[Water Resources Research]

Supporting Information for

Assessing contaminant mass discharge uncertainty with application of hydraulic conductivities derived from geoelectrical cross-borehole induced polarization and other methods

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Introduction

The main article refers to the text sections in the supporting information. SIx in the main article refers to Text Sx in the supporting information. In text Sx there are references to the relevant figures and tables in the supporting information.

Text S1: Comparison between previous studies in similar geological settings and the current study at Hvedemarken.

Hydraulic properties from large studies of sandy aquifers are found in table S1.

Text S2: Pointwise comparison of Slug test and GSA K-values to IP K-values

For pointwise comparison, K-values have been extracted and averaged over multiple grid cells from the IP K-estimates. For comparison to slug test K-estimates, IP K-estimates have been extracted and averaged from an area of 12 grid cells (6 cells deep, 2 cells wide), equal to an area of 1 meter width and 0.9 m depth. Width is 2 cells, as the slug test screens are horizontally placed between two data cells, and depth is reflecting the length of the screen, which is 1 m. For comparison to GSA K-estimates, based on core samples of 10 cm length and 1.25" width, the GSA core samples are horizontally and vertically located in between the IP K-cells, defining the width and length of IP K-extraction. Therefore, IP K-estimates have been extracted and averaged over an area of 2 data cells width and 2 data cells depth (1 x 0.3 m). See Figure S1 for compared areas.
Pointwise comparison of slug-K to IP-K shown in Figure S2. Error bars on K IP error bars based on double estimation uncertainty (Error = 0.403). Slug test error bars based on estimated measuring uncertainty (Error = 0.0561).
Pointwise comparison of GSA-K to IP-K are shown in Figure S3. GSA error bars based estimated uncertainty (Error = 0.81). IP K-error bars based on double estimation uncertainty (Error = 0.403).

Text S3: Double estimation based uncertainty evaluation of IP K-estimates

Figure S4 shows the lnK-values over depth for co-located estimates in E2 and E7. Figure S5 shows the histogram of the differences between co-located K-estimates.

Text S4: Slug test K-estimates

Table S2 shows all slug test K-estimates by the Hvorslev method, and table S3 shows all slug test K-estimates by the Bouwer-Rice method.

Text S5: GSA K-estimates

Table S4 shows all GSA K-estimates.

Text S6: K-simulation flowchart

Figure S6 shows the flowchart of the simulation of K by different estimation methods.

