

National Exams December 2004

98-Geol-A2 Hydrogeology

3 hours duration

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. Any non-communicating calculator is permitted. This is an Open Book exam. Note to candidates you must indicate the type of calculator being used. i.e. write the name and model designation of the calculator, on the first inside left hand sheet, of the exam work book.
3. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.
4. All questions are of equal value.

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1. Consider a system of two aquifers separated by an 8 m thick clay aquitard (permeability of 10^{-12} cm^2 , porosity of 0.37). The absolute pressure at the top of the aquitard is 600 kPa, and the absolute pressure at the bottom of the aquitard is 720 kPa. (Assume water density is 1 g/cm^3 , water viscosity is 1 cP)
 - a. Determine the water levels in two wells, one screened only at the top of the aquitard, and one screened only at the bottom of the aquitard.
 - b. Determine the Darcy velocity through the aquitard (magnitude and direction).
 - c. Determine the water level in a well that was screened only at the midpoint of the aquitard.
 - d. Determine how long it would take for a water molecule to be transported across the aquitard.

2. A 75 micron diameter capillary tube of an unknown material is placed in a tray of water. The water rises up the capillary tube a distance of 3 cm. The surface tension of the water is 72 dynes/cm.
 - a) Determine the contact angle of the fluid on the capillary tube if the water density is 1 g/cm^3 and the absolute water pressure (in Pa) at the top of the water column.
 - b) Explain why the water rises up the capillary tube.
 - c) Explain, with diagrams, the concept of capillary fringe.
 - d) Explain with diagrams, the phenomenon of hysteresis with respect to drainage and imbibition of water in a soil.

3. Two 10 cm diameter wells are drilled 120 m apart in a 30 m thick, confined aquifer and one is directly north of the other. The aquifer hydraulic conductivity is $2.0 \times 10^{-5} \text{ m/sec}$, and the porosity is 0.35.
 - a. If flow in the aquifer is due south and the water level in the northern well is 102.1 m.a.s.l. and the water level in the southern well is 99.2 m.a.s.l., determine the total volumetric flow rate through a 300 m wide section of the aquifer .
 - b. If initially there was no flow in the aquifer, the initial water level in the entire aquifer was 102.1 m.a.s.l. and the northern well is pumped at 5 L/sec, determine the steady state water level in the southern well if the steady state water level in the northern pumping well is 80.5 m.a.s.l.

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4. A 1000 m wide unconfined aquifer has a hydraulic conductivity of 1.2×10^{-4} m/sec, and the bottom of the aquifer is 45 m below the ground surface. The water level in one well in the aquifer is 40 m from the bottom of the aquifer. In a second well located 250 m away from the first well in the direction of groundwater flow the water level is 37 m from the aquifer bottom.
 - a) Determine the total flow through the aquifer, assuming that aquifer recharge is negligible.
 - b) Determine the head at a point 100 m from the first well, assuming that aquifer recharge is negligible.
 - c) If the vertical recharge to the aquifer increases to 0.13 m/year, but all other conditions are unchanged calculate the water level 125 m from the first well.

5. A confined aquifer consists, in descending order, of a 10 m thick layer of coarse sand (permeability of 2.0×10^{-7} cm²), a 5 m thick silty sand (permeability of 5.0×10^{-10} cm²), and a 12 m thick fine sand layer (permeability of 3.0×10^{-8} cm²).
 - a) Determine the average vertical and horizontal hydraulic conductivities of the aquifer.
 - b) If the water level in a well screened only at the top of the aquifer is 121.2 m.a.s.l. and the water level in a well screened only at the bottom of the aquifer is 120.8 m, determine the water pressure heads at the boundaries between the first and second layers.
 - c) If the Darcy velocity in the upper aquifer at the interface between the first and second layers has vertical and horizontal components of 1 m/day and 0.2 m/day, respectively, determine the direction of groundwater flow in the second layer at the interface between the first and second layers.

6. A confined aquifer is 10 m thick, with a hydraulic conductivity of 10^{-3} cm/sec, and a specific storativity of 1×10^{-5} m⁻¹. A 10 m thick aquitard with a hydraulic conductivity of 10^{-6} cm/sec and a negligible specific storativity separates the confined aquifer from an upper unconfined aquifer. A pump in the confined aquifer withdraws water at a rate of 600 m³/day for 24 hours.
 - a) Determine the drawdown at a distance of 100 m from the pumping well after 24 hours, assuming no change in water level in the unconfined aquifer as a result of pumping.
 - b) Would the drawdown be larger or smaller if the well was only screened over the top 5 m of the confined aquifer? Explain your answer.
 - c) If the aquitard had a significant specific storativity, explain the impact on drawdown due to pumping in the confined aquifer.

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7. A slug test was conducted in a confined aquifer in a well with a 1 m screen length and a 10 cm diameter diameter. The initial water level in the aquifer before starting the slug test was 100 m.a.s.l. 10 minutes after the start of the slug test the water level in the well was 101.2 m.a.s.l., and 50 minutes after the start of the slug test the water level in the well was 100.3 m.a.s.l.
 - a) Determine the hydraulic conductivity of the aquifer.
 - b) Discuss what slug test field procedures and analytical procedures you would follow if you wished to determine both the aquifer transmissivity and storativity.
 - c) Discuss under what circumstances you would use a slug test, and under what circumstances you would use a pump test to determine aquifer properties.

8. Two pumping wells are installed in an aquifer. Well A is 50 m from an observation well, and Well B is 100 m from the same observation well. Well A is pumped for 24 hours at $10 \text{ m}^3/\text{hr}$, and then turned off. Well B is started at the same time as Well A, but is pumped for 48 hours at a rate of $5 \text{ m}^3/\text{hr}$. If the aquifer is fully confined, and infinite in extent, with a thickness of 20 m, a hydraulic conductivity of $1 \times 10^{-3} \text{ cm/sec}$, and a specific storativity of $1 \times 10^{-5} \text{ m}^{-1}$, determine the drawdown at the observation well 24, 48, and 60 hours after pumping from the wells was first started.

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)*

#	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		5.4228					
0.0001		8.3983	8.1414	7.2122	6.2282	5.4062	4.8530				
0.0005		6.9750	6.9152	6.6219	6.0821	5.3078	4.8292	4.0595	3.5054		
0.001		6.3069	6.2765	6.1202	5.7965	5.3078	4.2960	3.8821	3.4567	2.7428	2.2290
0.005		4.7212	4.7152	4.6829	4.6084	4.4713	4.2960	3.8821	3.4567	2.7104	2.2253
0.01		4.0356	4.0326	4.0167	3.9795	3.9091	3.8150	3.5725	3.2875	1.9283	1.7075
0.05		2.4675	2.4670	2.4642	2.4576	2.4448	2.4271	2.3776	2.3110	1.6704	1.5644
0.1		1.8227	1.8225	1.8213	1.8184	1.8128	1.8050	1.7829	1.7527	0.5453	0.5344
0.5		0.5598	0.5597	0.5596	0.5594	0.5588	0.5581	0.5561	0.5532	0.2161	0.2135
1.0		0.2194	0.2194	0.2193	0.2193	0.2191	0.2190	0.2186	0.2179	0.0011	0.0011
5.0		0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011		
#	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. Copyright by Amer. Geophys. Union.