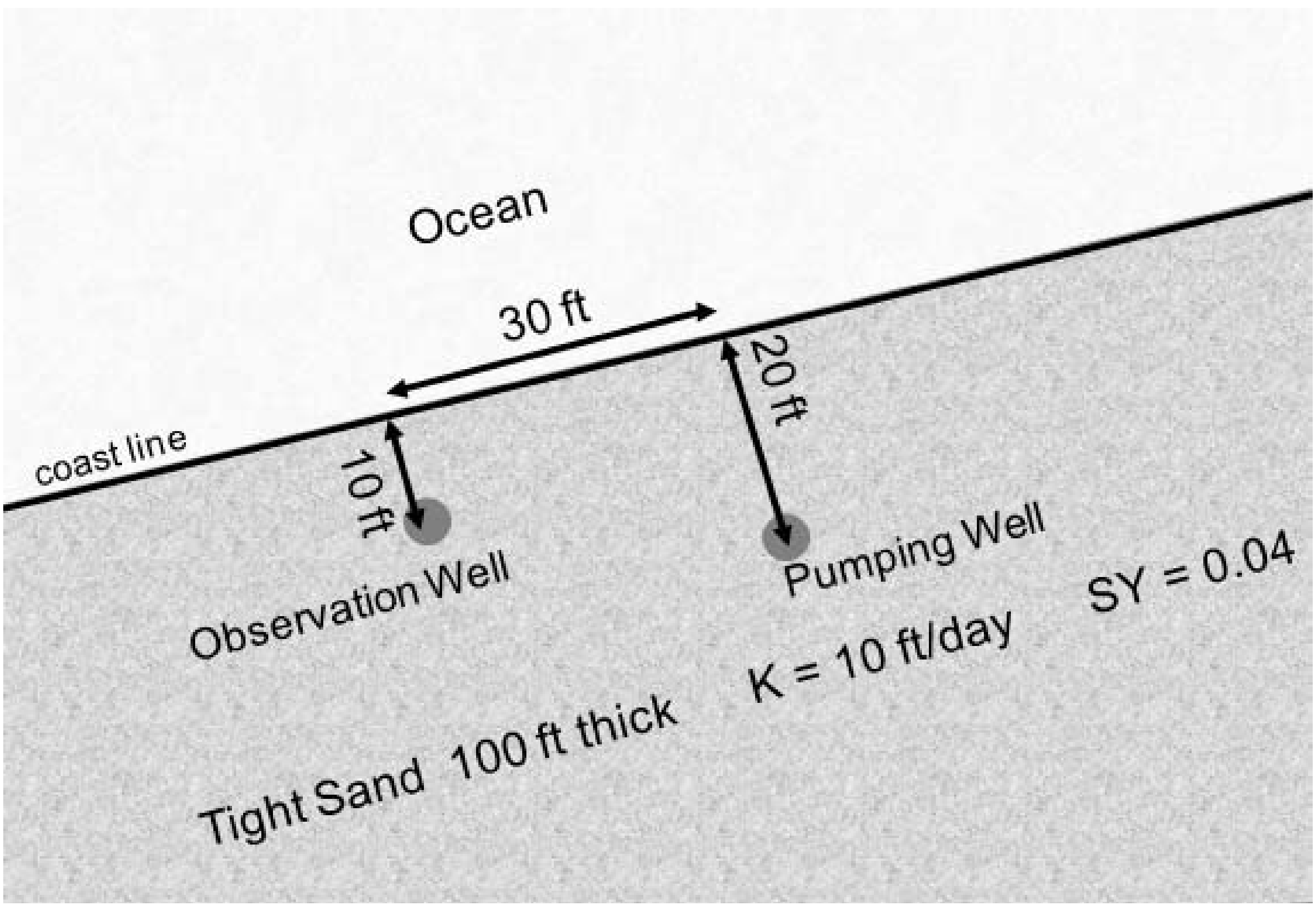
NOTE: Supplemental Materials pages 9-12
Page 9 Piper Graph Paper Page 10-11 Chemical Constants
Page 12 Well Functions

PROBLEM #1 - 25 points **USE UNITS of FEET and DAYS**

WRITE YOUR ANSWER TO THE FOLLOWING QUESTION ON THE NEXT PAGE, SHOW YOUR WORK. The question is repeated on the next page for your convenience.

