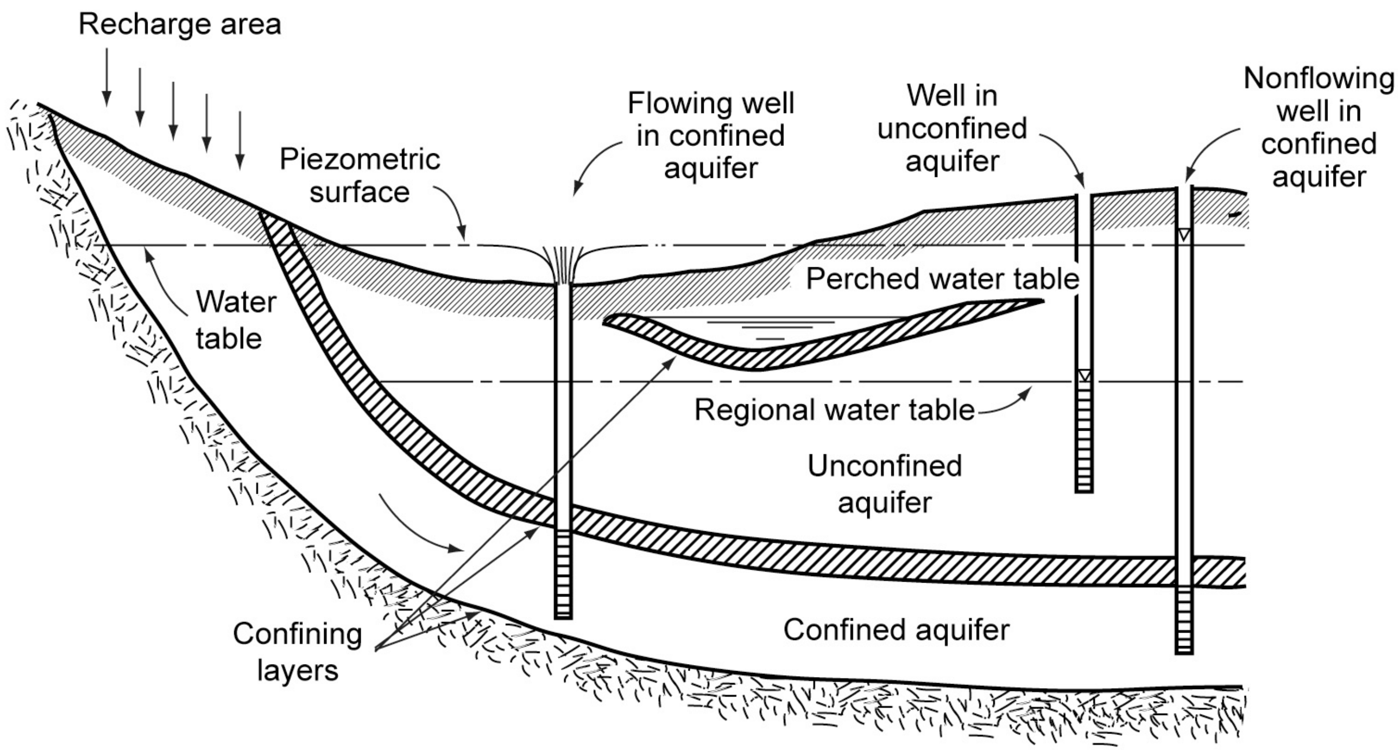
Table 5.1 Groundwater Classification According to the Manner in Which it Has Been Formed

Group	Section	Type	Class	Subclass		Special Conditions	
				Water in strata of porous rocks (pore and stratal water)	Water in fissured cavernous rocks (fissure and vein-fissure water)	Water in permafrost regions	Water in volcanically active regions
Continental groundwater	Groundwater of the zone of aeration	Suspended water	Perched water (in the broad sense)	Salt water and infiltrating water, perched water	Salt water and infiltrating water, perched water	Active layer	Upper part of lava cover
						Suprapermafrost	Lower part of lava cover
	Groundwater of the zone of saturation on continents	Mainly nonpressure water	Groundwater	Aquifer nearest to the surface on stable impermeable layer	Upper parts of the zone of intensive fissuring and karst massif	Interpermafrost and intrapermafrost	Water of hydrothermal systems underhydrostatic pressure
		Pressure water	Artesian water	Industrial water under hydrostatic pressure	Buried fissured zone under hydrostatic-pressure	Subpermafrost	
			Deep-lying	Sedimentary layers, which are subjected to the action of geostatic pressure and endogenic forces	Water of deep-lying faults within the sphere of activity of endogenic forces	Absent	Water of volcanic structures and hot spring systems, connected with a rising stream from the magma chamber
Groundwater below seas and oceans	Groundwater of the submarine zone of saturation	Mainly pressure water	Water connected with the land mass	Shelf and marine deposits	Karsted rock of the shelf and fault zones	Subpermafrost shelf of the northern seas	Submarine volcanic structures and marine hot spring systems
			Water not connected with the land mass	Water of deep basins	Trenches and mid-oceanic rifts	Absent	

Source: Pinneker (1983). Used with permission of Cambridge University Press.

Water Bearing Formations

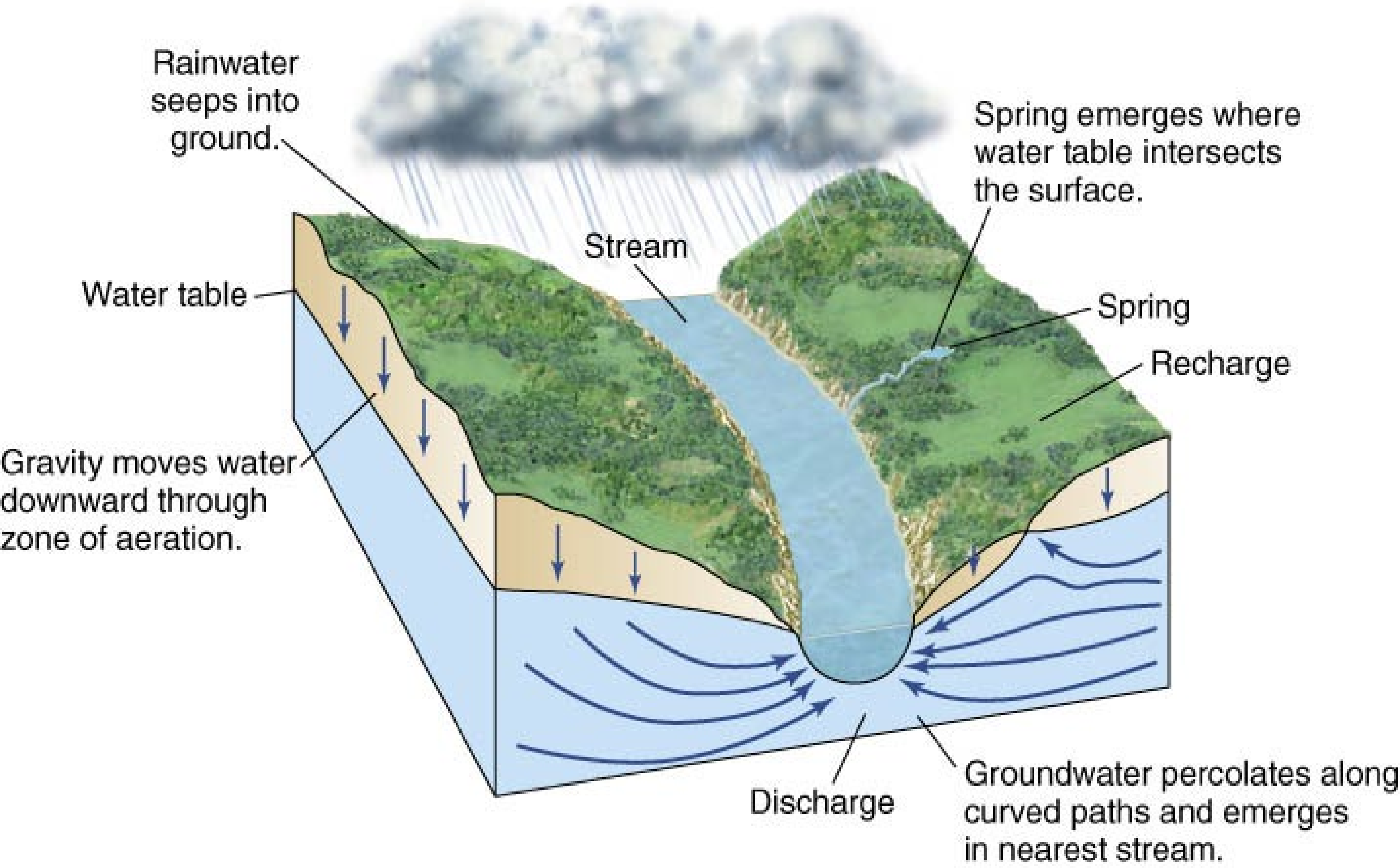
Figure 5.2 Types of aquifers.



