CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	Groundwater uranium origin and fate control in a river valley aquifer
Authors	Banning, Andre;Demmel, Thomas;Rüde, Thomas R;Wrobel, Michael
Publication date	2013-10-10
Original Citation	Banning, A., Demmel, T., Rüde, T. R. and Wrobel, M. (2013) 'Groundwater Uranium Origin and Fate Control in a River Valley Aquifer', Environmental Science & Technology, 47 (24), pp. 13941-13948. doi: 10.1021/es304609e
Type of publication	Article (peer-reviewed)
Link to publisher's version	https://pubs.acs.org/doi/10.1021/es304609e - 10.1021/es304609e
Rights	This document is the Accepted Manuscript version of a Published Work that appeared in final form in Environmental Science and Technology, copyright © American Chemical Society after peer review and technical editing by the publisher. To access the final edited and published work see https://pubs.acs.org/doi/10.1021/es304609e
Download date	2026-10-07 09:55:18
Item downloaded from	https://hdl.handle.net/10468/12342

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Supporting information

on the article

Groundwater uranium origin and fate control in a river valley aquifer

by

Andre Banning, Thomas Demmel, Thomas R. Rüde, Michael Wrobel

- 12 pages, 5 figures, 7 tables -

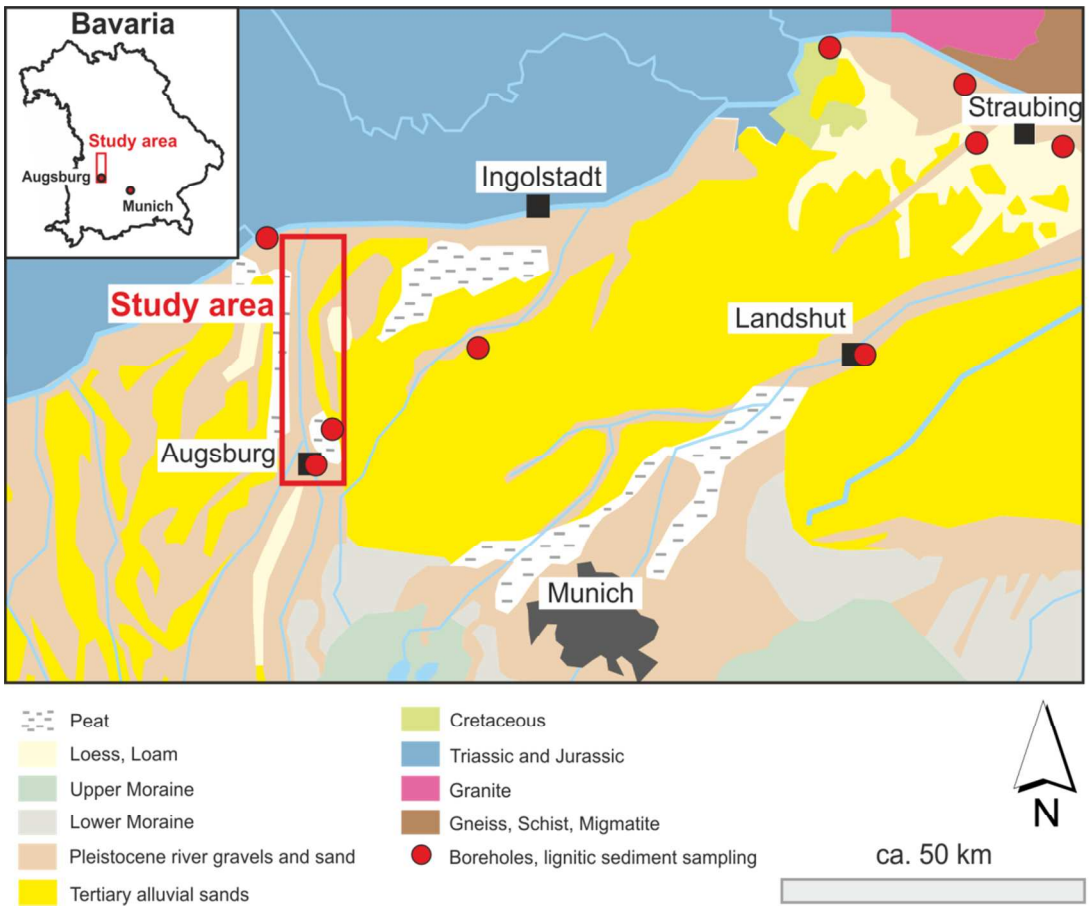

Figure S1. Location of the study area in Bavaria (upper left), geological overview map of the study area and its surroundings, and location of the 9 boreholes sampled for lignitic layers from the core warehouse of the Bavarian Environment Agency.