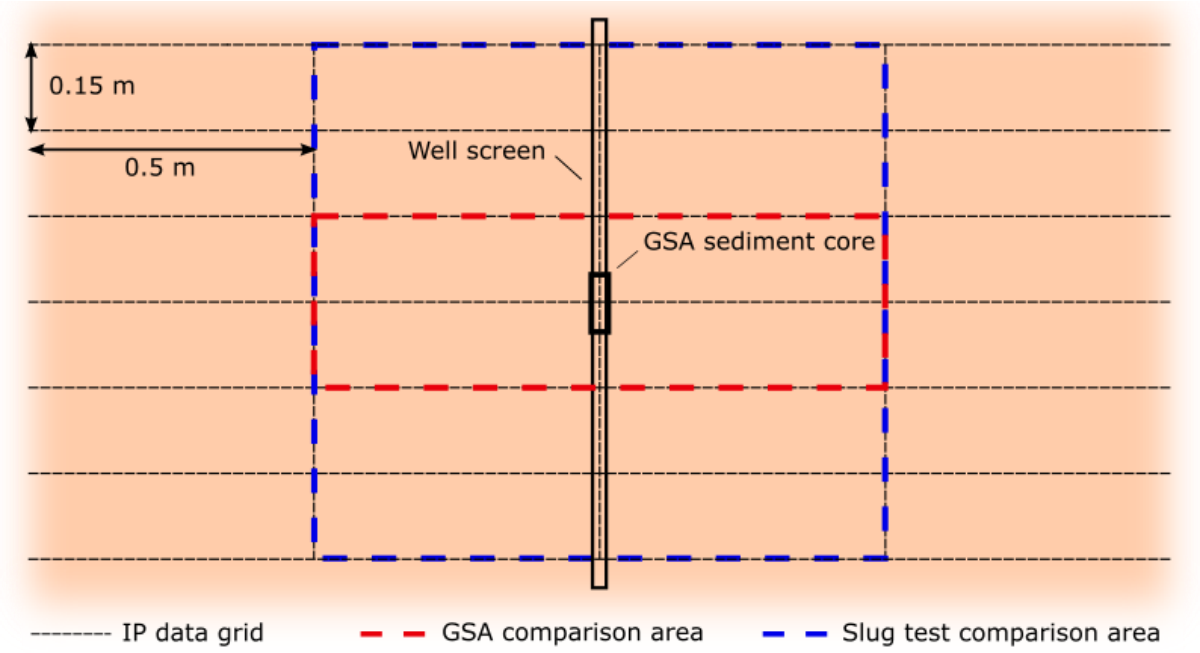

Figure S1. Comparison areas for IP, slug test and GSA K-values.

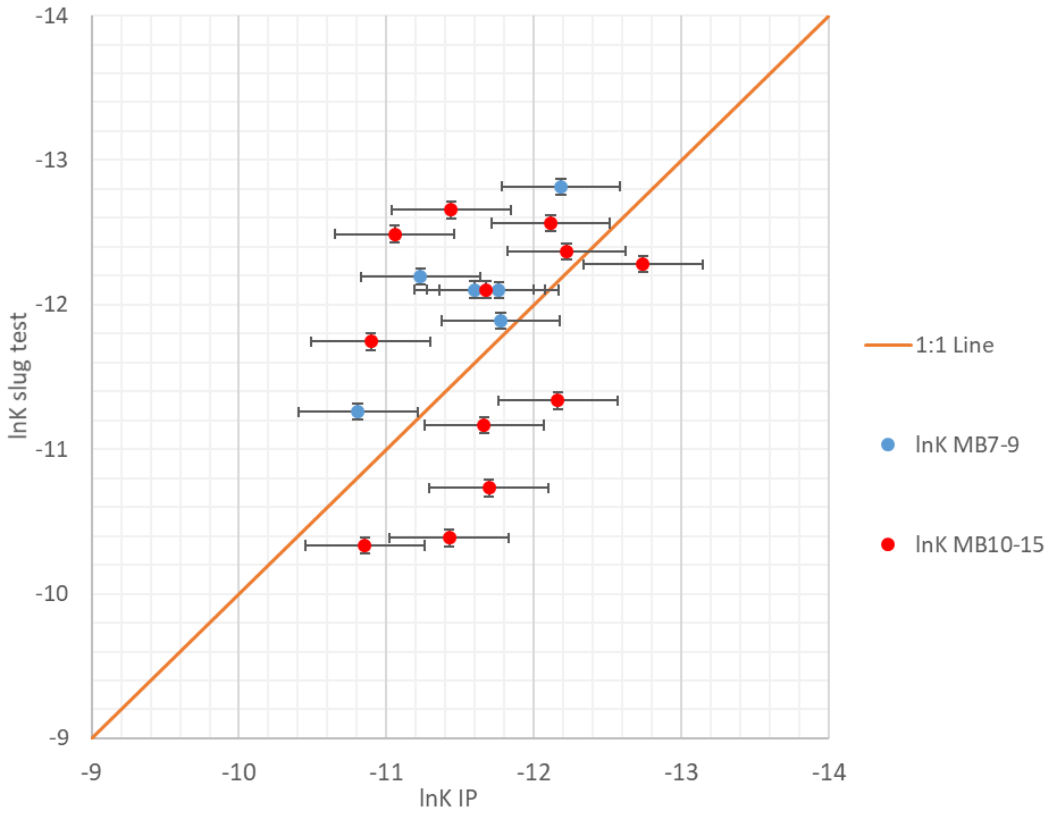

Figure S2. lnK-values inferred from cross borehole IP plotted with lnK-values from slug test. For IP lnK-values, mean of cells covering the tested screen is shown. Blue dots compare values in the transect E6789 to slug test estimates and red dots compare values from E1234. All data points represent meltwater sand or the transition layer.

