National Exams December 2019

18-Geol-A2, Hydrogeology

Duration: 3 hours

Notes:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. This is an OPEN BOOK EXAM.
   Any non-communicating calculator is permitted.
3. FIVE (5) questions constitute a complete exam paper.
4. Each question is of equal value.
5. Clarity and organization of the answers are important. Please show your work in detail while answering the questions.
6. Unless otherwise specified, use water density = 1000 kg/m^3, water viscosity = 0.001 kg/m-sec, and g = 9.81 m/s^2.

Marking Scheme:

1.	(a) 6 marks;	(b) 8 marks;	(c) 6 marks.	
2.	(a) 8 marks;	(b) 6 marks;	(c) 6 marks.	
3.	(a) 7 marks;	(b) 7 marks;	(c) 6 marks.	
4.	(a) 6 marks;	(b) 5 marks;	(c) 4 marks;	(d) 5 marks.
5.	(a) 4 marks;	(b) 4 marks;	(c) 4 marks;	(d) 8 marks.

Question 1

a) The soil in an aquifer system is determined to have a horizontal hydraulic conductivity tensor with $K_{xx} = 10^{-3}$ cm/sec, $K_{xy} = 5.0 \times 10^{-4}$ cm/sec, and $K_{yy} = 10^{-4}$ cm/sec. If the aquifer has dh/dx = 0.015, and dh/dy = -0.008, determine the Darcy velocities in the x and y directions in the aquifer and the overall magnitude and direction (show a sketch with angle identified in degrees) of the Darcy velocity vector. **(6 marks)**

b) Three wells (X, Y, and Z) are drilled in an aquifer. Well Y is 300 m directly north of Well X. Well Z is 300 m directly east of Well X. The water level in Well X is 180 m.a.s.l., in Well Y it is 200 m.a.s.l. In Well Z the water level is 190 m.a.s.l. Estimate the magnitude and direction of the hydraulic head gradient in the aquifer. Include a sketch showing the basis for your calculations. **(8 marks)**

c) A moist soil sample has a mass of 1020 g, total volume of 650 cm^3, and oven dried mass of 950 g. The soil solid particle density is 2.62 g/cm^3. Determine dry bulk density, porosity, and saturation of the soil. **(6 marks)**

Question 2

a) Three geological formations, each 25 m thick, overlie on another. The hydraulic conductivity of the top formation s 0.001 m/s, the middle formation is 0.005 m/s and the bottom formation is 0.001 m/s. If a constant-velocity vertical flow field is set up across the set of formations with the hydraulic head of 180 m at the top of the formations and hydraulic head of 80 m at the bottom, calculate water pressure at the two internal boundaries (between the formations). **(8 marks)**

b) A fresh water (water density = 1000 kg/m^3) aquifer is separated from an underlying saline (density of 1160 kg/m^3) aquifer by a 20 m thick aquitard. A well screened at the top of the aquitard in the fresh water aquifer contains 12 m of fresh water. A well screened at the bottom of the aquitard in the saline aquifer contains 30 m of saline water. Determine the direction of water flow across the aquitard if i) the density of the saline aquifer water was assumed to be 1000 kg/m^3, ii) if the true density of the saline aquifer water was used. **(6 marks)**

c) A fully confined aquifer has a specific storativity of 2.5×10^{-6} m^{-1}, a thickness of 35 m, a width of 2200 m and a length of 2000 m. What volume of water would be pumped to lower the piezometric head in the aquifer by 1.2 m? **(6 marks)**