USE UNITS of FEET and DAYS

The pumping well in the figure below withdraws 40,000 ft^3/day of groundwater beginning on Nov 1st at noon. At noon on Nov 4 the withdrawal of groundwater is decreased to a rate of 25,000 ft^3/day. What is the drawdown at the observation well on Nov 6 @ noon?



PROVIDE CALCULATIONS AND ANSWERS TO PROBLEM 1 HERE

USE UNITS of FEET and DAYS SHOW YOUR WORK!!!!

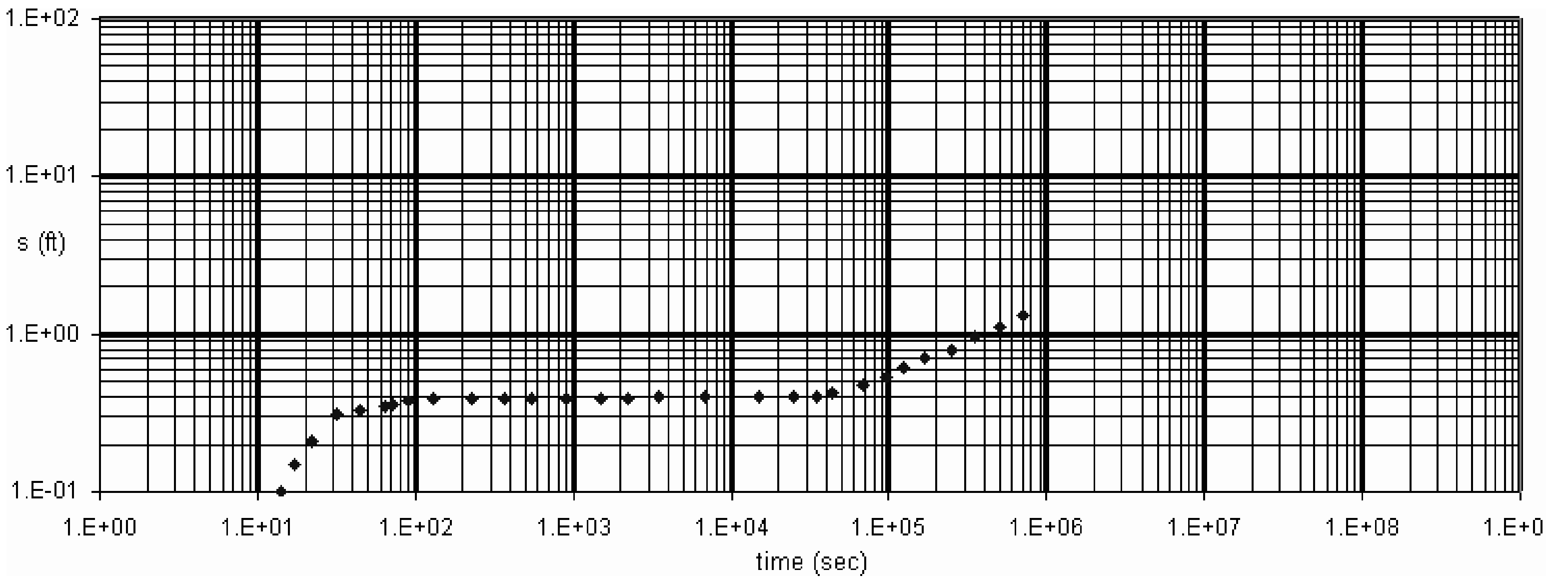
The pumping well in the figure on the previous page withdraws 40,000 ft^3/day of groundwater beginning on Nov 1st at noon. At noon on Nov 4 the withdrawal of groundwater is decreased to a rate of 25,000 ft^3/day. What is the drawdown at the observation well on Nov 6 @ noon?

PROBLEM #2 – 25 points **USE UNITS of FEET SECONDS**

WRITE YOUR ANSWER TO THE FOLLOWING QUESTIONS ON THE NEXT PAGE, SHOW YOUR WORK. The question is repeated on the next page for your convenience.

USE UNITS of FEET SECONDS

An aquifer test was conducted and data are shown below. The fully penetrating observation well where the drawdown data were collected was 190 ft from the pumping well. Initial saturated thickness of the aquifer was = 88 ft. The pumping rate was 35 GPM which is 0.078 ft^3/sec. Tell me everything you can about the aquifer using these data.



PROVIDE CALCULATIONS AND ANSWERS TO PROBLEM 2 HERE

USE UNITS of FEET SECONDS SHOW YOUR WORK!!!!