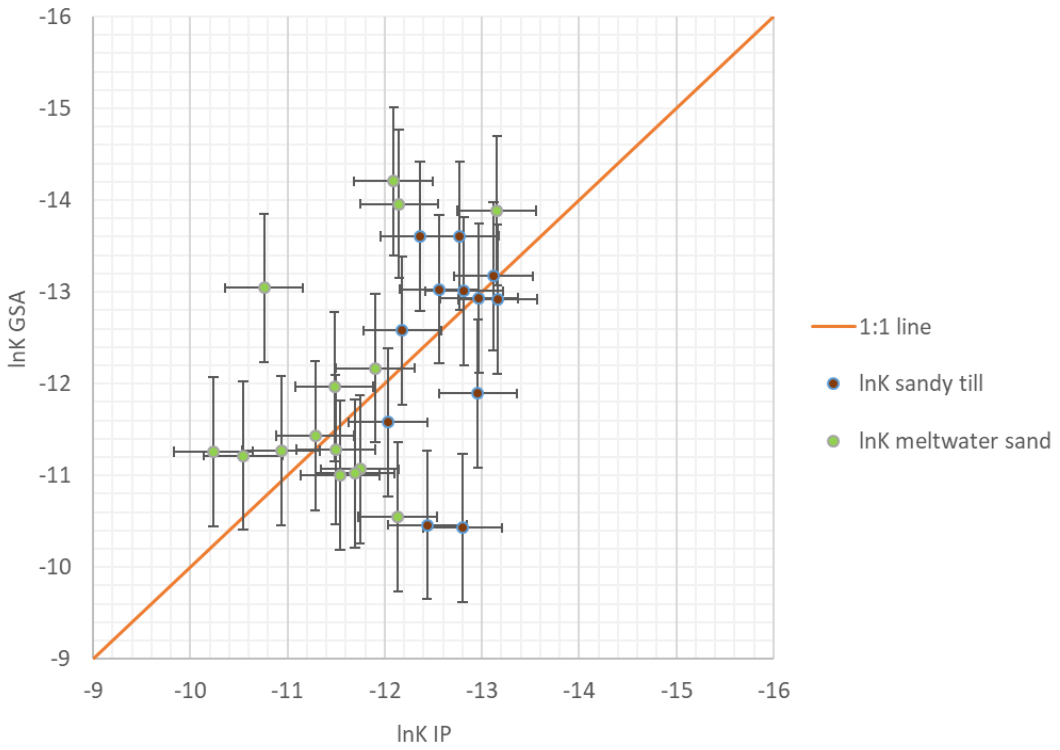

Figure S3. lnK-values inferred from cross borehole IP plotted with lnK-values from GSA.

