Groundwater Exam Solution 2019

In [54]:

```
from xlrd import *


import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import ipysheet as ips
import panel as pn
from scipy import stats
pn.extension('katex', 'mathjax')
```

Q1. Aquifer Properties (ca. 8 pts.)

Due to a dry period, the water level of the unconfined aquifer including the “Großer Garten” in Dresden decreased by about 1.0 m. The aquifer consists of sand and gravel. The effective porosity is 0.30; the affected area is 3 km x 3 km.

a. How many m^3 of water have been lost in the aquifer? (ca. 2 pts.)

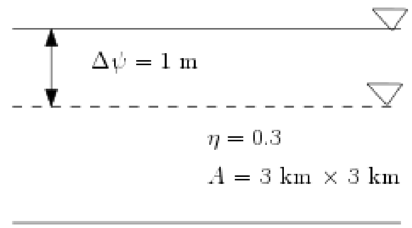
b. What is the definition of the term “storativity”? (ca. 1 pt.)

c. What is in general the range of storativity coefficient for an unconfined aquifer and a confined aquifer? (ca. 2 pt.)

d. Why are storavity values for confined and unconfined aquifer different? (ca. 1 pt.)

e. What is the difference between effective and total porosity? (ca. 2 pt.)

Solution 1a - (T01/P1)



In [2]:

```
A = 3 *3*10**6 # A= Area m^2
delta_h = 1.0 # m
eta = 0.3 # porosity
V_t = A*delta_h # change in volume of aquifer V_t
W_v = eta*V_t # Change in water volumen

print('The change in aquifer volume is '  '%.3g '  % V_t, 'm\xB3')
print('The change in water volume is ' '%.3g'  % W_v, 'm\xB3')
```

```
The change in aquifer volume is 9e+06  m³
The change in water volume is 2.7e+06 m³
```

Answer 1b - (L04/29)

Storativity is the volume of water released from an aquifer volume extending from the aquifer bottom up to the aquifer top over a unit area if the hydrostatic pressure is reduced by one unit.

Answer 1c - (T01/HW1)

Storativity or storage coefficient for an unconfined aquifer can be in a range below 2 orders of magnitude and that of a confined aquifer is below over 3 orders of magnitude.

Answer 1d - (L04/31-32)

Effective porosity is a volumetric share of voids that is occupied by mobile water. Total porosity is the total voids that may or may not be occupied by mobile and immobile water.

Answer 1e - (L04/31-32)

Storativity for confined aquifer is lower because there is limited voids to fill the water whereas in an unconfined aquifer the change in water volume leads to increase space for water storage.

Q2. Darcy Law (ca. 8 pts.)

Darcy's experiment is to be set up. The flow direction is from the bottom to the top in a vertical tube. The following data are known: the column is 100 cm long with an internal diameter of 0.03 m and is packed with sample for which the effective porosity is 25%. At steady-state the discharge through the column is 100 mL/min.

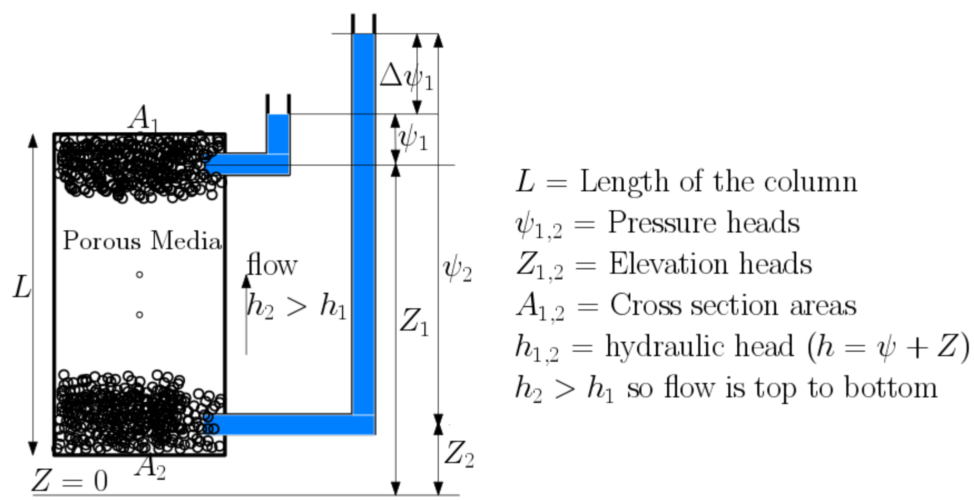
a. Make a schematic figure of the Darcy's experiment and label the figure completely with all important symbols and names. (ca. 3 pts.)

b. What is the difference between hydraulic conductivity and permeability? (ca. 1 pt.)

c. If the head difference between the two ends of the column is 10 cm, what will be the hydraulic conductivity of the sample? What type of material (fine/medium/coarse gravel, sand or silt or mixture) do you expect to be present in the column? (ca. 2 pts.)

d. Calculate linear velocity in the column. Explain how linear velocity is related to specific discharge. (ca. 2 pts.)