An aquifer test was conducted and data are shown on the previous page. The fully penetrating observation well where the drawdown data were collected was 190 ft from the pumping well. Initial saturated thickness of the aquifer was = 88 ft. The pumping rate was 35 GPM which is 0.078 ft^3/sec. Tell me everything you can about the aquifer using these data.

PROBLEM #3 – 25 points

WRITE ANSWERS TO THE FOLLOWING QUESTIONS ON THE NEXT PAGE, SHOW YOUR WORK. These questions are repeated on the next page for your convenience.

Evaluate the water analysis shown below. Provide calculations to support your answer.

a) (15) Is the water analysis shown below of sufficient quality to use for an aquifer water chemistry study?

b) (5pts) Plot the analysis on the attached Piper Diagram (page 9 of this exam).

c) (2pts) What type of water is this sample?

d) (3pts) If the analysis of another sample from a well 50 miles down gradient in the same aquifer plotted at location [A] on the piper diagram of page 9 what could you say about groundwater in the aquifer?

TEMP	15	C
HCO_3^-	198.4	mg/L
Cl^-	114.9	mg/L
K^+	9.9	mg/L
Ca^{+2}	74.4	mg/L
Mg^{+2}	18.1	mg/L
Na^+	130	mg/L
SO_4^{-2}	227.1	mg/L
Total Dissolved Solids	733	mg/L
Alkalinity as $CaCO_3$	162.6	mg/L
pH	7.37	units

PROVIDE CALCULATIONS AND ANSWERS TO PROBLEM 3 HERE

a) **(15) Is the water analysis on the previous page of sufficient quality to use for an aquifer water chemistry study?**

b) **(5pts) Plot the analysis on the attached Piper Diagram (page 9 of this exam).**

c) **(2pts) What type of water is this sample?**

d) **(3pts) If the analysis of another sample from a well 50 miles down gradient in the same aquifer plotted at location [A] on the piper diagram of page 9 what could you say about groundwater in the aquifer?**

PROBLEM #4 - 25 points **USE UNITS of METERS SECONDS and GRAMS**

WRITE ANSWERS TO THE FOLLOWING QUESTIONS ON THE NEXT PAGE, SHOW YOUR WORK. These questions are repeated on the next page for your convenience.

NOTE: THIS IS THE SAME WATER ANALYSIS THAT YOU EVALUATED IN PROBLEM #3

a) **(5pts) All of the alkalinity is comprised of HCO_3. Why does the value for alkalinity differ from the concentration of HCO_3? Provide calculations to support your answer.**

b) **(12pts) Is the water saturated with calcium sulfate ($CaSO_4$)? Provide calculations to support your answer.**

c) **(5pts) Will calcium carbonate ($CaCO_3$) precipitate from this sample? Provide calculations to support your answer.**

d) **(3pts) Will this water cause corrosion? Provide calculations to support your answer.**

TEMP	15	C
HCO_3^-	198.4	mg/L
Cl^-	114.9	mg/L
K^+	9.9	mg/L
Ca^{+2}	74.4	mg/L
Mg^{+2}	18.1	mg/L
Na^+	130	mg/L
SO_4^{-2}	227.1	mg/L
Total Dissolved Solids	733	mg/L
Alkalinity as $CaCO_3$	162.6	mg/L
pH	7.37	units