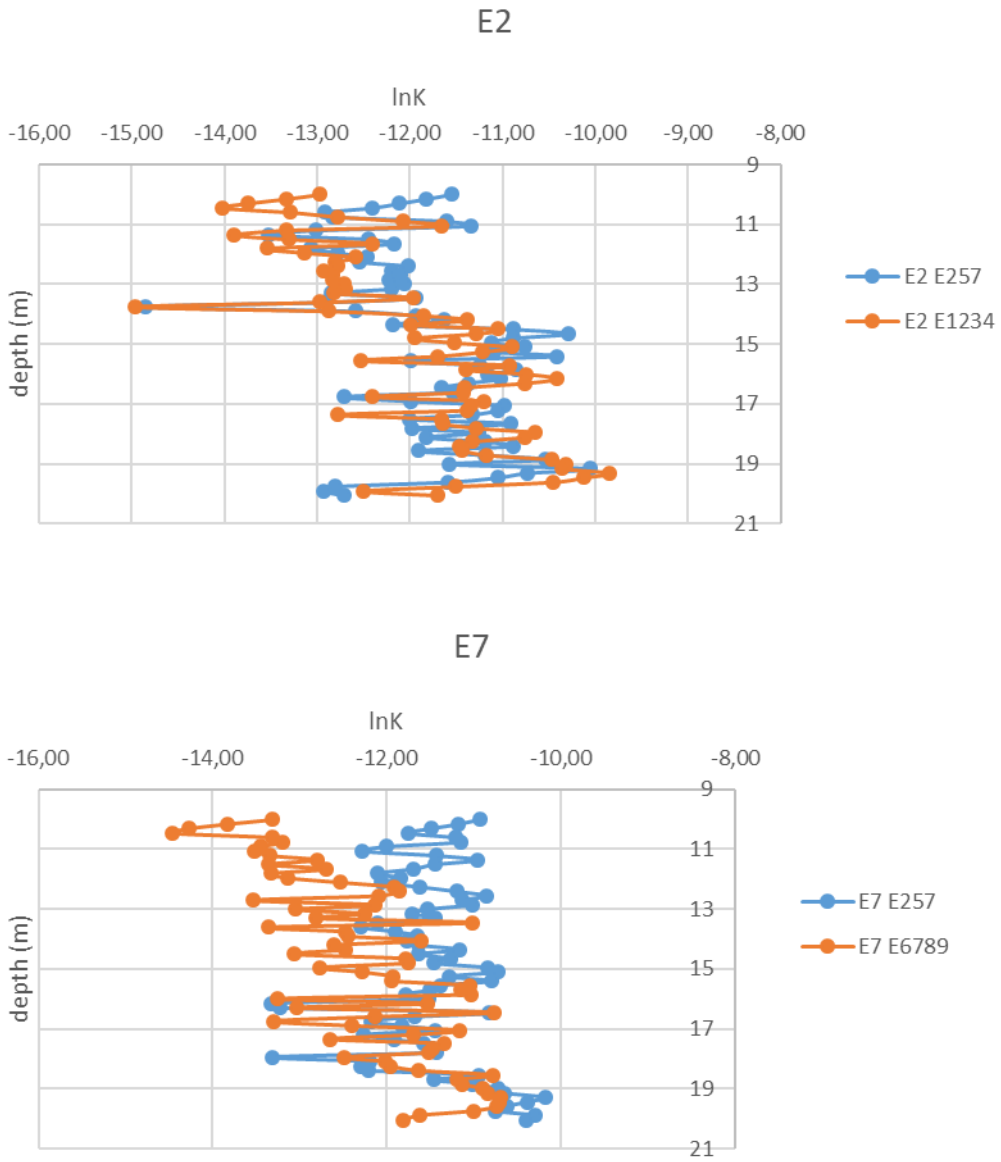

Figure S4. lnK values at co-located IP estimation points E2 (top) and E7 (bottom)

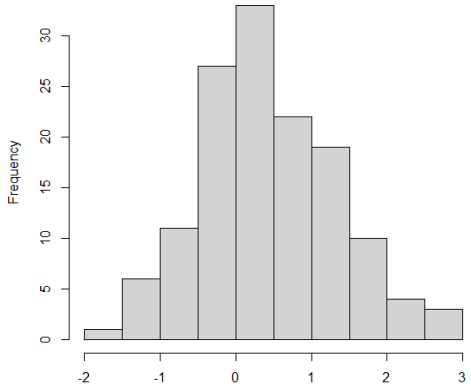

Figure S5. Total residual of lnK from co-located IP estimation points at electrode wells E2 and E7.

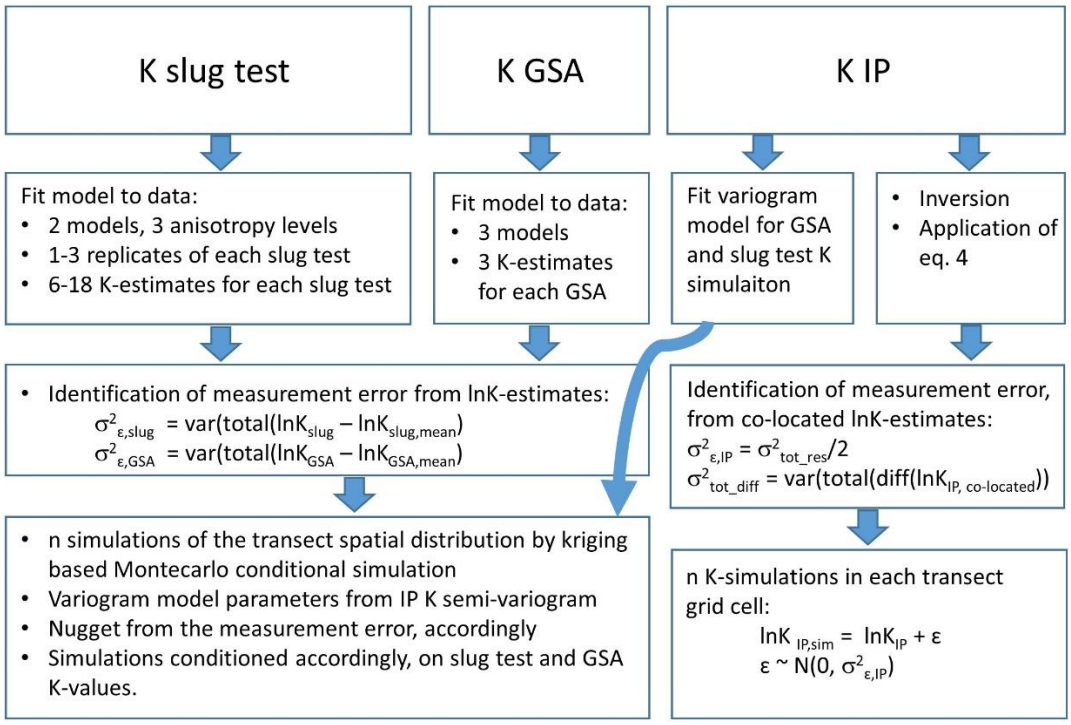

Figure S6. Flowchart for simulations of K.