Solution 2a - (L05/08)



Solution 2b - (L05/18,20)

Permeability is only a property of porous medium, whereas conductivity is a property of both porous media and fluid.

Solution 2c - (L05/09 and T02/P9)

Use Figure from Solution 2a

In [31]:

```
# Given are:
l = 1 # 100 cm = 1m


d = 0.03 # m
eta = 0.25 # effective porosity
delta_h = 0.1 # head difference
Q = 1.6e-6 # 100ml/min* 1L/1000mL * 1 m^3/1000L * 1 min/60 s

# intermediate calculations
A = np.pi*(d**2/4) # Area
i = delta_h/l # gradient

print('The cross sectional area of column  is '  '%.3g'  %A, 'm\xB2')
print('The hydraulic gradient in the column is ' '%.3g' %i)
```

```
The cross sectional area of column  is 0.000707 m²
The hydraulic gradient in the column is 0.1
```

$$Q = -Aki$$

so,

$$K = \frac{Q}{Ai}$$

In [5]:

```
K = Q / (A * i)
print('The cross sectional area of column  is ' '%.3g' % K, 'm/s')
print('Based on table in L05/11- Gravel is likely the porous medium')
```

```
The cross sectional area of column  is 0.0226 m/s
Based on table in L05/11- Gravel is likely the porous medium
```

Solution 2d - (L05/23)

The linear velocity (v) is the ratio of discharge through the column to the cross sectional area of the column. It is obtained from:

$$v = \frac{Q}{\eta A}$$

In [6]:
```python
v = Q/(eta*A)
print('The linear velocity in the column is ' '%0.3e' %v, 'm/s')
```

```
The linear velocity in the column is 9.054e-03 m/s
```

Q3. Soil Analysis (ca. 9 pts.)

A soil sample with a total mass of 492.1 g was characterized by wet sieving and sedimentation with a Hyprob-System with regard to the grain size composition.

a) Draw the granulometric curve in the diagram below. (ca. 6 pts.)

In [8]:
```python
df1 = pd.read_excel('Q2a.xlsx', usecols="A:E", header=0, keep_default_na=False)
df1.style.set_properties(**{'text-align': 'right'})
df1
```

Out[8]:

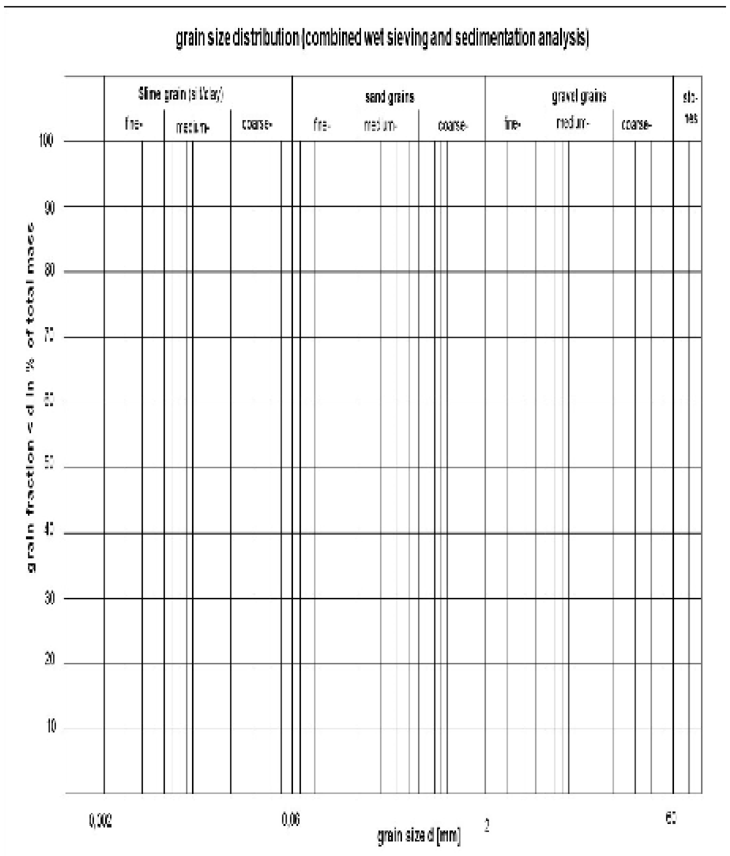
	method	diameter [mm]	mass [g]	Σ total (%)	Σ/Σ total passing (%)
0	wet sieving	10.0000	0.0	0	100
1	wet sieving	4.0000	57.4		
2	wet sieving	0.6300	153.4		
3	wet sieving	0.0630	220.2		
4	sedimentation analysis (HYPROB)	0.0200	19.2		
5	sedimentation analysis (HYPROB)	0.0063	9.9		
6	sedimentation analysis (HYPROB)	0.0020	4.5		
7	sedimentation analysis (HYPROB)	0.0010	27.5		