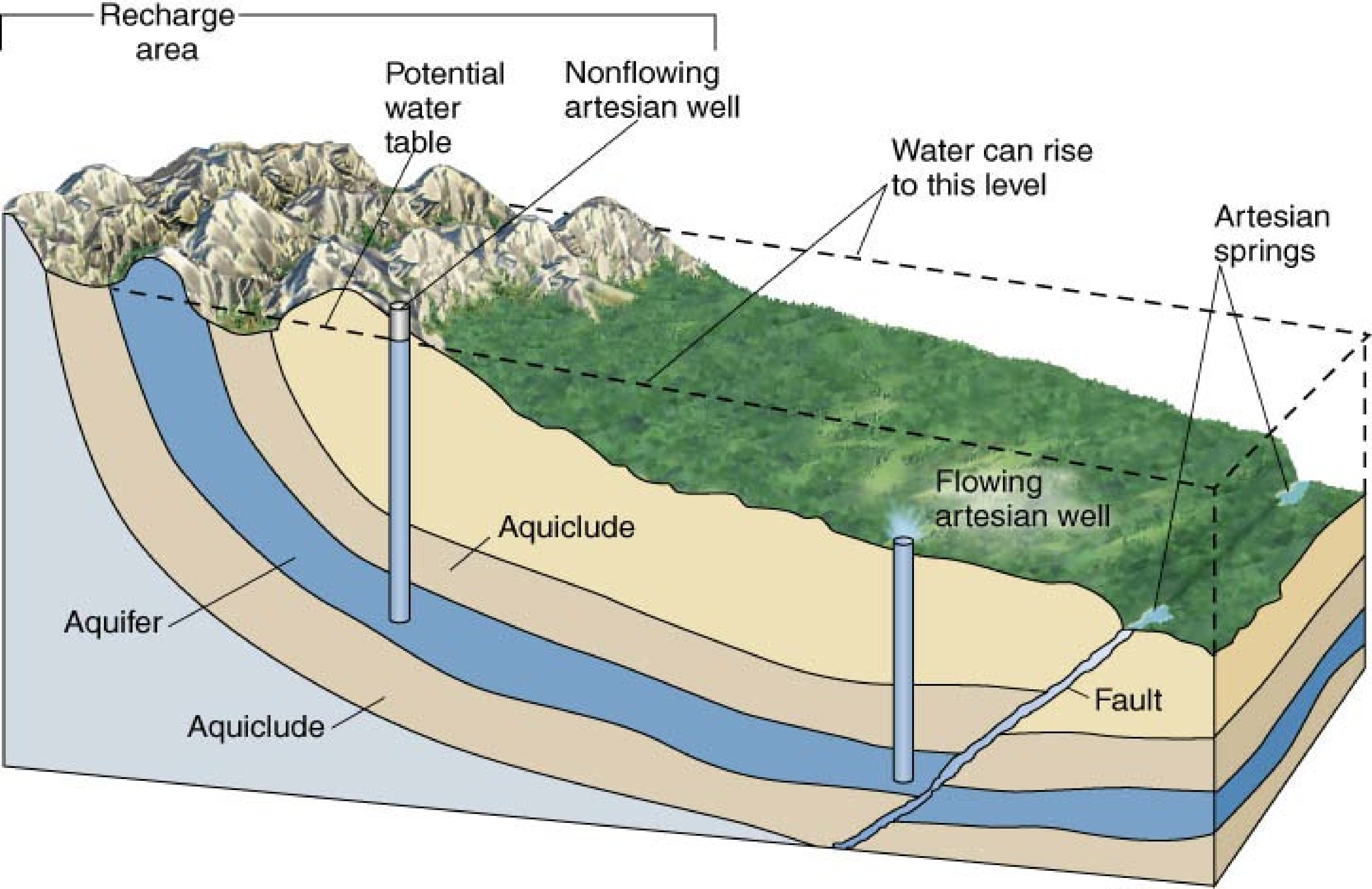
Aquifers & Other Formations

- *Aquifers* = can yield significant quantity of water due to their interconnected openings or pores for water flow (e.g., alluvial deposits, volcanic rocks, limestone, and sandstone)
- *Types of Aquifers*
  - Unconfined: upper surface of water is exposed to atmospheric pressure - water table
  - Confined: water in under greater-than-atmospheric pressure due to impermeable confinement – pressure or artesian
- *Aquiclude* = saturated but relatively impermeable material yielding little water to wells (e.g., clays)
- *Aquifuge* = relatively impermeable formation neither containing nor transmitting water (e.g., solid granite)
- *Aquitards* = saturated but poorly permeable stratum that may store and transmit water to adjacent aquifers (e.g., sandy clay)

Shallow Groundwater – Surface Interaction



Layered Aquifer Features



Main Physical Properties

- <u>Porosity</u> (i.e., voids, pores, interstices), “n”
- <u>Hydraulic Permeability</u> (i.e., ability of a material or formation to transmit water), “K”

Types of Porosity (primary and secondary)

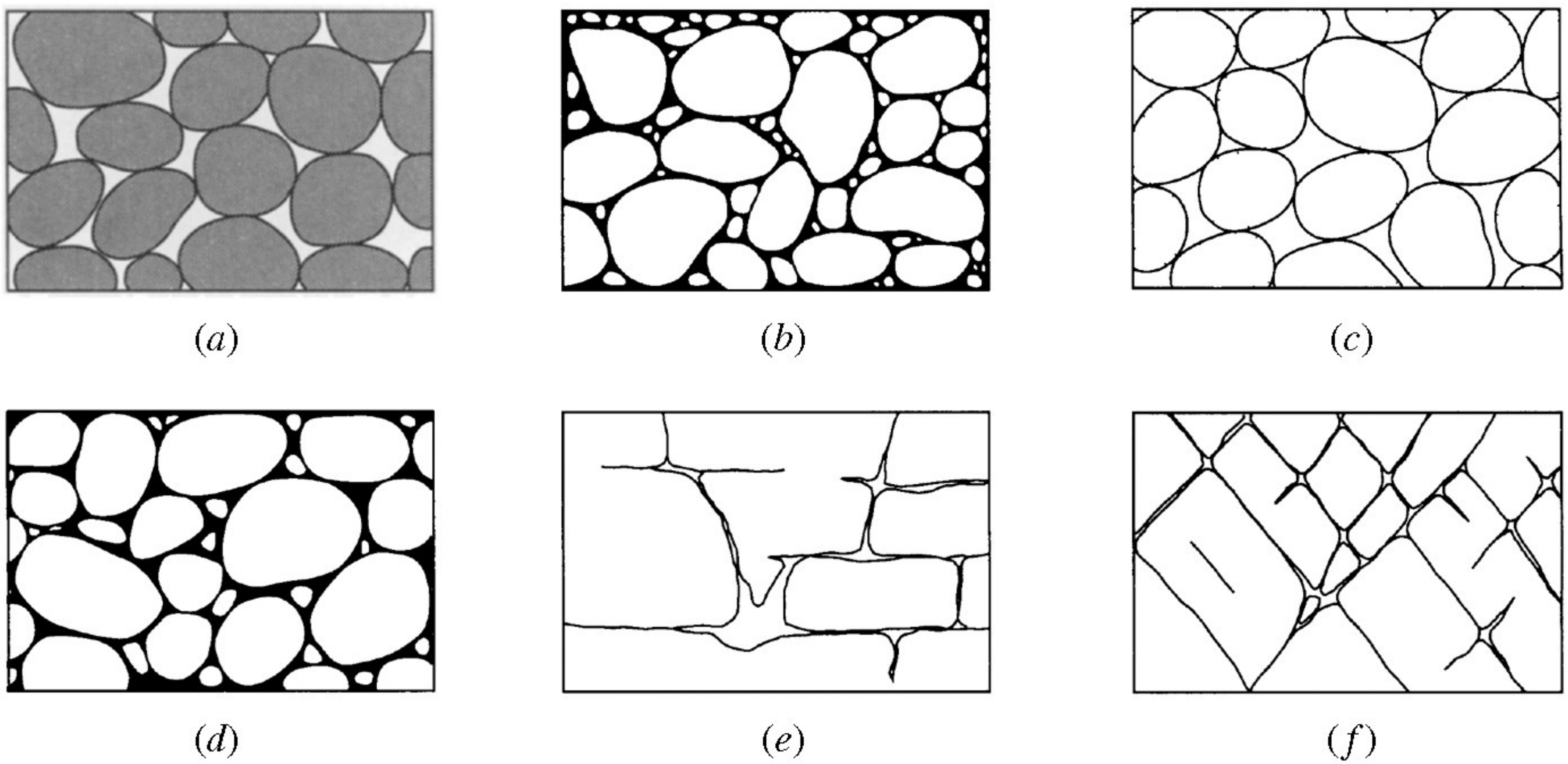


Figure 2.2.1

Material Porosity Ranges, n

Table 2.2.1 Representative Values of Porosity (after Morris and Johnson (1967))

Material	Porosity, percent	Material	Porosity, percent
Gravel, coarse	28[a]	Loess	49
Gravel, medium	32[a]	Peat	92
Gravel, fine	34[a]	Schist	38
Sand, coarse	39	Siltstone	35
Sand, medium	39	Claystone	43
Sand, fine	43	Shale	6
Silt	46	Till, predominantly silt	34
Clay	42	Till, predominantly sand	31
Sandstone, fine-grained	33	Tuff	41
Sandstone, medium-grained	37	Basalt	17
Limestone	30	Gabbro, weathered	43
Dolomite	26	Granite, weathered	45
Dune sand	45		

[a] These values are for repacked samples; all others are undisturbed.

Table 2.2.1

Specific Yield & Specific Retention: In Unconfined Aquifers

- $\eta = S_y + S_r$

Table 5.5 Representative Values of Specific Yield for Soils and Rocks

Formation	Range of values	Typical
Gravel, coarse	0.10–0.25	0.21
Gravel, medium	0.15–0.45	0.24
Gravel, fine	0.15–0.40	0.28
Sand, coarse	0.15–0.45	0.30
Sand, medium	0.15–0.45	0.32
Sand, fine	0.01–0.45	0.23
Silt	0.01–0.40	0.20
Till, gravel		0.16
Till, sand	0.05–0.20	0.16
Till, silt		0.06
Clay	0.01–0.20	0.06
Sandstone, medium grained		0.27
Sandstone, fine grained	0.01–0.40	0.21
Limestone	0.01–0.35	0.14
Siltstone	0.01–0.35	0.12

Specific Storage, S_s:
In Confined Aquifers (Examples 5.13 and 5..14

- $S_s = \rho\ g\ (\alpha + \eta\ \beta)$ (Eq. 5.17)

  Where,
  - S_s – specific storage
  - α = aquifer compressibility
  - β = water compressibility
  - η = porosity
- $S = S_s\ b$ = storage coefficient in a confined aquifer, where,
  - b = aquifer thickness

Storage Coefficients

Table 5.6 Specific Storage Values

Formation	Specific storage, m^{-1}
Gravel, dense sandy	$1.0 \times 10^{-4} - 4.9 \times 10^{-5}$
Sand, dense	$2.0 \times 10^{-4} - 1.3 \times 10^{-4}$
Sand, loose	$1.0 \times 10^{-3} - 4.9 \times 10^{-4}$
Clay, medium hard	$1.3 \times 10^{-3} - 9.2 \times 10^{-4}$
Clay, stiff	$2.6 \times 10^{-3} - 1.3 \times 10^{-3}$
Clay, plastic	$2.0 \times 10^{-2} - 2.6 \times 10^{-3}$
Rock, fissured	$6.9 \times 10^{-5} - 3.3 \times 10^{-6}$
Rock, unfissured	$< 3.3 \times 10^{-6}$

Lab Porosity Measurement

- $\eta = V_{voids}/V_{total}$ (i.e., a sample of rock, sediment, solid)

Fluid Potential & Hydraulic head

- Ø = g h fluid potential,
  - where Ø is fluid potential at any point or *energy per unit of mass* and *h is energy head per unit weight of fluid at that point*
- h (*or H*) = Z + Ψ + $V^2/2g$ = hydraulic or “energy” head

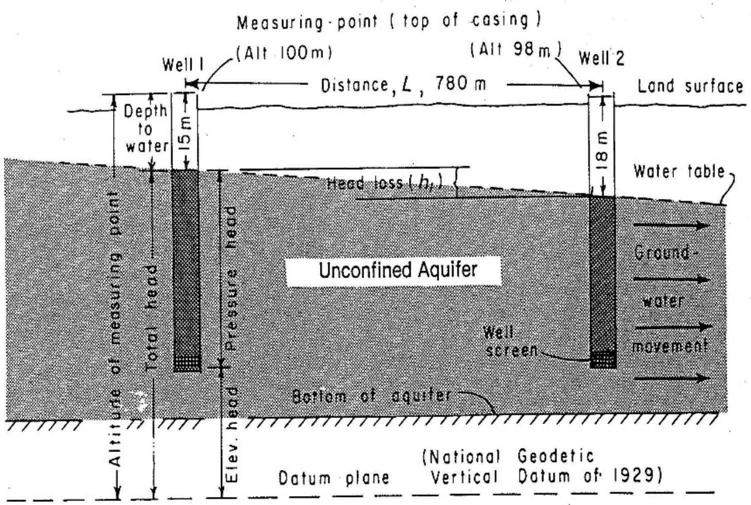
  where
  - Z is elevation of a point with reference to a datum
  - Ψ = p/γ with p being the pressure above atmospheric at the point
  - V = average fluid velocity (“nil” in alluvial materials, such as sedimentary rock)