Parameter \ Site	Borden, Canada (Sudicky, 1986)	Vejen field injection site, Denmark (Bjerg et al., 1992)	Cape Cod, US (Hess et al., 1992)	Columbus, US (Rehfeldt et al., 1992)	North Bay, Canada (Sudicky et al., 2010)	Skuldelev site, Denmark (Troldborg et al., 2012)	This study
Aquifer type	Glaciofluvial Sand with silt	Glaciofluvial Sand with gravel	Glaciofluvial sand and gravel	Alluvial deposit (sand, gravel and clayey gravel)	Glacial lacustrine and glaciofluvial sands	Quaternary sand	Quaternary sand
Sample size	1279	334	825	2187	1878	38	3128
K-method	Falling head permeameter	Slug test	Falling head permeameter	Flowmeter	Falling head permeameter	Grain size analysis	Cross borehole IP
Min. sampling distance [cm] *)	5 (v) 100 (h)	50 (v) 45 (h)	7.3 (v) 90 (h)	16 (v) < 500 (h)	5 (v) 200 (h)	50 (v) 500 (h)	15 (v) 50 (h)
Study Scale [m]*)	2 (v) 20 (h)	3 (v) 200 (h)	6-7 (v) 24 (h	4-10 (v) 250 (h)	3.5-5.5 (v) 40 (h)	3.5-4 (v) 80 (h)	10 (v) 8 (h)
Kg [10^{-5} m/s]	72	50.5	35	5.5	3.5	3	0.64
σ^2_{lnK}	0.29	0.37	0.14	4.5	1.79	1.4	0.84
Correlation length	2.8 (h) 0.12 (v)	1-2.5	0.18 (v) 1.2-2.0 (h)	1.64 (v) 12.8 (h)	1.02 (v) 7.4-17.2 (h)	≈ 5 (h) ≈ 1 (v)	0.83-1.39

Table S1. Hydraulic properties from large studies of sandy aquifers. Kg is the geometric mean of estimated hydraulic conductivities, σ^2_{lnK} is the variance of log-transformed K-estimates. *) (v) = vertical, (h) = horizontal.