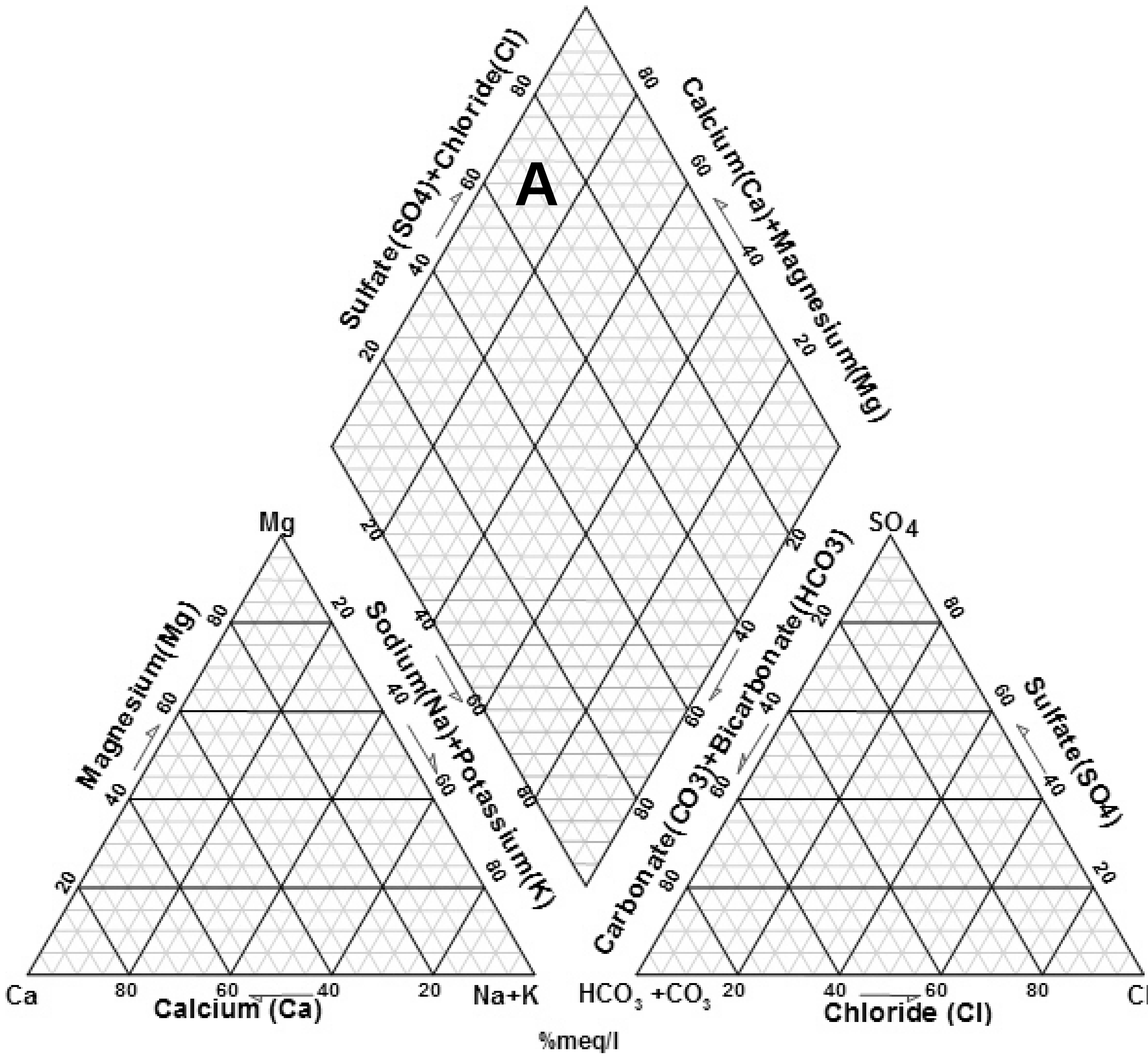
PROVIDE CALCULATIONS AND ANSWERS TO PROBLEM 4 HERE

a) **(5pts) All of the alkalinity is comprised of HCO_3. Why does the value for alkalinity differ from the concentration of HCO_3? Provide calculations to support your answer.**

b) **(12pts) Is the water saturated with calcium sulfate ($CaSO_4$)? Provide calculations to support your answer.**

c) **(5pts) Will calcium carbonate ($CaCO_3$) precipitate from this sample? Provide calculations to support your answer.**

d) **(3pts) Will this water cause corrosion? Provide calculations to support your answer.**


A
Sulfate(SO4)+Chloride(Cl)
Calcium(Ca)+Magnesium(Mg)
Mg
Magnesium(Mg)
Sodium(Na)+Potassium(K)
Ca
Calcium (Ca)
Na+K
SO4
Carbonate(CO3)+Bicarbonate(HCO3)
Sulfate(SO4)
HCO3 +CO3
Chloride (Cl)
Cl
%meq/l

Carbonate Equilibrium Constants as a Function of Temperature

T, °C	K_m	K_1	K_2	K_{sp}
5		3.02×10^{-7}	2.75×10^{-11}	8.13×10^{-9}
10		3.46×10^{-7}	3.24×10^{-11}	7.08×10^{-9}
15		3.80×10^{-7}	3.72×10^{-11}	6.03×10^{-9}
20		4.17×10^{-7}	4.17×10^{-11}	5.25×10^{-9}
25	1.58×10^{-3}	4.47×10^{-7}	4.68×10^{-11}	4.57×10^{-9}
40		5.07×10^{-7}	6.03×10^{-11}	3.09×10^{-9}
60		5.07×10^{-7}	7.24×10^{-11}	1.82×10^{-9}