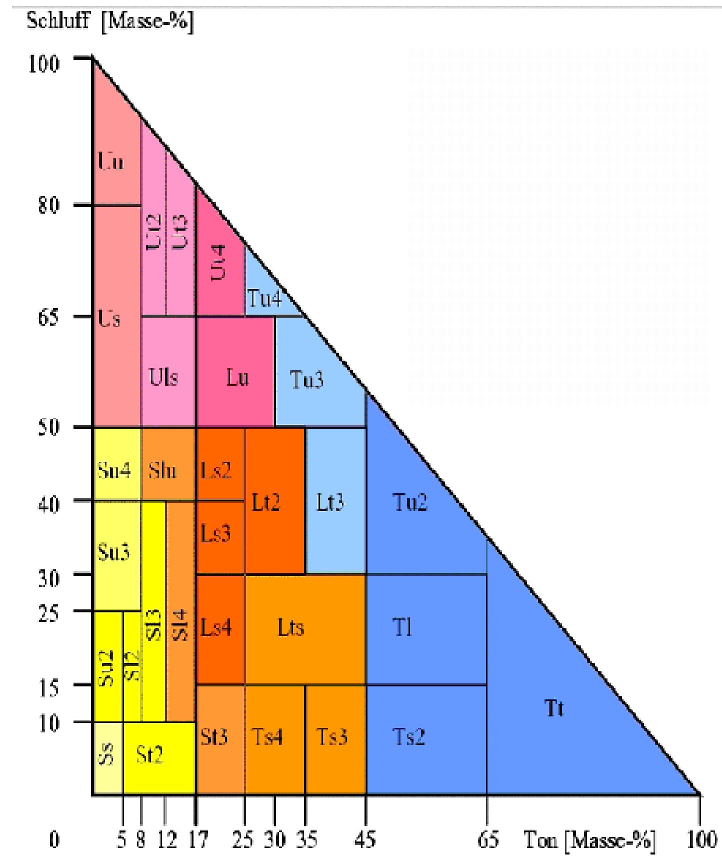
In [9]:

```python
fig, ax = plt.subplots(nrows=1, ncols=2, figsize=(18, 10))
ax1 = ax[0]
img1 = plt.imread('figs/Q3a1.png')
ax1.set_axis_off()
ax1.imshow(img1,  aspect='auto')

ax2 = ax[1]
img2 = plt.imread("figs/Q3a2.png")
ax2.set_axis_off()
ax2.imshow(img2,  aspect='auto')
```

Out[9]: <matplotlib.image.AxesImage at 0x7905bd4499d0>





b. Briefly characterise the sediment by plotting the silt (‘Schluff’) fraction (mass d =0,002 – 0,063 mm)/total mass <0,063 mm) and the clay (‘Ton’) fraction (mass d<0,002 mm/ total mass <0,063 mm) from the sedimentation analysis in the soil texture diagram below. (ca. 3 pt.)

Solution 3a (L03/19 and Lab Manual)

In [11]:

```
mat = df1.values # convert data into matrix so that we apply numpy
dia = mat[:,1] # extract diam column as array
mass = mat[:,2] # extract mass columm as array

# Calculation steps - filling table
Total_mass = mass.sum()  # add the mass column to get total mass
retain_per = mass/Total_mass *100  # retain percentage
retain_per_cumsum = retain_per.cumsum() # get the cummulative sum of the reatined
passing_per = 100 - retain_per_cumsum # substract 100-cummsum to get passing %

df1['Σ total (%)'] = retain_per
df1['Σ/Σ total passing (%)'] = passing_per
df1
```

Out[11]:

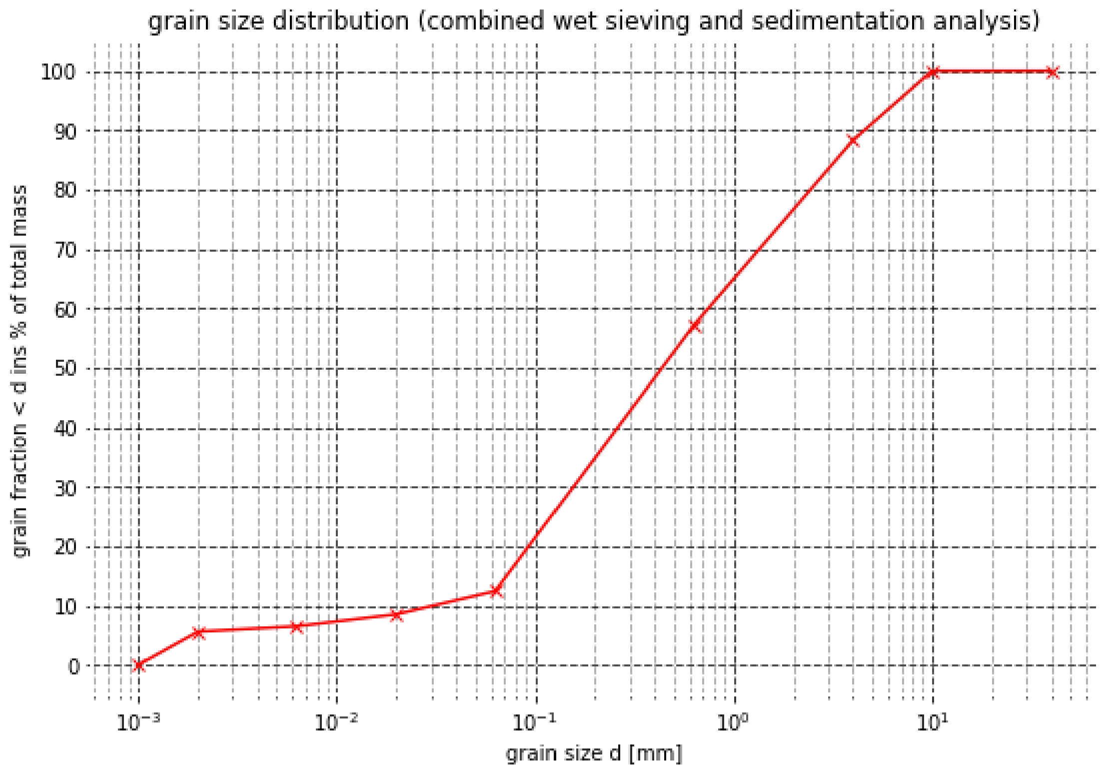
	method	diameter [mm]	mass [g]	Σ total (%)	Σ/Σ total passing (%)
0	wet sieving	10.0000	0.0	0	100
1	wet sieving	4.0000	57.4	11.6643	88.3357
2	wet sieving	0.6300	153.4	31.1725	57.1632
3	wet sieving	0.0630	220.2	44.747	12.4162
4	sedimentation analysis (HYPROB)	0.0200	19.2	3.90165	8.51453
5	sedimentation analysis (HYPROB)	0.0063	9.9	2.01179	6.50274
6	sedimentation analysis (HYPROB)	0.0020	4.5	0.914448	5.5883
7	sedimentation analysis (HYPROB)	0.0010	27.5	5.5883	1.42109e-14

In [83]:

```
# plotting
plt.rcParams['axes.linewidth']=2
#plt.rcParams["axes.edgecolor"]='white'
plt.rcParams['grid.linestyle']='--'
plt.rcParams['grid.linewidth']=1
x = np.append([40],dia)
y = np.append([100],passing_per)
fig = plt.figure(figsize=(9,6))
plt.plot(x, y, 'x-', color='red')
tics=x.tolist()
plt.xscale('log')
plt.grid(which='major', color='k', alpha=0.7)
plt.grid(which='minor', color='k', alpha=0.3)
#plt.xticks(x, tics)
plt.yticks(np.arange(0,110,10));
plt.title('grain size distribution (combined wet sieving and sedimentation analysis)');
plt.xlabel('grain size d [mm]');
plt.ylabel('grain fraction < d ins % of total mass')
```

Out[83]:

```
Text(0, 0.5, 'grain fraction < d ins % of total mass')
```



In [84]:

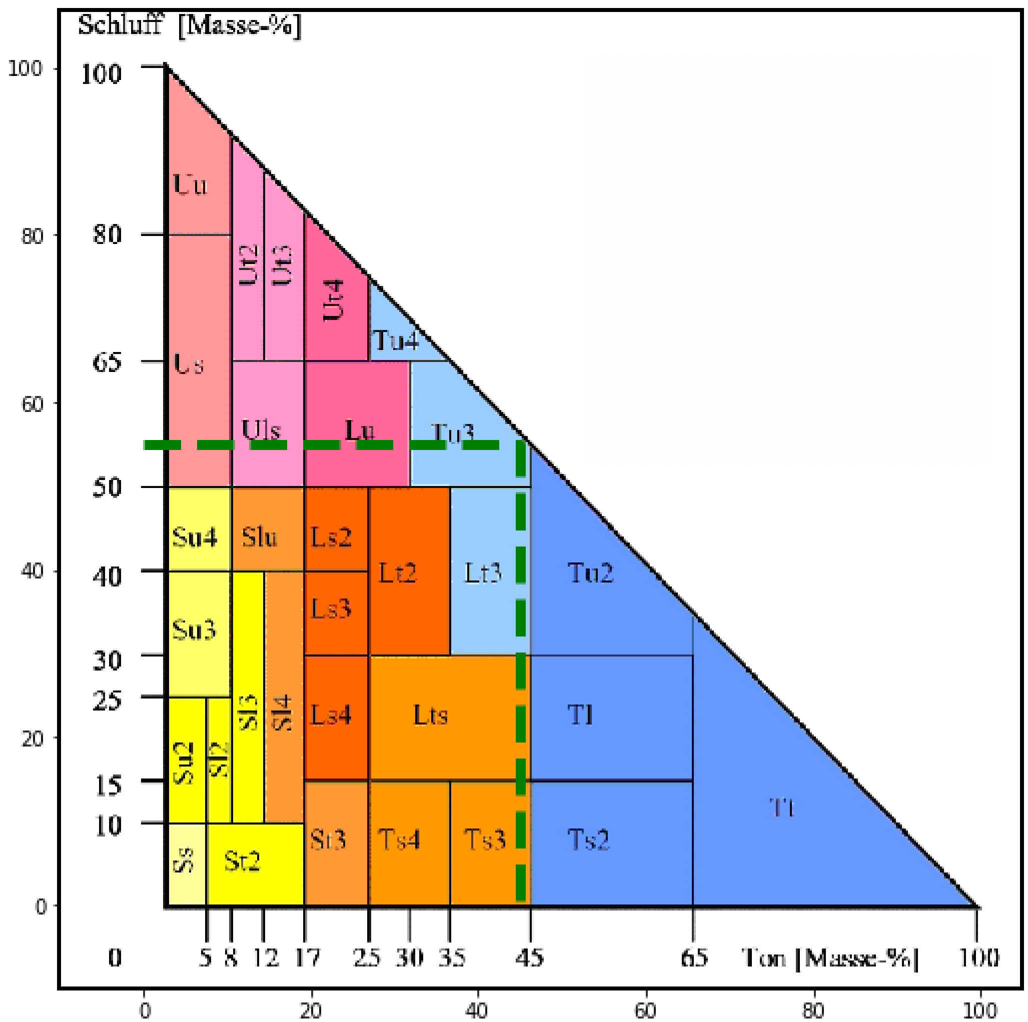
```
mass_below_0_0063_mm = np.sum(mass[4:])
mass_silt = np.sum(mass[4:7]) # mass of silt
mass_clay = np.sum(mass[7]) # mass of clay
percentage_silt =100*(mass_silt/mass_below_0_0063_mm) # % silt
percentage_clay = 100*(mass_clay/mass_below_0_0063_mm) # % clay
print('Mass of Silt is ' '%g' %mass_clay, 'g' )
print('Mass of Silt is ' '%g' %mass_silt, 'g' )
print("The Silt percentage is {:0.2f}".format(percentage_silt), '%')
print("The Clay percentage is {:0.2f}".format(percentage_clay), '%')
```

```
Mass of Silt is 27.5 g
Mass of Silt is 33.6 g
The Silt percentage is 54.99 %
The Clay percentage is 45.01 %
```

In [23]:
```
img = plt.imread("figs/Q3a2.png")
fig, ax = plt.subplots(figsize=(9,9))
x1 = [0, percentage_clay, percentage_clay]
y1 = [percentage_silt, percentage_silt, 0]
ax.imshow(img, extent=[-10,105, -10,107])
#ax.plot(x1,y1, '--', linewidth=5, color='firebrick')
ax.plot(x1, y1, '--', lw=5, color = 'green')

print('The sample can be characterize as: TU3 ')
```

```
The sample can be characterize as: TU3
```

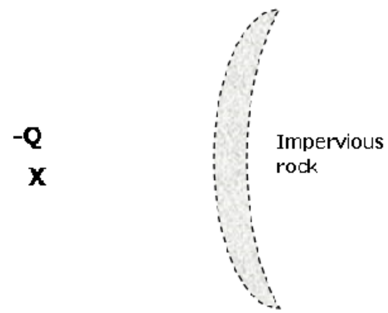


In [24]:
```
v = Q/(eta*A)
print('The linear velocity in the column  is '  '%e'  %v, 'm/s')
```

```
The linear velocity in the column  is 9.054148e-03 m/s
```

Q4. Flow Net and Isolines (ca. 5 pts.)

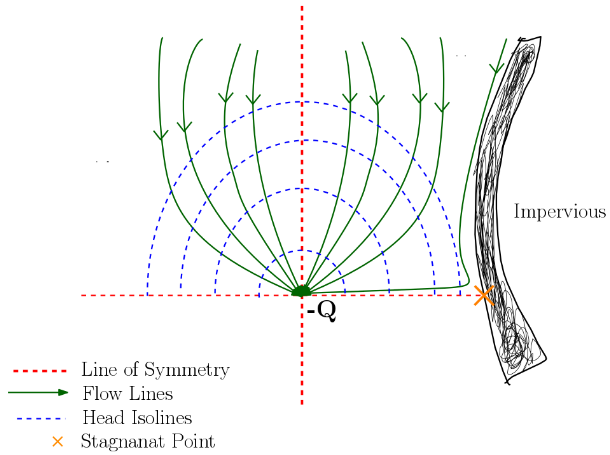
The figure below shows one water abstraction well (plan view) operating with a steady-state pumping rate near an impervious wall. The corresponding flow net is to be deter-mined under the assumption that there is NO uniform groundwater flow component.



a. Sketch several streamlines. Results of sub-problem a) can be favourably taken into ac-count here. (ca. 2 pts.)