Darcy's Law

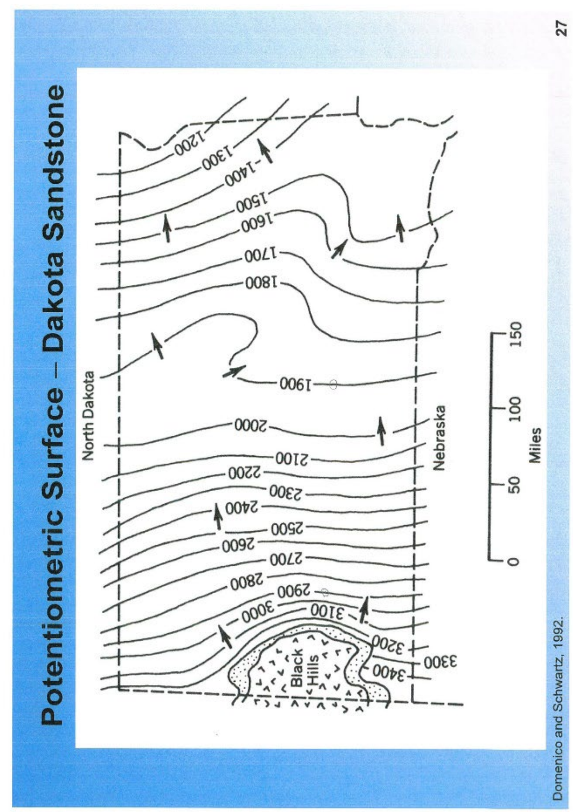
- $Q = K A (h_1 - h_2)/ L$, $h_1 > h_2$ *or* flow goes from 1 to 2
- $v = K (h_1 - h_2)/ L = (K) (\Delta h_{1\text{-}2}/L)$ or *Darcy's velocity* or *specific discharge*
- $v_v = (K/\eta) (\Delta h_{1\text{-}2}/L)$ = seepage or interstitial velocity,

  Where,
  - K = hydraulic conductivity
  - A = area of flow
  - L = length
  - $h_1 – h_2$ = + head drop
  - $\Delta h/L$ = + energy or hydraulic gradient
  - η = porosity

Hydraulic Head



SOURCE: EPA/625/4-85/016
Protection of Public Water
Supplies from Ground-Water
Contamination, September 1985



Darcy's Law (cont.)

- $Q = \mathrm{K\ A}\ (h_1 - h_2)/\ L$, h1 > h2 but can <u>also</u> be expressed as
  - $v = -\ K\ (h_2 - h_1)/\ L = -\ (K)\ (\Delta h_{2\text{-}1}/L)$ or *<u>Darcy's velocity</u>* or *specific discharge and*
  - $v_v = -\ (K/\eta)\ (\Delta h_{2\text{-}1}/L)$ = seepage or interstitial velocity,

  where,
  - K = hydraulic conductivity
  - A = area of flow
  - L = length
  - $h_2 - h_1 = -$ head drop
  - $\Delta h_{2\text{-}1}/L = -$ energy or hydraulic gradient
  - η = porosity

Validity of Darcy's Law

- Validity of Darcy's Law
  - $N_R = (\rho\ \upsilon\ D)/\mu \leq 1\text{-}10$, where $D = d_{10}$

Example of Darcy's Law Applicability (Mays, 2012)

Example of Verification of Darcy's Law Validity

EXAMPLE 3.1.3 The following additional information is given for the aquifer sample in Example 3.1.1. The sample has a median grain size of 0.037 cm and a porosity of 0.30. The test is conducted using pure water at 20°C. Determine the Darcy velocity, average interstitial velocity, and assess the validity of Darcy's law.

SOLUTION Darcy velocity is computed using Equation (3.1.5):

$$v = -K\frac{dh}{dl} = -(23.54 \text{ m/day})(-0.326) = 7.67 \text{ m/day}$$

The average linear velocity is computed using Equation (3.1.6):

$$v_a = \frac{Q}{\alpha A} = \frac{v}{\alpha} = \frac{7.67 \text{ m/day}}{0.30} = 25.6 \text{ m/day}$$

In order to assess the validity of Darcy's law, we must determine the greatest velocity for which Darcy's law is valid using Equation (3.1.7), $N_R = \frac{\rho v D}{\mu}$, knowing Darcy's law is valid for $N_R < 1$. For water at 20°C, $\mu = 1.005 \times 10^{-3}$ N/m^2 and $\rho = 998.2$ kg/m^3, so that for $N_R = 1$,

$$v_{\max} = \frac{\mu}{\rho D} = \frac{1.005 \times 10^{-3} \text{ kg/ms}}{(998.2 \text{ kg/m}^3)(0.00037 \text{ m})} = 0.00272 \text{ m/s} = 235 \text{ m/day}$$

Then Darcy's law will be valid for Darcy velocities equal to or less than 235 m/day for this sample. Thus, the answer we have found in Example 3.1.1 is valid since $v = 7.67$ m/day < 235 m/day. ■

Hydraulic Conductivity

- Coefficient of permeability or hydraulic conductivity, K = constant of proportionality between the *rate of flow* and the *energy gradient* in Darcy's Law (or permeability of the medium, formation or stratum) (in m/d, m/s, ft/s, etc.)
- $K = k\ (\gamma/\mu)$, where
  - k = intrinsic permeability (in darcies, 1 darcy = 1.062×10^{-11} ft^2)
  - γ = specific weight of fluid (i.e., water) and
  - μ = dynamic viscosity of fluid (i.e.., water, 1.12 cP or 1.12×10^{-2} P or g/(cm-s)

Darcy’s Experimental Set-Up

[Les Fontaines de la Ville de Dijon, France, Henry Darcy (1855)]

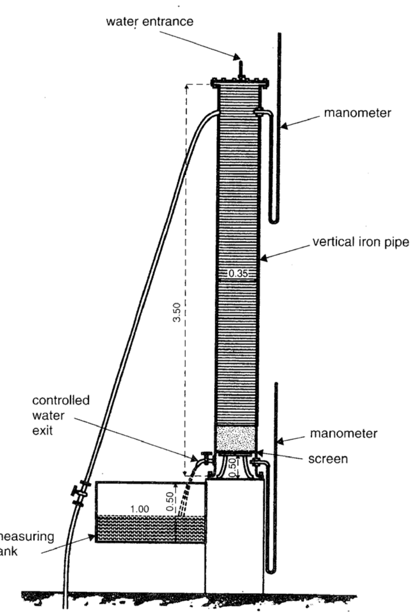


FIGURE 2.14. Apparatus intended to determine the law of the water flow through sand.

Source:

G. F. Pinder and M. A. Celia, “ Subsurface Hydrology”, Wiley-Interscience, Hoboken, NJ (2006)

Darcy’s Experimental Data

October 29 and 30 & November 2 (1855)

Experiment Number	Duration min	Mean Flow L/min	Mean Pressure m	Ratio of Volumes and Pressure	Observations
1st Series, with a thickness of sand of 0.58 m					
1	25	3.60	1.11	3.25	Sand was not washed
2	20	7.65	2.36	3.24	
3	15	12.00	4.00	3.00	The manometer column had weak movements
4	18	14.28	4.90	2.91	
5	17	15.20	5.02	3.03	
6	17	21.80	7.63	2.86	Very strong oscillations.
7	11	23.41	8.13	2.88	
8	15	24.50	8.58	2.85	
9	13	27.80	9.86	2.82	Strong manometer oscillations.
10	10	29.40	10.89	2.70	
2nd Series, with a thickness of sand of 1.14 m					
1	30	2.66	2.60	1.01	Sand not washed.
2	21	4.28	4.70	0.91	
3	26	6.26	7.71	0.81	
4	18	8.60	10.34	0.83	Very strong oscillations.
5	10	8.90	10.75	0.83	
6	24	10.40	12.34	0.84	
3rd Series, with a thickness of sand of 1.71 m					
1	31	2.13	2.57	0.83	Washed sand
2	20	3.90	5.09	0.77	Very strong oscillations.
3	17	7.25	9.46	0.76	
4	20	8.55	12.35	0.69	
4th Series, with a thickness of sand of 1.70 m					
1	20	5.25	6.98	0.75	Sand washed, with a grain size a little coarser than the proceeding.
2	20	7.00	9.95	0.70	Low oscillations because of the partial blockage of the manometer opening
3	20	10.30	13.93	0.74	

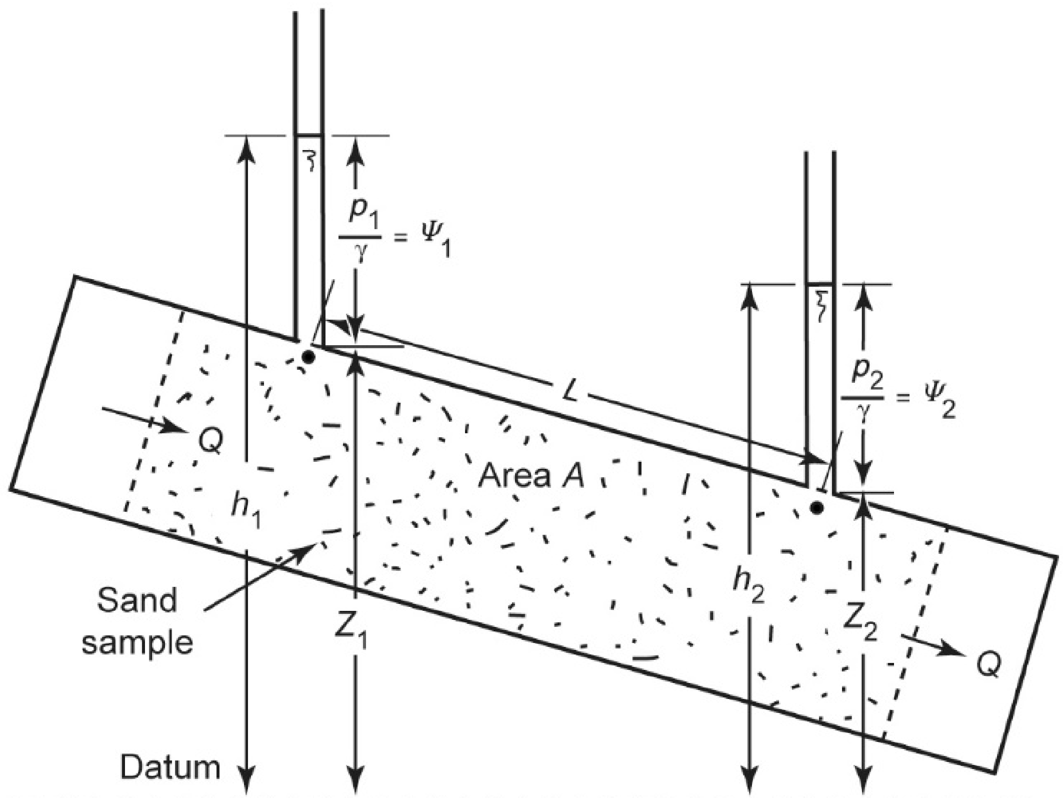
FIGURE 2.15. Table of the experiments made in Dijon on October 29 and 30, and November 2, 1855.