Model					Hvorslev				
Replicate	I	II	III	I	II	III	I	II	III
Anisotropy	0.33	0.33	0.33	1.00	1.00	1.00	0.10	0.10	0.10
Screen					**K (m/s)**				
B10	1.68E-05	1.57E-05		1.35E-05	1.27E-05		2.02E-05	1.9E-05	
MB2-1	8.53E-06	8.65E-06		6.88E-06	6.99E-06		1.03E-05	1.05E-05	
MB2-2	4.39E-06			3.55E-06			5.31E-06		
MB3-1	8.64E-06			6.98E-06			1.04E-05		
MB3-2	1.63E-06	2.01E-06	1.54E-06	1.31E-06	1.62E-06	1.25E-06	2E-06	2.43E-06	1.87E-06
MB4-1	8.60E-07			6.94E-07			1.04E-06		
MB4-2	1.39E-05	1.35E-05		1.13E-05	1.09E-05		1.69E-05	1.63E-05	
MB5-1	2.09E-06			1.69E-06			2.53E-06		
MB5-2	7.66E-06	7.55E-06		6.18E-06	6.09E-06		9.26E-06	9.12E-06	
MB6-1	3.12E-06			2.62E-06			3.93E-06		
MB6-2	2.52E-05	2.52E-05		2.03E-05	2.04E-05		3.04E-05	3.05E-05	
MB7-1	6.02E-06	7.74E-06	7.98E-06	4.86E-06	6.27E-06	6.44E-06	7.28E-06	9.35E-06	9.65E-06
MB7-2	5.41E-06	5.71E-06	5.84E-06	4.37E-06	4.62E-06	4.71E-06	6.54E-06	6.91E-06	7.06E-06
MB8-1	5.21E-06	5.42E-06	5.98E-06	4.21E-06		4.83E-06	6.3E-06		7.23E-06
MB8-2	2.68E-06	2.72E-06	2.75E-06	2.16E-06	2.2E-06	2.22E-06	3.24E-06	3.29E-06	3.32E-06
MB9-1	1.29E-05	1.3E-05	1.29E-05	1.04E-05	1.05E-05	1.04E-05	1.55E-05	1.57E-05	1.55E-05
MB9-2	5.24E-06	0.000005	4.96E-06	4.23E-06		4.01E-06	6.33E-06		6E-06
MB10-1	1.54E-05	1.29E-05		1.25E-05	1.04E-05		1.86E-05	1.56E-05	
MB10-2	2.16E-05	2.21E-05		1.77E-05	1.78E-05		2.65E-05	2.68E-05	
MB11-1	5.54E-06			4.72E-06			7.07E-06		
MB11-2	4.66E-06	4.64E-06	4.63E-06	3.76E-06	3.75E-06	3.74E-06	5.63E-06	5.61E-06	5.6E-06
MB12-1	8.11E-06	7.77E-06		6.55E-06	6.27E-06		9.81E-06	9.39E-06	
MB12-2	3.25E-05			2.63E-05			3.93E-05		
MB13-1	3.8E-06	3.74E-06		3.07E-06	3.02E-06		4.59E-06	4.52E-06	
MB13-2	3.19E-06			2.58E-06			3.86E-06		
MB14-1	3.86E-06	3.14E-06	3.46E-06	3.11E-06	2.53E-06	2.8E-06	4.66E-06	3.79E-06	4.19E-06
MB14-2	2.86E-05	3.32E-05	2.76E-05	2.31E-05	2.68E-05	2.23E-05	3.46E-05	4.01E-05	3.33E-05
MB15-1	1.18E-05	1.21E-05	1.18E-05	9.54E-06	9.75E-06	9.56E-06	1.43E-05	1.46E-05	1.43E-05
MB15-2	4.21E-06	4.28E-06	3.42E-06	3.4E-06	3.46E-06	2.77E-06	5.09E-06	5.17E-06	4.14E-06

Table S2. Slug test K-estimates by the Hvorslev model for all tested screens, replicates and anisotropy levels. Note – each sample had between 1-3 replicate. A blank space indicates no replicate

Model	Bouwer-Rice								
Replicate	I	II	III	I	II	III	I	II	III
Anisotropy	0.33	0.33	0.33	1.00	1.00	1.00	0.10	0.10	0.10
Screen	K (m/s)								
B10	1.27E-05	1.19E-05		9.85E-06	9.22E-06		1.63E-05	1.52E-05	
MB2-1	6.64E-06	6.74E-06		5.14E-06	5.21E-06		8.45E-06	8.58E-06	
MB2-2	3.32E-06			2.57E-06			4.24E-06		
MB3-1	6.63E-06			5.13E-06			8.46E-06		
MB3-2	1.2E-06	1.48E-06	1.14E-06	9.29E-07	1.15E-06	8.81E-07	1.54E-06	1.9E-06	1.46E-06
MB4-1	6.70E-07			5.18E-07			8.52E-07		
MB4-2	1.05E-05	1.02E-05		8.14E-06	7.9E-06		1.35E-05	1.3E-05	
MB5-1	1.6E-06			1.24E-06			2.04E-06		
MB5-2	5.68E-06	5.6E-06		4.38E-06	4.32E-06		7.25E-06	7.15E-06	
MB6-1	2.52E-06			1.95E-06			3.21E-06		
MB6-2	1.9E-05	1.91E-05		1.47E-05	1.48E-05		2.43E-05	2.44E-05	
MB7-1	4.66E-06	5.99E-06	6.17E-06	3.6E-06	4.63E-06	4.77E-06	5.93E-06	7.62E-06	7.86E-06
MB7-2	4.36E-06	4.04E-06	4.27E-06	3.37E-06	3.12E-06	3.3E-06	5.57E-06	5.16E-06	5.45E-06
MB8-1	4.02E-06		4.61E-06	3.11E-06		3.57E-06	5.12E-06		5.87E-06
MB8-2	2E-06	2.03E-06	2.05E-06	1.55E-06	1.57E-06	1.59E-06	2.55E-06	2.59E-06	2.62E-06
MB9-1	9.93E-06	1E-05	9.93E-06	7.68E-06	7.76E-06	7.68E-06	1.27E-05	1.28E-05	1.27E-05
MB9-2	3.92E-06	3.71E-06		3.02E-06	2.87E-06		5E-06	4.74E-06	
MB10-1	1.2E-05	1E-05		9.3E-06	7.77E-06		1.53E-05	1.28E-05	
MB10-2	1.66E-05	1.68E-05		1.28E-05	1.3E-05		2.12E-05	2.14E-05	
MB11-1	4.49E-06			3.47E-06			5.72E-06		
MB11-2	3.45E-06	3.44E-06	3.43E-06	2.66E-06	2.65E-06	2.65E-06	4.4E-06	4.39E-06	4.38E-06
MB12-1	6.32E-06	6.05E-06		4.89E-06	4.68E-06		8.04E-06	7.7E-06	
MB12-2	2.46E-05			1.9E-05			3.14E-05		
MB13-1	2.92E-06	2.87E-06		2.26E-06	2.22E-06		3.72E-06	3.66E-06	
MB13-2	2.37E-06			1.83E-06			3.02E-06		
MB14-1	2.99E-06	2.43E-06	2.69E-06	2.31E-06	1.88E-06	2.08E-06	3.81E-06	3.1E-06	3.42E-06
MB14-2	2.16E-05	2.5E-05	2.08E-05	1.67E-05	1.93E-05	1.61E-05	2.75E-05	3.19E-05	2.65E-05
MB15-1	9.05E-06	9.24E-06	9.06E-06	7E-06	7.15E-06	7.01E-06	1.15E-05	1.18E-05	1.16E-05
MB15-2	3.11E-06	3.16E-06	2.53E-06	2.4E-06	2.44E-06	1.95E-06	3.97E-06	4.04E-06	3.23E-06