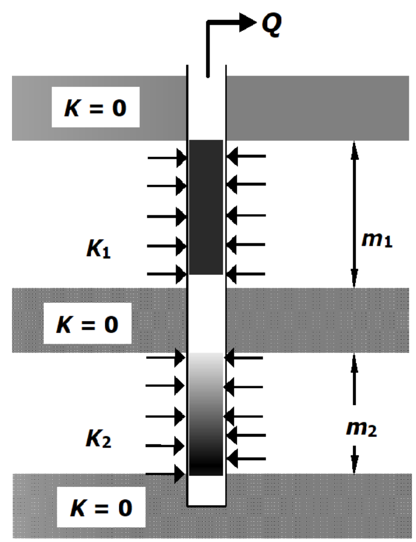
b. Sketch corresponding head isolines and a stagnant point. (ca. 3 pts.)

Solution 4a/4b



Q5. Effective Conductivity (ca. 7 pts.)

Two confined aquifers are separated by an impervious layer (see figure). A withdrawal well is screened over the entire thicknesses ($m_1 = 4$ m, $m_2 = 2$ m) of both aquifers. Its total pumping rate Q is $4 \cdot 10^{-3}$ m³/s. Hydraulic conductivities of the two aquifers are equal to $K_1 = 1 \cdot 10^{-5}$ m/s and $K_2 = 2.5 \cdot 10^{-4}$ m/s, resp.



a. Determine the effective horizontal hydraulic conductivity of the two-aquifer system. (ca. 3 pts.) (Hint: $mK = m_1 K_1 + m_2 K_2$ or $m/K = m_1/K_1 + m_2/K_2$; choose the correct one for your answer)

b. Calculate discharges Q1 and Q2 withdrawn from the two aquifers. (Hint: Aquifer has a unit width) (ca. 4 pts.)

Solution 5a - (L06/10)

The effective horizontal conductivity is given by:

$$K_{eff_h} = \sum_{i=1}^{n} \frac{m_i K_i}{m}$$

with $m = \sum m_i$ for $i = 1 \cdots n$.

In [25]:

```
#Given
m1, m2, K1, K2, Q = 4, 2, 1e-5, 2.5e-4, 4e-3

#Solution
m = m1+m2
Keff_h = (m1*K1+m2*K2)/m
print('The effective horizontal conductivity  is '  '%e'  %Keff_h, 'm/s')
```

```
The effective horizontal conductivity  is 9.000000e-05 m/s
```

The discharge of the homogeneous layer is:

$$Q = w\, m\, K_{eff_h} \Delta h/L$$

with w (= 1 considered here) the width of the aquifer and L is the length of the flow along the layer.

The discharges in each levels is:

$$Q_i = w\, m_i\, K_i \Delta h/L$$

with $i = 1 \text{ and } 2$. To obtain the discharge at each level we need to find $\Delta h/L$ from eq. 3 and then use it to obtain discharge Q at each level using eq. 4.

In [26]:

```
deltah_L = Q/(m*Keff_h)
deltah_L
```

Out[26]:

```
7.407407407407407
```

In [27]:
```
Q1 = m1*K1*deltah_L
Q2 = m2*K2*deltah_L
print(u'The discharge at the top of the aquifer Q\u2081 is '  '%e'  %Q1, 'm/s')
print(u'The discharge at the top of the aquifer Q\u2082 is '  '%e'  %Q2, 'm/s')
print(u'Check Q\u2081 + Q\u2082  is '  '%e'  %(Q1+Q2), 'm/s')
```

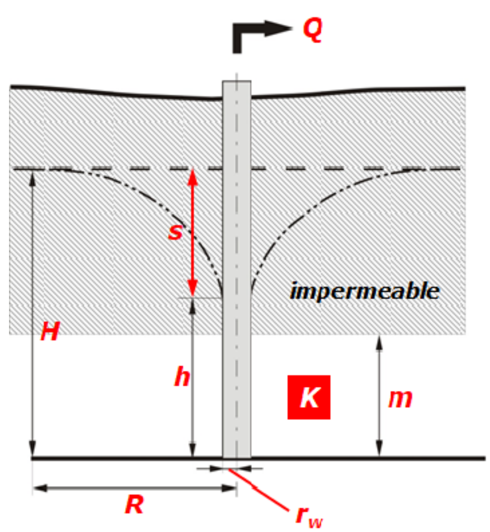
```
The discharge at the top of the aquifer Q₁ is 2.962963e-04 m/s
The discharge at the top of the aquifer Q₂ is 3.703704e-03 m/s
Check Q₁ + Q₂  is 4.000000e-03 m/s
```

6. Pumping Test (ca. 5 pts)

a. Sketch the pumping scenario of a confined aquifer (vertical cross section) and label all possible quantities (ca 2 pts.)

b. Indicate the three requirements needed to evaluate a pumping test by the Theis method (3 pts.)