Source:

G. F. Pinder and M. A. Celia, “ Subsurface Hydrology”, Wiley-Interscience, Hoboken, NJ (2006)

Darcy's Application: Hydraulic Conductivity Measurement

Figure 5.3 Simulation of Darcy's experiment.



Hydraulic Conductivity Ranges, K

Table 5.3 Representative Values of Hydraulic Conductivity for Soils and Rocks

Formation	Hydraulic Conductivity, m/day
Unconsolidated Formations	
Gravel, coarse	1000–8600
Gravel, medium	20–1000
Gravel, fine	20–50
Sand, coarse	0.1–500
Sand, medium	0.1–50
Sand, fine	0.01–20
Silt, sandy	1–4
Silt, clayey	0.2–1
Till, gavel	30
Till, sandy	0.2
Till, clayey	$\leq 10^{-5}$
Clay	≤ 0.0005
Sedimentary Rocks	
Limestone	10^{-4}–800
Sandstone	10^{-5}–3
Siltstone	10^{-6}–0.001

Hydraulic Conductivity Ranges

Table 3.2.1 Representative Values of Hydraulic Conductivity (after Morris and Johnson (1967))

Material	Hydraulic conductivity (m/day)	Type of measurement[a]
Gravel, coarse	150	R
Gravel, medium	270	R
Gravel, fine	450	R
Sand, coarse	45	R
Sand, medium	12	R
Sand, fine	2.5	R
Silt	0.08	H
Clay	0.0002	H
Sandstone, fine-grained	0.2	V
Sandstone, medium-grained	3.1	V
Limestone	0.94	V
Dolomite	0.001	V
Dune sand	20	V
Loess	0.08	V
Peat	5.7	V
Schist	0.2	V
Slate	0.00008	V
Till, predominantly sand	0.49	R
Till, predominantly gravel	30	R
Tuff	0.2	V
Basalt	0.01	V
Gabbro, weathered	0.2	V
Granite, weathered	1.4	V

[a] H is horizontal hydraulic conductivity, R is a repacked sample, and V is vertical hydraulic conductivity.

Table 3.2.1

Permeameter (Lab K-determination): *(constant and falling head tests)*

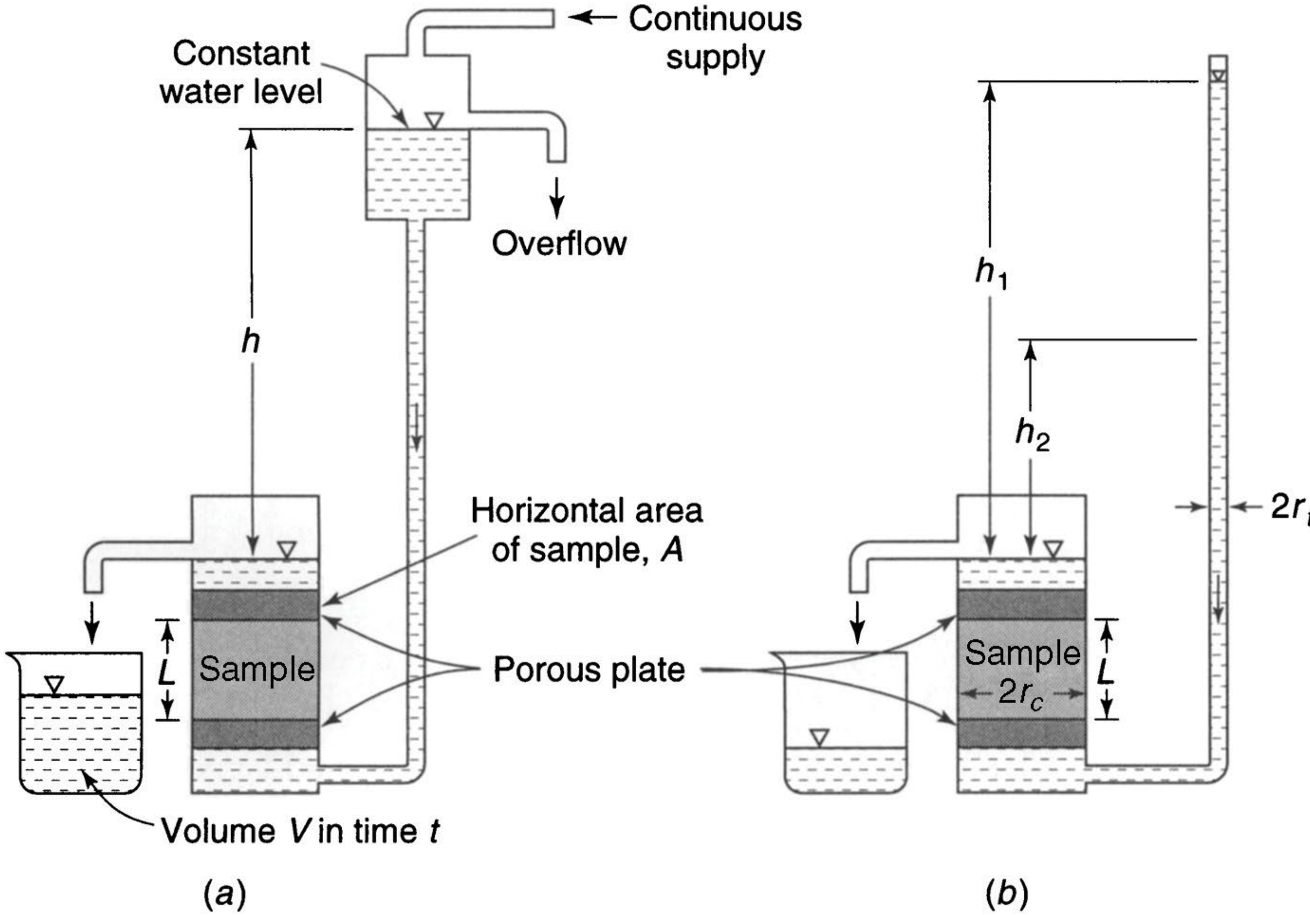


Figure 3.3.1

Example of Darcy's Law Applicability to Lab Permeameter Testing
(Mays 2012)

Example of Application of Darcy's Law to a Laboratory Test Evaluation

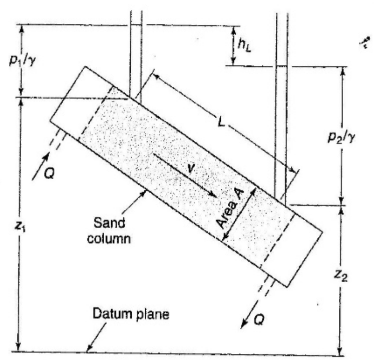


Figure 3.1.1 Pressure distribution and head loss in flow through a sand column.

EXAMPLE 3.1.1

A field sample of an unconfined aquifer is packed in a test cylinder (see Figure 3.1.1). The length and the diameter of the cylinder are 50 cm and 6 cm, respectively. The field sample is tested for a period of 3 min under a constant head difference of 16.3 cm. As a result, 45.2 cm^3 of water is collected at the outlet. Determine the hydraulic conductivity of the aquifer sample.

SOLUTION

The cross-sectional area of the sample is

$$A=\frac{\pi D^2}{4}=\frac{\pi(0.06\text{ m})^2}{4}=0.00283\text{ m}^2$$

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

$$\frac{dh}{dl}=\frac{(-16.3\text{ cm})}{50\text{ cm}}=-0.326$$

and the average flow rate is

$$Q=\frac{45.2\text{ cm}^3}{3\text{ min}}=15.07\text{ cm}^3/\text{min}=0.0217\text{ m}^3/\text{day}$$

Apply Darcy's law, Equation (3.1.4), to obtain the hydraulic conductivity as

$$Q=-KA\frac{dh}{dl}\rightarrow K=-\frac{Q}{A(dh/dl)}=-\frac{0.0217\text{ m}^3/\text{day}}{(0.00283\text{ m}^2)(-0.326)}=23.5\text{ m}^3/\text{day}$$