Question 3

a) A community is planning a new subdivision which will use a new town well water as their main domestic water source. The aquifer they are planning to use is a confined aquifer with a transmissivity of 250 m^2/day and a storativity of 0.0002. Compute the drawdown caused by the new pumping well at observation wells 50 m and 150 m away from the town well, if the pumping rate is 2.5 m^3/min, and the pump is continuously pumping for 25 days. **(7 marks)**

b) If the aquifer in part 3a) is not fully confined but is overlain by a 3 m confining layer with a vertical hydraulic conductivity of 0.04 m/day, and no storage, what would be the drawdown after 25 days at the two observation wells (50 m and 150 m away) (assume same pumping rate). **(7 marks)**

c) The confined aquifer (same as in part 3a) located at the new subdivision is being evaluated as the possible source of potable water for the residents. The average daily requirement is 1,000 cubic meters. A consulting company has installed two wells in the confined aquifer. The wells are screened at the same depth and are 1.2 km apart horizontally. The depth to water in well # 1 is 20 m while the depth to water in well # 2 is 26.5 m. Initial measurements show that the hydraulic conductivity of the aquifer is 10^{-3} cm/s, the average depth is 22 m, and it spans 5 km. Will the aquifer be suitable for the new subdivision? **(6 marks)**

Question 4

a) A landfill cap is constructed, in descending order, of a 50 cm thick layer of topsoil (k = 10^{-13} m^2), a 40 cm thick lateral drainage layer (k = 2 x 10^{-10} m^2), and a 110 cm thick barrier layer (k = 2 x 10^{-16} m^2). Determine the average vertical and horizontal hydraulic conductivities of the landfill cap. If a heavy rainstorm produces water ponding on the topsoil layer to a depth of 3 cm, determine the volumetric water flow rate through a 1 m^2 area of the barrier layer. Assume that the cap is completely saturated, but the waste layer immediately below the cap is unsaturated. **(6 marks)**

b) A landfill has been designed with a clay aquitard that separates the waste from the aquifer. The clay is 3 m thick with a permeability of 10^{-16} m^2. A piezometer measuring the water level at the top of the aquitard contains 0.5 m of water. What would the hydraulic head need to be at the bottom of the aquitard if you wanted to induce a Darcy velocity upwards of 1×10^{-3} m/yr through the aquitard? What would the pressure be (in Pa) at the same point and why might inducing an upward velocity be a good idea. **(5 marks)**

c) For a slug test in a confined aquifer the Copper-Bredehoeft-Papadopolous curve matching method is used to determine aquifer storativity and transmissivity. The well has a casing radius of 7.5 cm, and a screened section radius of 5 cm. The match point is t_1 = 20 seconds (for $Tt/rc^2 = 1$) and the best match is to the curve for log μ = - 6. Determine the storativity and transmissivity of the aquifer. (6 marks). **(4 marks)**

d) A well screened through the entire depth of a fully confined aquifer is pumped at 3 m^3/min. At a distance of 190 m from the pumping well the drawdowns in an observation well are 3.6 m after 4 hours and 6 m after 12 hours. Determine storativity and transmissivity of the aquifer. **(5 marks)**

Question 5

a) Discuss the difference between storativity and specific yield with respect to type of aquifer and method of water release. **(4 marks)**

b) If the pumping rate, time, and distance from the pumping well are kept the same, in what order (from smallest to biggest) would you expect the drawdown to be for a confined aquifer, leaky confined aquifer and confined aquifer bounded by an impermeable boundary. Please explain your answer. **(4 marks)**

c) What are the causes of saltwater encroachment, and what measures can be taken to minimize this process? **(4 marks)**

d) When designing an investigative study to evaluate the potential of an aquifer to supply water for a new subdivision, outline the steps that you would include in the study, including discussion of any techniques you would use in the investigation, any aquifer properties you would determine, and equipment needed. **(8 marks)**