Solution 6a (L08/15)



Q = Pumping rate
K = Hydraulic conductivity
m = Aquifer thickness
H = Water level at rest
h = Water level in pumping well
r_w = Radius of the well
R = Radius of influence
s = Drawdown $(H - h)$

Solution 6b (L08/30)

The three requirements are:

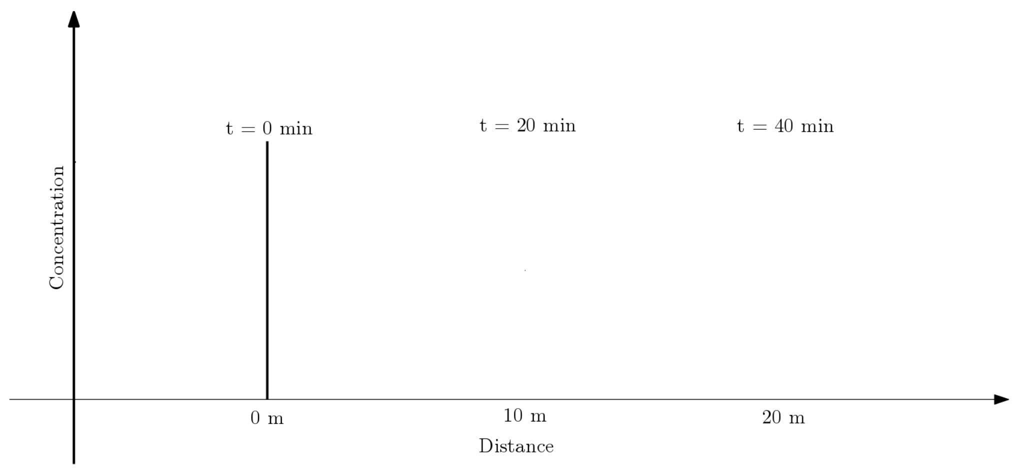
1. Aquifer is confined, homogeneous and isotropic
2. Aquifer thickness is uniform

3. Aquifer bottom is horizontal
4. The well is fully penetrating
5. $r_w << R$
6. The pumping rate is steady
7. No vertical flow component

Q7. Solute Transport (ca. 5 pts.)

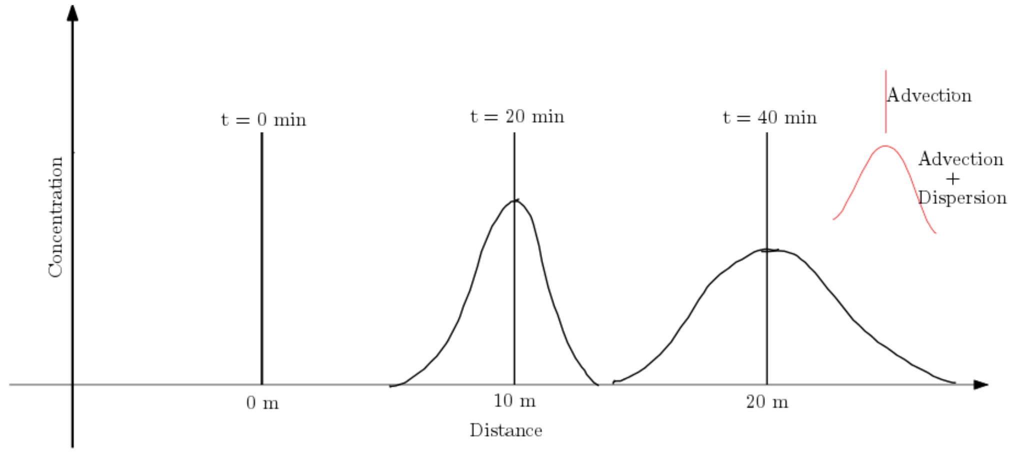
A column experiment (column length = 2 m, cross section area = 0.025 m^2, hydraulic head gradient = 0.01) was performed to evaluate a solute transport through a sample (Hydraulic Conductivity = 10^{-4} m/s and effective porosity = 30%).

a. Complete the profiles for all times for only advection case and for both advection and dis-persion case. (ca. 2 pts.)



b. What is a Retardation factor? If the groundwater velocity is 10^{-6} m/s, what will contaminant ve-locity be when there is no retardation and with the retardation factor 2 (ca. 3 pts.)