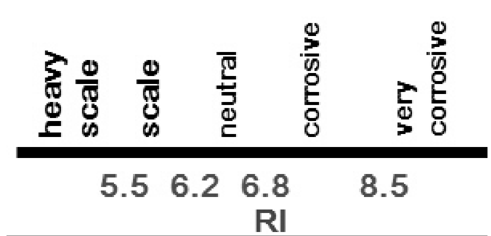
$$K_m = \frac{[H_2CO_3]}{[CO_2]_{aq}} \qquad K_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} \qquad K_2 = \frac{[H^+][CO_3^{-2}]}{[HCO_3^-]}$$

K_{sp} = Solubility product for $CaCO_3$

1	2	13	14	15	16	17	18
1 H Hydrogen 1.00794 (1)	2 IIA	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	2 He Helium 4.002602 (2)
3 Li Lithium 6.941 (2 1)	4 Be Beryllium 9.012182 (2 2)	5 B Boron 10.811 (2 3)	6 C Carbon 12.0107 (2 4)	7 N Nitrogen 14.00674 (2 5)	8 O Oxygen 15.9994 (2 6)	9 F Fluorine 18.9984032 (2 7)	10 Ne Neon 20.1797 (2 8)
11 Na Sodium 22.989770 (2 8 1)	12 Mg Magnesium 24.3050 (2 8 2)	13 Al Aluminum 26.981538 (2 8 3)	14 Si Silicon 28.0855 (2 8 4)	15 P Phosphorus 30.973761 (2 8 5)	16 S Sulfur 32.066 (2 8 6)	17 Cl Chlorine 35.4527 (2 8 7)	18 Ar Argon 39.948 (2 8 8)
19 K Potassium 39.0983 (2 8 8 1)	20 Ca Calcium 40.078 (2 8 8 2)	31 Ga Gallium 69.723 (2 8 18 3)	32 Ge Germanium 72.61 (2 8 18 4)	33 As Arsenic 74.92160 (2 8 18 5)	34 Se Selenium 78.96 (2 8 18 6)	35 Br Bromine 79.904 (2 8 18 7)	36 Kr Krypton 83.80 (2 8 18 8)
37 Rb Rubidium 85.4678 (2 8 18 8 1)	38 Sr Strontium 87.62 (2 8 18 8 2)	49 In Indium 114.818 (2 8 18 18 3)	50 Sn Tin 118.710 (2 8 18 18 4)	51 Sb Antimony 121.760 (2 8 18 18 5)	52 Te Tellurium 127.60 (2 8 18 18 6)	53 I Iodine 126.90447 (2 8 18 18 7)	54 Xe Xenon 131.29 (2 8 18 18 8)
55 Cs Cesium 132.90545 (2 8 18 18 8 1)	56 Ba Barium 137.327 (2 8 18 18 8 2)	81 Tl Thallium 204.3833 (2 8 18 32 18 3)	82 Pb Lead 207.2 (2 8 18 32 18 4)	83 Bi Bismuth 208.98038 (2 8 18 32 18 5)	84 Po Polonium (209) (2 8 18 32 18 6)	85 At Astatine (210) (2 8 18 32 18 7)	86 Rn Radon (222) (2 8 18 32 18 8)