■

Field K-Determination

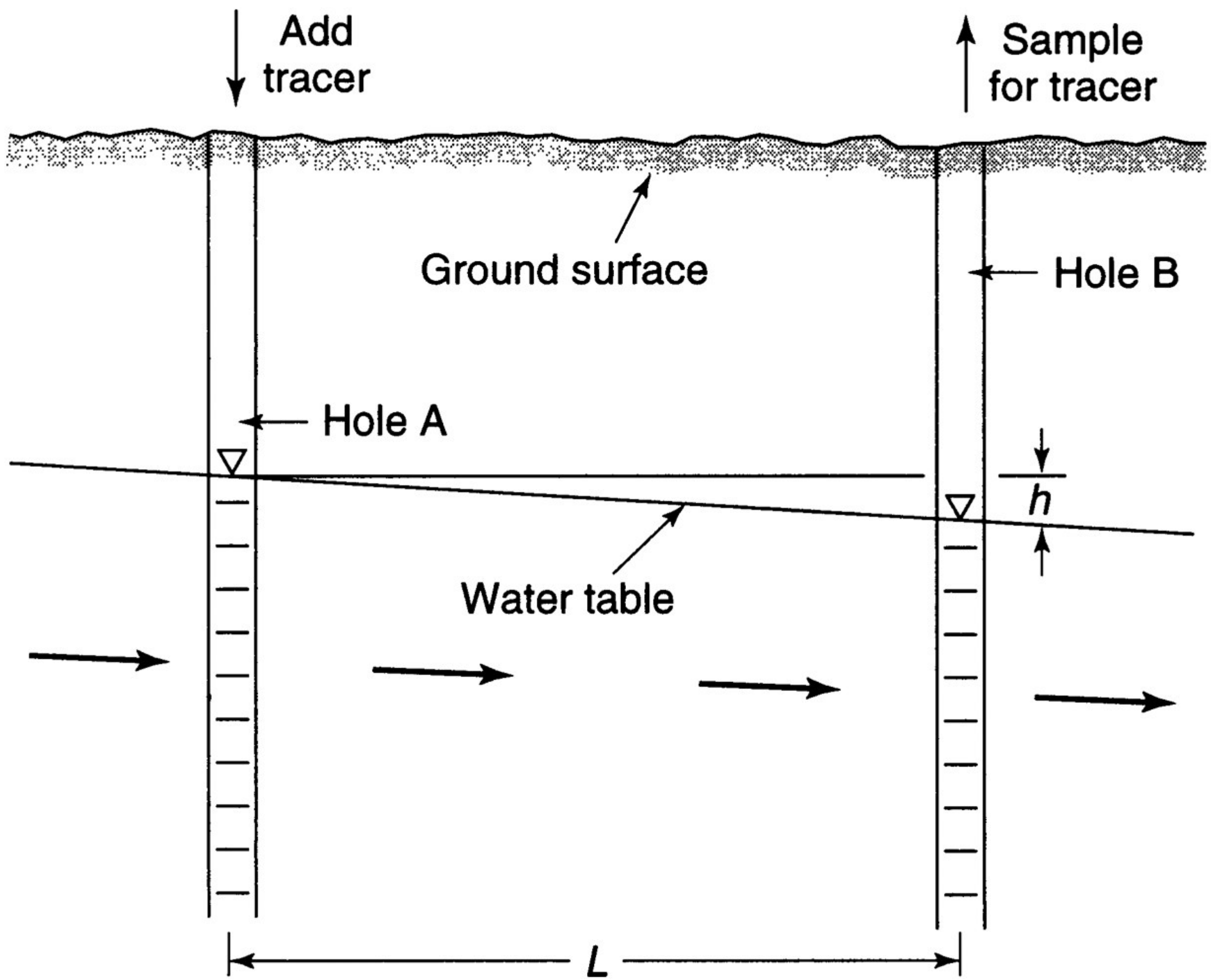


Figure 3.3.2

Example of Field-K Estimation

(Mays, 2012)

Example of Estimation of Average Hydraulic Conductivity in a Tracer Field Test: Unconfined Aquifer Using Two (2) Observation Wells

(Mays, 2012)

EXAMPLE 3.3.4 A tracer test is conducted to determine the hydraulic conductivity of an unconfined aquifer. The water levels in the two observation wells 20 m apart are 18.4 m and 17.1 m. The tracer injected in the first well arrives at the second observation well in 167 hr. Compute the hydraulic conductivity of the unconfined aquifer given that the porosity of the formation is 0.25.

SOLUTION Given $\alpha = 0.25$, $L = 20$ m, $h = 18.4\text{ m} - 17.1\text{ m} = 1.3$ m, $t = 167\text{ hr} = 6.96$ days, Equation (3.3.9) is used to compute the hydraulic conductivity of the aquifer:

$$K = \frac{\alpha L^2}{ht} = \frac{(0.25)(20\text{ m})^2}{(1.3\text{ m})(6.96\text{ days})} = 11.1\text{ m/day}$$

■

Case of Confined Pervious Formation Between Two Canals (Example 5.1)

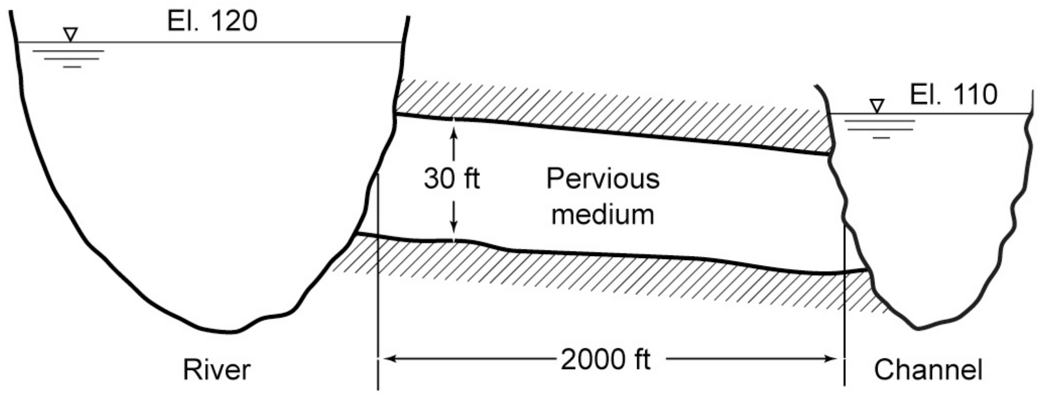


Figure 5.4 Model of river and channel in Example 5.1.

Vertical Flow through a Confined Aquifer (Example 5.5)

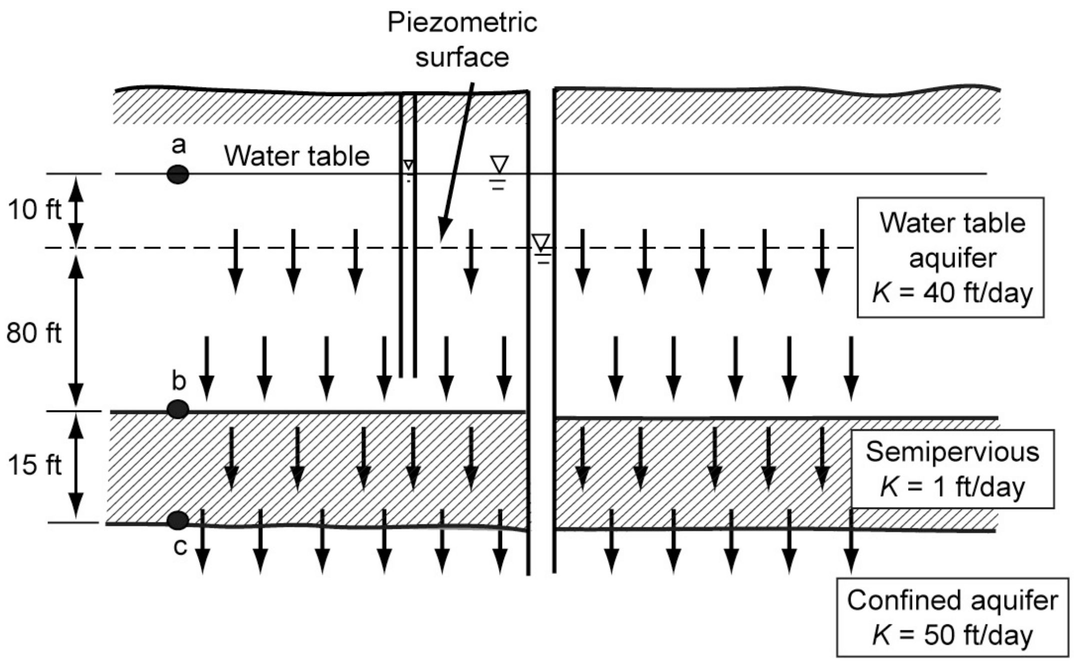
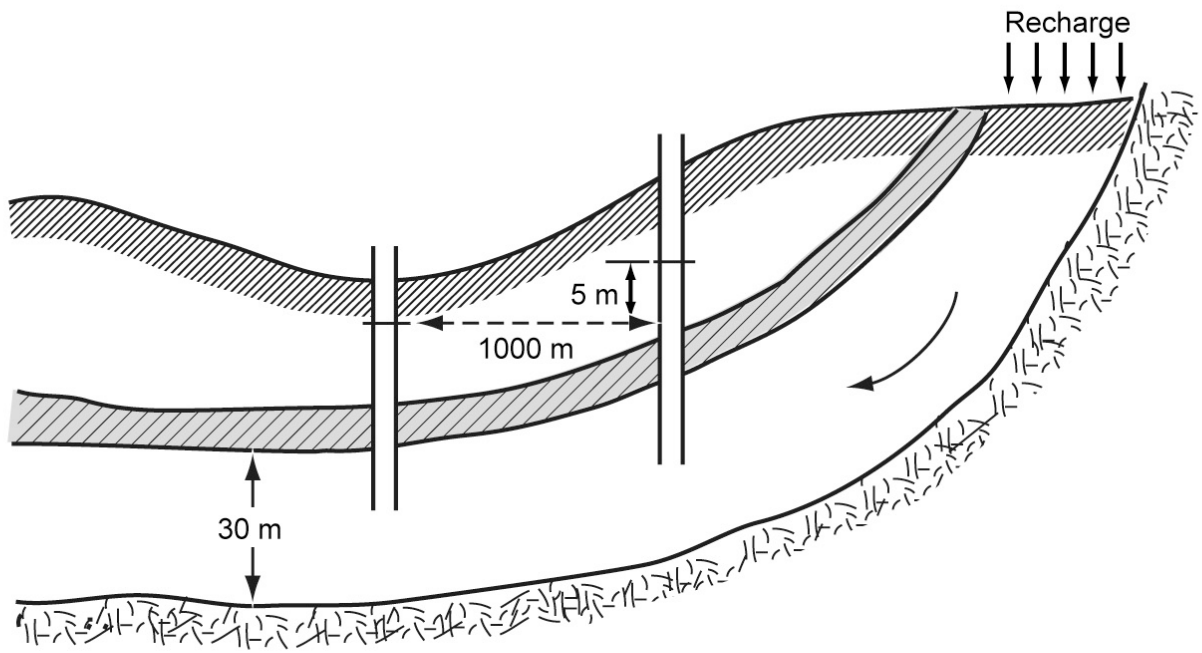


Figure 5.5 Vertical downward flow through a semipervious layer, Example 5.2.

Case of a Confined Aquifer (Example 5.3)

Figure 5.6 Travel time in a uniform-sized aquifer.



Variation of Hydraulic Conductivity

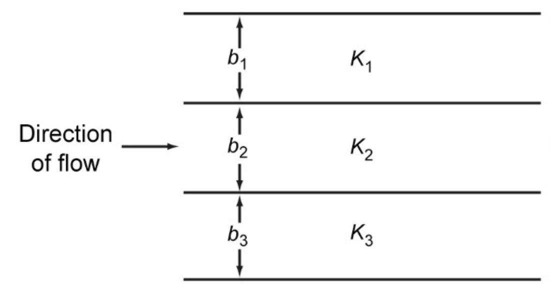
- K varies in space (i.e., x, y, z)
- If K is constant in space, more of an ideal approximation, the medium, soil or rock, is said to be *"homogeneous".* If not, is *"heterogeneous".*
- If K is constant in direction, more of an ideal approximation, the medium, soil or rock, is said to be *"isotropic".* If not, is *"anisotropic".*
- *See respectively Equations 5.9 and 5.10 to estimate an average K*
  - *when flow is parallel to the soil/rock stratification*
  - *when flow is perpendicular to the soil/rock stratification*

K-estimate for Stratified Soil/Rock Settings

- Flow Parallel to Stratification – Eq. 5.9:
  - $\underline{K} = 1/b\ [K_1 b_1 + k_2 b_2 + \ldots K_i b_i)$,

    $i = 1, n$

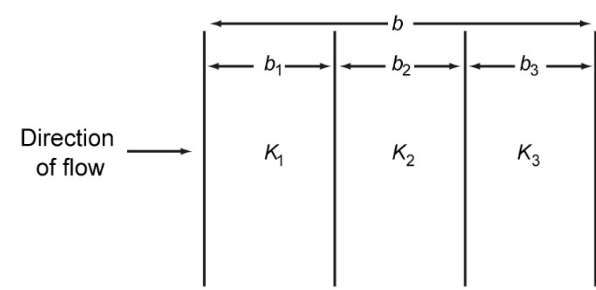
Figure 5.7 Flow parallel to stratifications.