Solution 7a (L09/24)



Solution 7b (T06/8)

Retardation factor (R) is the ratio between the groundwater flow velocity (v_w) and the retarded velocity of the mass flow speed with the groundwater (v_w) , i.e.,

$$R = \frac{v_w}{v_m}$$

In [86]:

```
v_w = 1e-6 # m/s

# Case 1
R_1 = 2
v_m1 = v_w/R_1

# Case 2
R_2 = 1 # When there is no retardation
v_m2 = v_w/R_2

print("The mass transport when retardation factor R = 2 is " '%g' %v_m1, 'm/s'  )
print("The mass transport without any retardation (R = 1) is " '%g' %v_m2, 'm/s'  )
```

```
The mass transport when retardation factor R = 2 is 5e-07 m/s
The mass transport without any retardation (R = 1) is 1e-06 m/s
```

Q8. Flow and Transport Modeling (ca. 8 pts.)

a. What are isotherms? Name two non-linear isotherms. (ca. 3 pts.)

b. How is degradation different to sorption? You are asked to find the decay constant (λ) of the radioactive element whose initial concentration was recorded to be 100 mg/L and the present concentration after 10 years is found to be 10 mg/L. The element is known to agree with the first order decay model ($C(t) = C_0 \exp^{-\lambda t}$) , where t is time). What will be the half life ($T_{1/2}$) of the element? (ca. 3 pts.)

c. Schematically draw and label a conceptual model for a horizontal 2D flow scenario. Flow is from left to right. You may put your choice of at least 2 different boundary conditions at sides of the domain? (ca. 2 pts.)

Solution 8a - (L10/10)

Isotherm is a relationship between the solute concentration (C) in the dissolved phase and the mass ratio adsorbate:adsorbent (C_a).

Few types of Isotherms are:

1. Freundlich
2. Langmuir

Solution 8b - (L10/20)

The first order decay model is given as:

$$C(t) = C_0 \exp^{-\lambda t}$$

Rearranging it becomes

$$\frac{C(t)}{C_0} = \exp^{-\lambda t}$$

Taking ln both side we get

$$\ln \frac{C(t)}{C_0} = -\lambda t$$

Rearranging and letting -ve sign go, will lead to

$$\lambda = \frac{1}{t} \ln \frac{C_0}{C(t)}$$

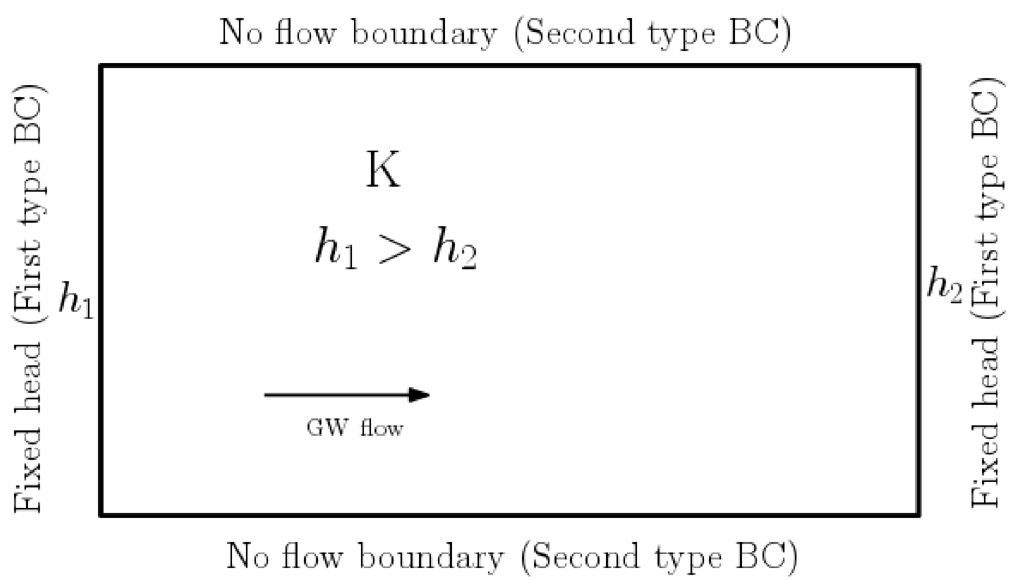
In [29]:
```
# Given are
c0, ct, t = 100, 10, 10

# Solve
lambd_a = 1/t*(np.log(c0)-np.log(ct))
T_half = np.log(2)/lambd_a

print('The decay constant is ' '%.3f' %lambd_a, '1/y' )
print('The half life of the massis ' '%.3f' %T_half, 'y' )
```

```
The decay constant is 0.230 1/y
The half life of the massis 3.010 y
```

Solution 8c - (L13/14)



Good Luck.