Substance (form)	Gibbs $\Delta_f G$ (kJ)mol^{-1}
Al (s)	0
Al_2SiO_5 (kyanite)	-2443.88
Al_2SiO_5 (andalusite)	-2442.66
Al_2SiO_5 (sillimanite)	-2440.99
Ar (g)	0
C (graphite)	0
C (diamond)	2.9
CH_4 (g)	-50.72
C_2H_6 (g)	-32.82
C_3H_8 (g)	-23.49
C_2H_5OH (l)	-174.78
$C_6H_{12}O_6$ (glucose)	-910
CO (g)	-137.17
CO_2 (g)	-394.36
CO_3^{-2} (aq)	-527.81
H_2CO_3 (aq)	-623.08
HCO_3^- (aq)	-586.77
Ca^{2+} (aq)	-553.58
$CaCO_3$ (calcite)	-1128.8
$CaSO^4$ (anhydrite)	-1321.8
$CaCO_3$ (aragonite)	-1127.8
$CaCl_2$ (s)	-748.1
Cl_2 (g)	0
Cl^- (aq)	-131.23
Cu (s)	0
Fe (s)	0
H_2 (g)	0
H (g)	203.25
H^+ (aq)	0
H_2O (l)	-237.13
H_2O (g)	-228.57
He (g)	0
Hg (l)	0
N_2 (g)	0
NH_3 (g)	-16.45
Na^+(aq)	-261.91
NaCl (s)	-384.14
$NaAlSi_3O_8$ (albite)	-3711.5
$NaAlSi_2O_6$ (jadeite)	-2852.1
Ne (g)	0
O_2 (g)	0
O_2 (aq)	16.4
OH^- (aq)	-157.24
Pb (s)	0
PbO_2(s)	-217.33
$PbSO_4$(s)	-813
SO_4^{2-} (aq)	-744.53
HSO_4^- (aq)	-755.91
SiO_2 (α quartz)	-856.64
H_4SiO_4(aq)	-1307.67

Values of *R*	Units ($V \cdot P \cdot T^{-1} \cdot n^{-1}$)
8.314472	$J \cdot K^{-1} \cdot mol^{-1}$
0.0820574587	$L \cdot atm \cdot K^{-1} \cdot mol^{-1}$
83.14472	$cm^3 \cdot bar \cdot mol^{-1} \cdot K^{-1}$
$8.20574587 \times 10^{-5}$	$m^3 \cdot atm \cdot K^{-1} \cdot mol^{-1}$
8.314472	$cm^3 \cdot MPa \cdot K^{-1} \cdot mol^{-1}$
8.314472	$L \cdot kPa \cdot K^{-1} \cdot mol^{-1}$
8.314472	$m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}$
62.36367	$L \cdot mmHg \cdot K^{-1} \cdot mol^{-1}$
62.36367	$L \cdot Torr \cdot K^{-1} \cdot mol^{-1}$
83.14472	$L \cdot mbar \cdot K^{-1} \cdot mol^{-1}$
0.08314472	$L \cdot bar \cdot K^{-1} \cdot mol^{-1}$
1.987	$cal \cdot K^{-1} \cdot mol^{-1}$
6.132440	$lbf \cdot ft \cdot K^{-1} \cdot g\text{-}mol^{-1}$
10.73159	$ft^3 \cdot psi \cdot {}^\circ R^{-1} \cdot lb\text{-}mol^{-1}$
0.7302413	$ft^3 \cdot atm \cdot {}^\circ R^{-1} \cdot lb\text{-}mol^{-1}$
998.9701	$ft^3 \cdot mmHg \cdot K^{-1} \cdot lb\text{-}mol^{-1}$
8.314472×10^7	$erg \cdot K^{-1} \cdot mol^{-1}$



u	$W(u)$	u	$W(u)$	u	$W(u)$	u	$W(u)$
1×10^{-10}	22.45	7×10^{-8}	15.90	4×10^{-5}	9.55	1×10^{-2}	4.04
2	21.76	8	15.76	5	9.33	2	3.35
3	21.35	9	15.65	6	9.14	3	2.96
4	21.06	1×10^{-7}	15.54	7	8.99	4	2.68
5	20.84	2	14.85	8	8.86	5	2.47
6	20.66	3	14.44	9	8.74	6	2.30
7	20.50	4	14.15	1×10^{-4}	8.63	7	2.15
8	20.37	5	13.93	2	7.94	8	2.03
9	20.25	6	13.75	3	7.53	9	1.92
1×10^{-9}	20.15	7	13.60	4	7.25	1×10^{-1}	1.823
2	19.45	8	13.46	5	7.02	2	1.223
3	19.05	9	13.34	6	6.84	3	0.906
4	18.76	1×10^{-6}	13.24	7	6.69	4	0.702
5	18.54	2	12.55	8	6.55	5	0.560
6	18.35	3	12.14	9	6.44	6	0.454
7	18.20	4	11.85	1×10^{-3}	6.33	7	0.374
8	18.07	5	11.63	2	5.64	8	0.311
9	17.95	6	11.45	3	5.23	9	0.260
1×10^{-8}	17.84	7	11.29	4	4.95	1×10^{0}	0.219
2	17.15	8	11.16	5	4.73	2	0.049
3	16.74	9	11.04	6	4.54	3	0.013
4	16.46	1×10^{-5}	10.94	7	4.39	4	0.004
5	16.23	2	10.24	8	4.26	5	0.001
6	16.05	3	9.84	9	4.14		