Table 5.1
Values of $W(u)$ for values of u (from Wenzel, 1942)

u	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
$\times 1$	0.219	0.049	0.013	0.0038	0.0011	0.00036	0.00012	0.000038	0.000012
$\times 10^{-1}$	1.82	1.22	0.91	0.70	0.56	0.45	0.37	0.31	0.26
$\times 10^{-2}$	4.04	3.35	2.96	2.68	2.47	2.30	2.15	2.03	1.92
$\times 10^{-3}$	6.33	5.64	5.23	4.95	4.73	4.54	4.39	4.26	4.14
$\times 10^{-4}$	8.63	7.94	7.53	7.25	7.02	6.84	6.69	6.55	6.44
$\times 10^{-5}$	10.94	10.24	9.84	9.55	9.33	9.14	8.99	8.86	8.74
$\times 10^{-6}$	13.24	12.55	12.14	11.85	11.63	11.45	11.29	11.16	11.04
$\times 10^{-7}$	15.54	14.85	14.44	14.15	13.93	13.75	13.60	13.46	13.34
$\times 10^{-8}$	17.84	17.15	16.74	16.46	16.23	16.05	15.90	15.76	15.65
$\times 10^{-9}$	20.15	19.45	19.05	18.76	18.54	18.35	18.20	18.07	17.95
$\times 10^{-10}$	22.45	21.76	21.35	21.06	20.84	20.66	20.50	20.37	20.25
$\times 10^{-11}$	24.75	24.06	23.65	23.36	23.14	22.96	22.81	22.67	22.55
$\times 10^{-12}$	27.05	26.36	25.96	25.67	25.44	25.26	25.11	24.97	24.86
$\times 10^{-13}$	29.36	28.66	28.26	27.97	27.75	27.56	27.41	27.28	27.16
$\times 10^{-14}$	31.66	30.97	30.56	30.27	30.05	29.87	29.71	29.58	29.46
$\times 10^{-15}$	33.96	33.27	32.86	32.58	32.35	32.17	32.02	31.88	31.76

Table 5.2
Values of $W(u\ r/B)$ (after Hantush, 1956)*

u \ r/B	0.01	0.015	0.03	0.05	0.075	0.10	0.15	0.2	0.3	0.4
0.000001										
0.000005	9.4413									
0.00001	9.4176	8.6313								
0.00005	8.8827	8.4533	7.2450							
0.0001	8.3983	8.1414	7.2122	6.2282	5.4228					
0.0005	6.9750	6.9152	6.6219	6.0821	5.4062	4.8530				
0.001	6.3069	6.2765	6.1202	5.7965	5.3078	4.8292	4.0595	3.5054		
0.005	4.7212	4.7152	4.6829	4.6084	4.4713	4.2960	3.8821	3.4567	2.7428	2.2290
0.01	4.0356	4.0326	4.0167	3.9795	3.9091	3.8150	3.5725	3.2875	2.7104	2.2253
0.05	2.4675	2.4670	2.4642	2.4576	2.4448	2.4271	2.3776	2.3110	1.9283	1.7075
0.1	1.8227	1.8225	1.8213	1.8184	1.8128	1.8050	1.7829	1.7527	1.6704	1.5644
0.5	0.5598	0.5597	0.5596	0.5594	0.5588	0.5581	0.5561	0.5532	0.5453	0.5344
1.0	0.2194	0.2194	0.2193	0.2193	0.2191	0.2190	0.2186	0.2179	0.2161	0.2135
5.0	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011

u \ r/B	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5
0.000001									
0.000005									
0.00001									
0.00005									
0.0001									
0.0005									
0.001									
0.005									
0.01	1.8486	1.5550	1.3210	1.1307					
0.05	1.4927	1.2955	1.2955	1.1210	0.9700	0.8409			
0.1	1.4422	1.3115	1.1791	1.0505	0.9297	0.8190	0.4271	0.2278	
0.5	0.5206	0.5044	0.4860	0.4658	0.4440	0.4210	0.3007	0.1944	0.1174
1.0	0.2103	0.2065	0.2020	0.1970	0.1914	0.1855	0.1509	0.1139	0.0803
5.0	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0010	0.0010	0.0009

*Trans. Amer. Geophys. Union, 37, p. 702–714.