- Flow Perpendicular to Stratification – Eq. 5.10:
  - $\underline{K} = b\ /[b_1/K_1 + b_2/K_2 + \ldots b_i/K_i)$,

    $i = 1, n$

Figure 5.8 Flow normal to stratifications.



Estimation of Variable Hydraulic Conductivity (Examples 5.6 and 5.7)

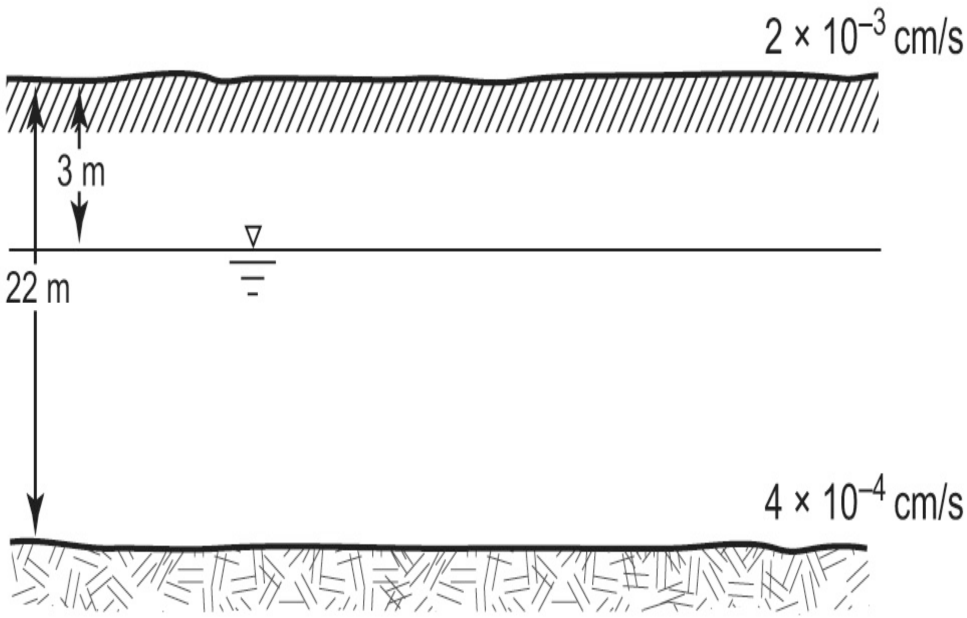


Figure 5.9 Stratum with uniformly varying hydraulic conductivity, Example 5.7.

Transmissivity: T = K x b

- $T = \underline{K}\, b$ (L^2T^{-1})

  where,

  T = ability of an aquifer to transmit water through its entire thickness

  $\underline{K}$ = <u>average</u> hydraulic conductivity

  b = thickness of the aquifer

Important Note: ***T*** applies is most commonly used for “confined aquifers”, because the ***b*** can be better estimated

Confined Flow Between Water Bodies (Examples 6.1 and 6.2)

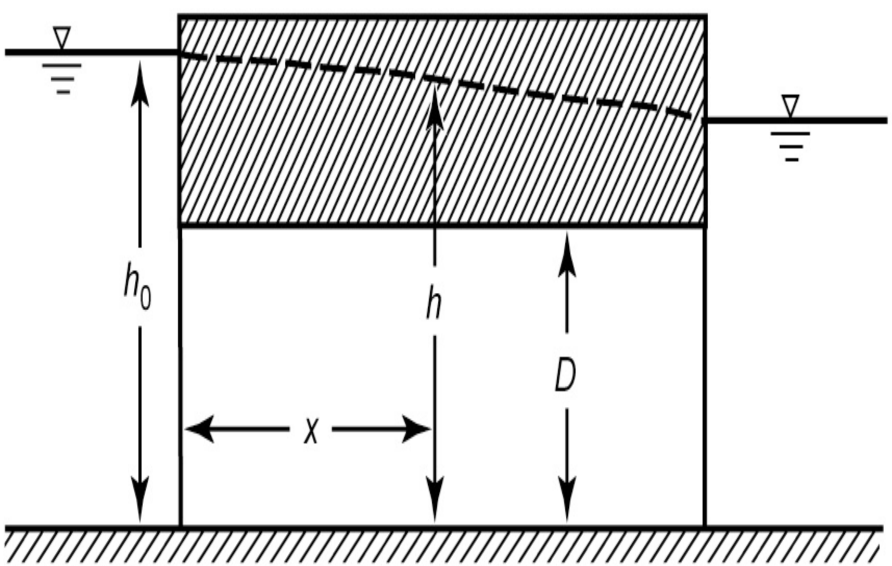
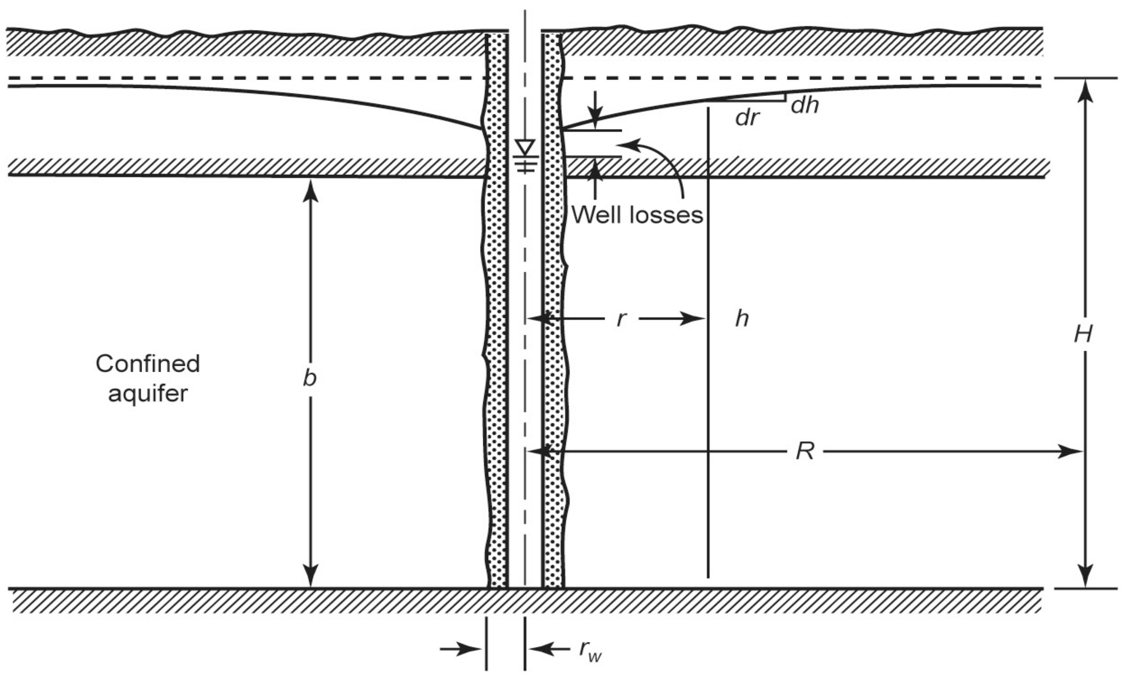


Figure 6.1 Confined flow between two water bodies.

Flow to a Fully Penetrating Well In Confined Aquifer: Steady-State Flow

(Thiem Equation, Eq. 6.4; Examples 6.3 and 6.4)

Figure 6.3 Fully penetrating well in a confined aquifer.



Thiem Equation, Equation 6.4 Examples 6.3 and 6.4 (p. 173)

- For *Steady-State flow* (i.e., Q = constant) from pumping at a single well in confined aquifers:

- $Q = [2 \pi b K (H - h)] / \ln (R/r)$, *(Eq. 6.3, p. 172)*

and generalizing for <u>any</u> two radii locations

- $Q = [2 \pi b K (h_1 - h_2)] / \ln (r_1/r_2)$, *(Eq. 6.4, p. 172)*

Steady Radial Flow to a Well in Confined Aquifer: Thiem Equation

$$T = Kb = \frac{Q}{2\pi(h_2 - h_1)} \ln \frac{r_2}{r_1}$$

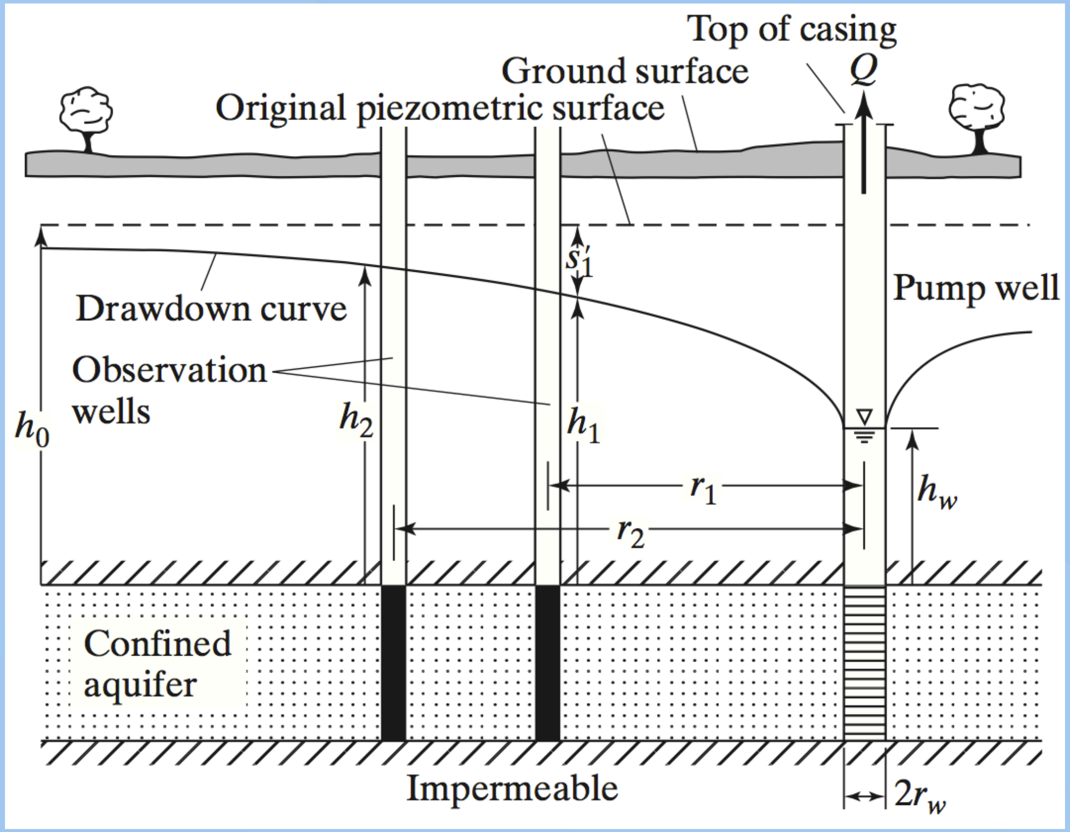
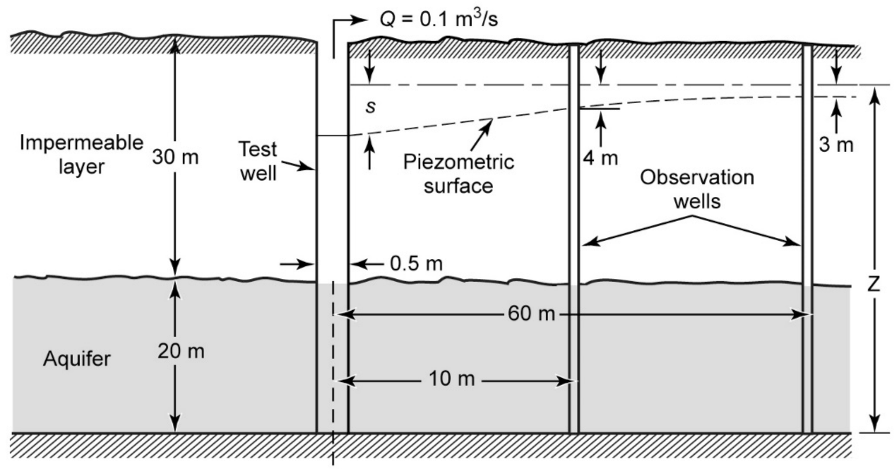