Appendix 3 Values of the functions $W(u, r/B)$ for various values of u

u \ r/B	0.002	0.004	0.006	0.008	0.01	0.02	0.04	0.06	0.08	0.1	0.2	0.4	0.6	0.8	1	2	4	6	8
0	12.7	11.3	10.5	9.89	9.44	8.06	6.67	5.87	5.29	4.85	3.51	2.23	1.55	1.13	0.842	0.228	0.0223	0.0025	0.0003
0.000002	12.1	11.2	10.5	9.89	9.44														
0.000004	11.6	11.1	10.4	9.88	9.44														
0.000006	11.3	10.9	10.4	9.87	9.44														
0.000008	11.0	10.7	10.3	9.84	9.43														
0.00001	10.8	10.6	10.2	9.80	9.42	8.06													
0.00002	10.2	10.1	9.84	9.58	9.30	8.06													
0.00004	9.52	9.45	9.34	9.19	9.01	8.03	6.67												
0.00006	9.13	9.08	9.00	8.89	8.77	7.98	6.67												
0.00008	8.84	8.81	8.75	8.67	8.57	7.91	6.67												
0.0001	8.62	8.59	8.55	8.48	8.40	7.84	6.67	5.87	5.29										
0.0002	7.94	7.92	7.90	7.86	7.82	7.50	6.62	5.86	5.29										
0.0004	7.24	7.24	7.22	7.21	7.19	7.01	6.45	5.83	5.29	4.85									
0.0006	6.84	6.84	6.83	6.82	6.80	6.68	6.27	5.77	5.27	4.85									
0.0008	6.55	6.55	6.54	6.53	6.52	6.43	6.11	5.69	5.25	4.84									
0.001	6.33	6.33	6.32	6.32	6.31	6.23	5.97	5.61	5.21	4.83	3.51								
0.002	5.64	5.64	5.63	5.63	5.63	5.59	5.45	5.24	4.98	4.71	3.50								
0.004	4.95	4.95	4.95	4.94	4.94	4.92	4.85	4.74	4.59	4.42	3.48	2.23							
0.006	4.54				4.54	4.53	4.48	4.41	4.30	4.18	3.43	2.23							
0.008	4.26				4.26	4.25	4.21	4.15	4.08	3.98	3.36	2.23							
0.01	4.04				4.04	4.03	4.00	3.95	3.89	3.81	3.29	2.23	1.55	1.13					
0.02	3.35				3.35	3.35	3.34	3.31	3.28	3.24	2.95	2.18	1.55	1.13					
0.04	2.68				2.68	2.68	2.67	2.66	2.65	2.63	2.48	2.02	1.52	1.13	0.842				
0.06	2.30				2.30	2.29	2.29	2.28	2.27	2.26	2.17	1.85	1.46	1.11	0.839				
0.08	2.03					2.03	2.02	2.02	2.01	2.00	1.94	1.69	1.39	1.08	0.832				
0.1	1.82						1.82	1.82	1.81	1.80	1.75	1.56	1.31	1.05	0.819	0.228			
0.2	1.22						1.22	1.22	1.22	1.22	1.19	1.11	0.996	0.857	0.715	0.227			
0.4	0.702						0.702	0.702	0.701	0.700	0.693	0.665	0.621	0.565	0.502	0.210			
0.6	0.454						0.454	0.454	0.454	0.453	0.450	0.436	0.415	0.387	0.354	0.177	0.0222		
0.8	0.311						0.311	0.310	0.310	0.310	0.308	0.301	0.289	0.273	0.254	0.144	0.0218		
1	0.219									0.219	0.218	0.213	0.206	0.197	0.185	0.114	0.0207	0.0025	
2	0.049										0.049	0.048	0.047	0.046	0.044	0.034	0.011	0.0021	0.0003
4	0.0038											0.0038	0.0037	0.0037	0.0036	0.0031	0.0016	0.0006	0.0002
6	0.0004														0.0004	0.0003	0.0002	0.0001	0
8	0																		0

Source: After M. S. Hantush, "Analysis of Data from Pumping Test in Leaky Aquifers," *Transactions, American Geophysical Union,* 37 (1956):702–14.