Table S3. Slug test K-estimates by the Bouwer-Rice model for all tested screens, replicates and anisotropy levels. Note – each sample had between 1-3 replicate. A blank space indicates no replicate

Borehole	Elevation masl	K (Alyamani and Sen) m/s	K (Sauerbrei) m/s	K (Barr) m/s
KB11	27.08	2.29E-07	6.04E-06	1.52E-06
	26.48	5.64E-06	2.00E-07	3.05E-08
	26.18	2.23E-05	1.72E-05	1.8E-05
	25.78	3.24E-06	1.23E-05	4.5E-06
	25.08	5.90E-08	1.17E-06	4.73E-07
	24.78	2.31E-06	5.38E-06	2.58E-06
KB12	27.18	3.28E-05	2.17E-05	2.25E-05
	26.68	1.54E-06	1.22E-06	2E-07
	26.18	1.62E-06	1.50E-06	2.13E-07
	25.68	3.26E-07	2.16E-06	8.25E-07
	25.18	8.63E-08	8.29E-07	2.48E-07
	24.18	1.03E-05	1.75E-05	8.41E-06
	23.58	1.54E-05	1.88E-05	1.21E-05
	23.08	4.11E-05	2.71E-05	2.97E-05
	22.58	1.74E-05	1.96E-05	1.33E-05
	22.08	8.01E-06	1.53E-05	6.56E-06
KB13	27.18	1.48E-07	2.85E-06	6.65E-07
	26.68	5.88E-06	2.25E-07	2.75E-08
	26.08	2.43E-06	1.32E-06	1.53E-07
	25.78	5.04E-06	7.88E-06	3.98E-06
	25.38	3.69E-07	3.66E-07	9.44E-08
	25.08	1.69E-05	1.95E-05	1.27E-05
	24.88	3.19E-06	9.08E-06	3.32E-06
	24.43	1.01E-05	1.89E-05	8.14E-06
	23.88	1.09E-05	1.72E-05	8.67E-06
	23.58	1.21E-05	1.67E-05	9.4E-06
	22.98	3.73E-07	3.49E-06	1E-06
DC1	27.18	3.89E-06	1.13E-05	5.19E-06
	26.18	4.07E-06	4.35E-07	4.85E-08
	25.98	2.11E-05	1.53E-05	1.55E-05
	25.68	9.83E-07	2.81E-06	1.24E-06

Table S4. GSA K-estimates based on the equations Alyamani and Sen, Sauerbrei and Barr.