Figure for Example 6.4

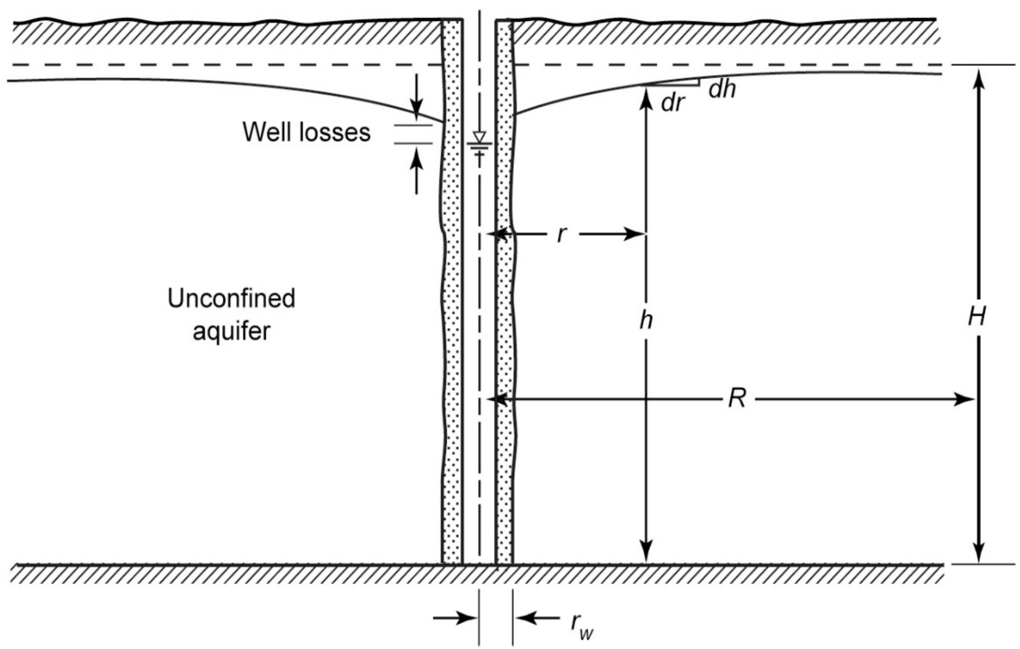
Figure 6.5 Testing of a confined aquifer, Example 6.4.



Flow to a Well in Unconfined Aquifer: Steady-State Flow

(Dupuit's Equation; Example 6.5)

Figure 6.6 Flow in an unconfined aquifer.



Dupuit's Equation, Equation 6.6: Example 6.5, p. 176

- For *Steady-State flow* (i.e., Q = constant) from pumping at a single well in unconfined aquifers:

- $Q = [\pi K (H^2 – h^2)] / \ln (R/r)$

and generalizing for <u>any</u> two radii locations

- $Q = [\pi K (h_1^2 – h_2^2)] / \ln (r_1/r_2)$

Steady Radial Flow to a Well in Unconfined Aquifer: Dupuit's Equation

$$K = \frac{Q}{\pi (h_2^2 - h_1^2)} \ln \frac{r_2}{r_1}$$

- K = Hydraulic Conductivity
- Q = Flow Out of Well
- h_j = Head of Observation well j
- r_i = Radial Distance from pumping well i

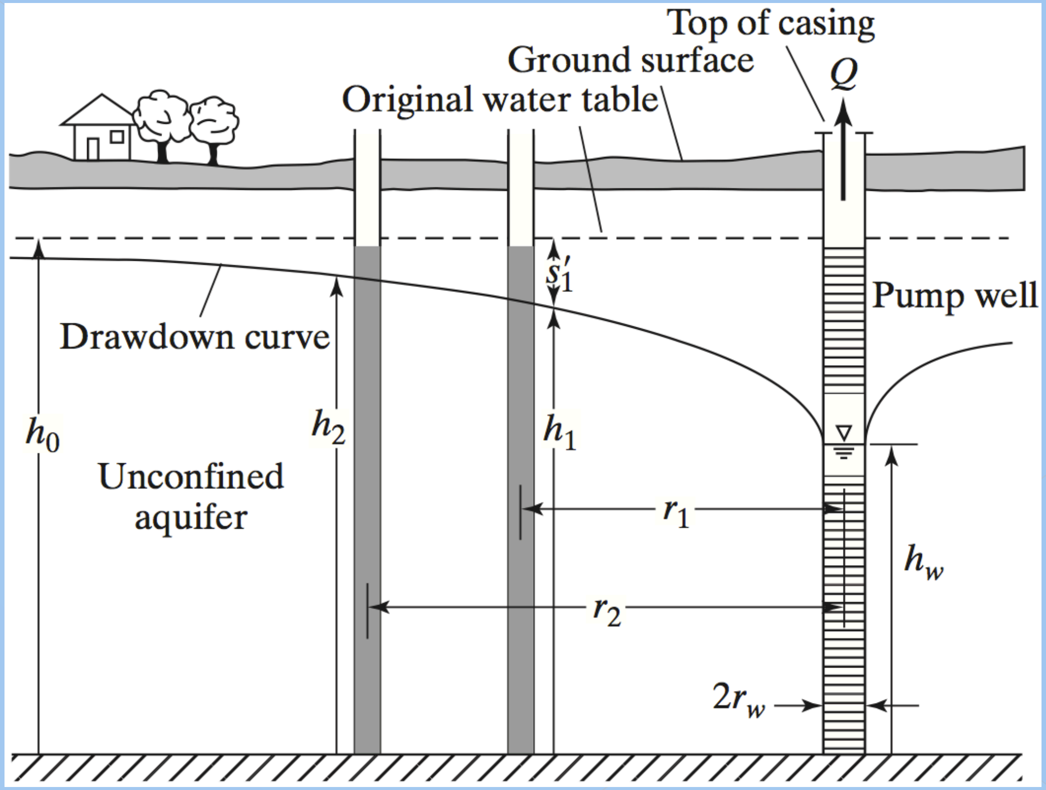
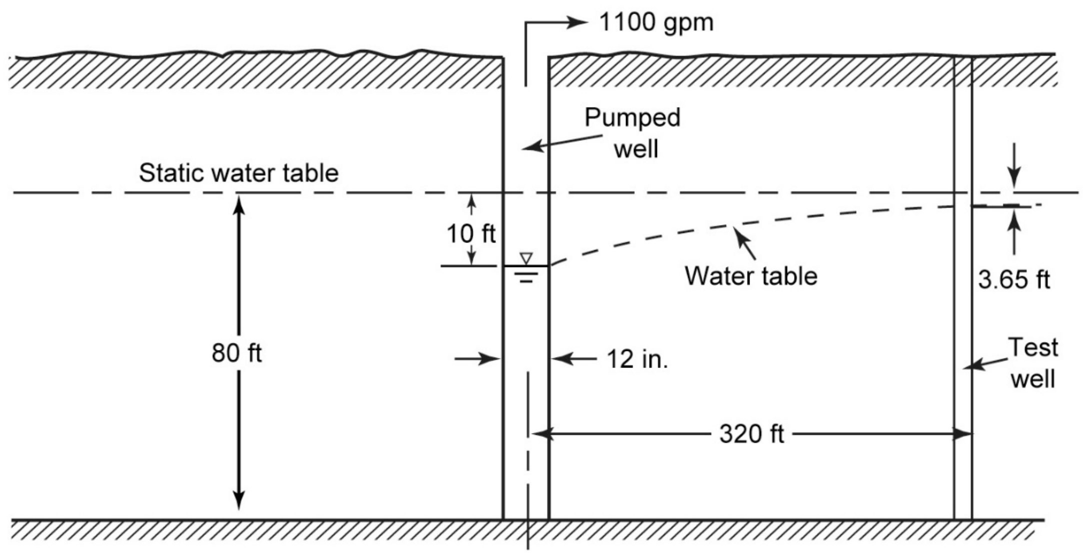
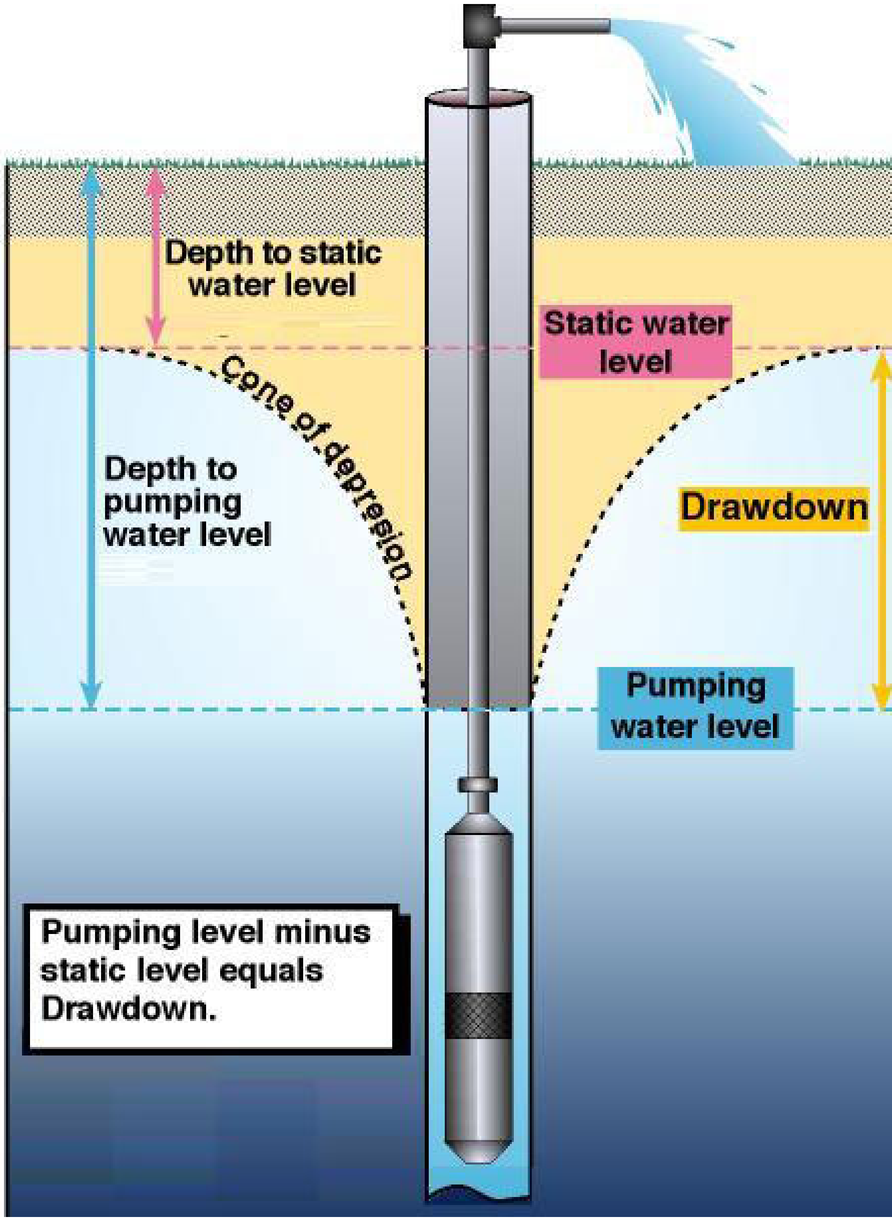


Figure for Example 6.5

Figure 6.7 Test well in an unconfined aquifer.



Steady-State Flow Well Hydraulics



Bedient, P. B., W. C. Huber and B. E. Vieux, Hydrology and Floodplain Analysis, 6th Edition, Prentice-Hall. Upper Saddle River, NJ

Groundwater Travel Time

- Radial velocity, $v_r = dr/dt$
- Using seepage velocity based on Darcy's Law for an average porosity η and integrating between any radial R and r distances
- Solving for Equation 6.6 (p. 177):

$$t_{travel} = [(\pi D \eta)/Q] (R^2 - r^2)$$

- Example 6.6 (p.178), for the conditions of the pumping of Example 6.4 (p. 173), yields the following travel time from the observation well at 60 m to the pumped well if the average porosity is 0.3:

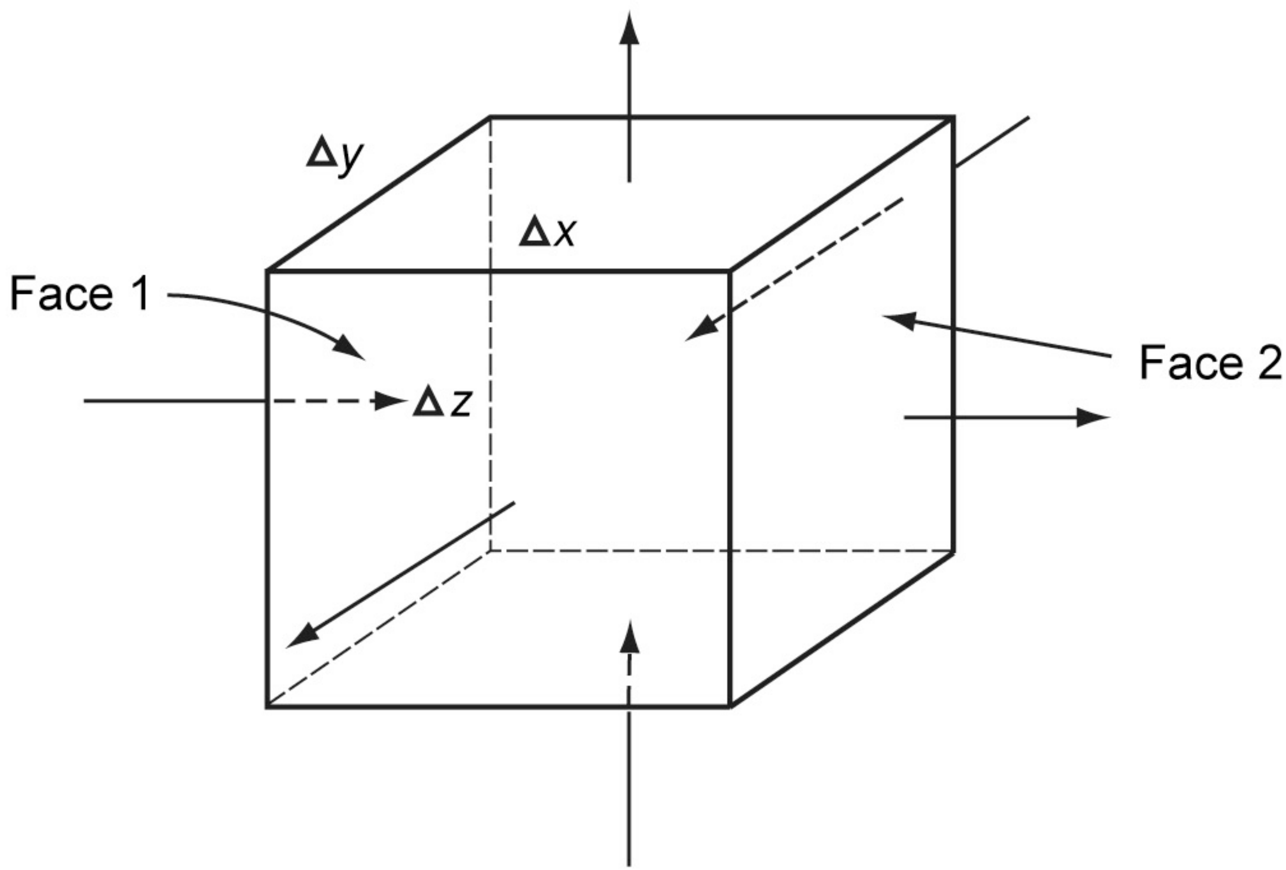
$$\mathit{t_{travel} = 678 \times 10^3\ s\ or\ 7.8\ days}$$

Groundwater Flow Equation

(1D, 2D, 3D - dimensions)

[Steady or Non-steady (also Unsteady) Flow Regimes]

Figure 5.14 Elemental volume in the field of flow.



Drilling

- Cable tool
  - A bit is raised and dropped over and over
  - Simple and cheap for shallow wells
  - Up to 600m

- Rotary (hollow stem auger)
  - Uses a hollow bit
  - Can exceed 150m

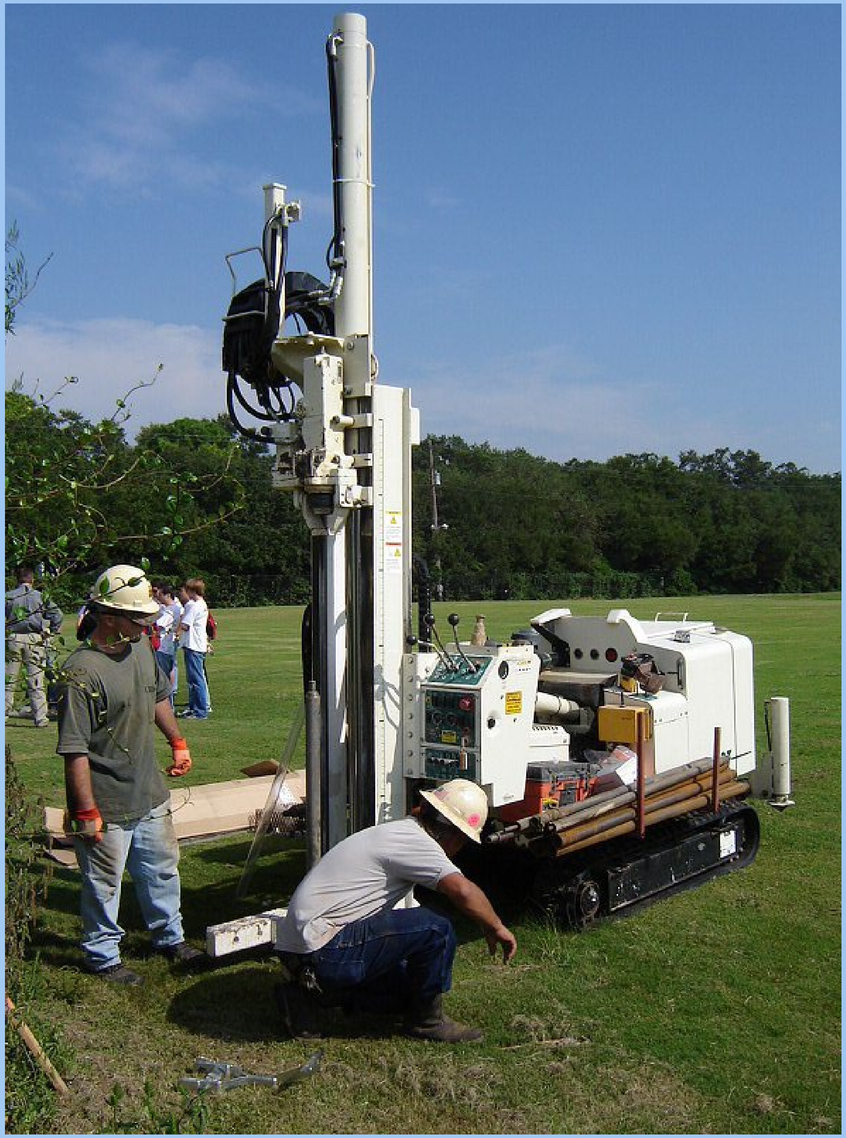
- Jetting – High pressure hydraulic drilling
  - Very fast construction, often used for observation.

Bedient, P. B., W. C. Huber and B. E. Vieux, Hydrology and Floodplain Analysis, 6th Edition, Prentice-Hall. Upper Saddle River, NJ,

Drilling

- Push tool
  - Uses hammer or weight
  - Simple and cheap for shallow wells
  - Up to 100 ft

- Cone penetrometer
  - Pushes with weight of truck
  - Insitu testing
  - Can insert small well
  - Can exceed 150 ft



Bedient, P. B., W. C. Huber and B. E. Vieux, Hydrology and Floodplain Analysis, 6th Edition, Prentice-Hall. Upper Saddle River, NJ

Theme 5: End of Summary Highlights

Refer to Textbook for Detailed Assigned Study Material, Example and Practice Problems