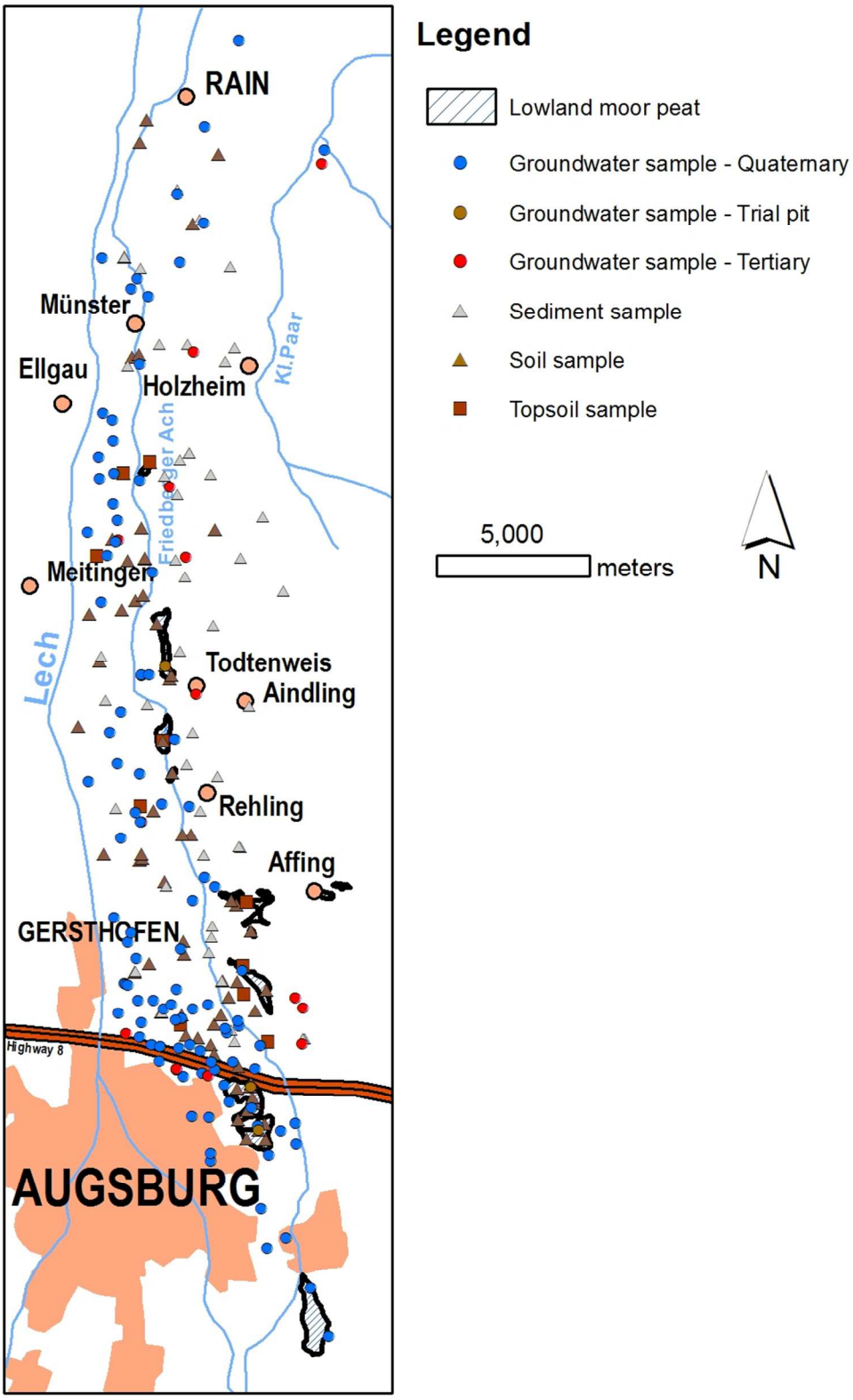

Figure S2. Study area map and sampling locations.

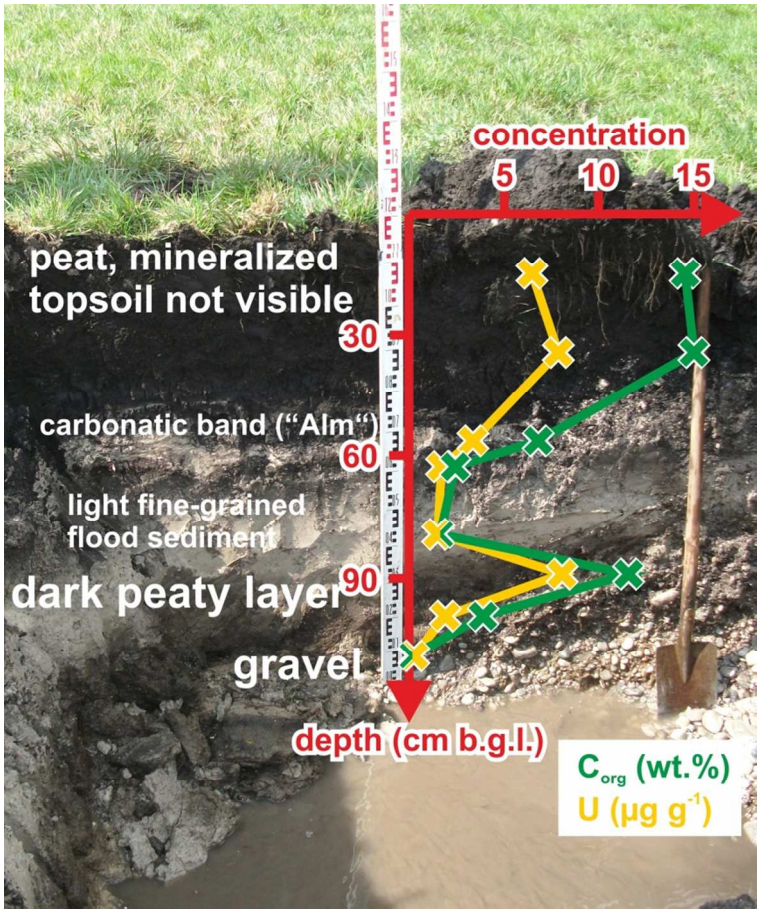

Figure S3. Profile and U/C_{org} development in trial pit 2.

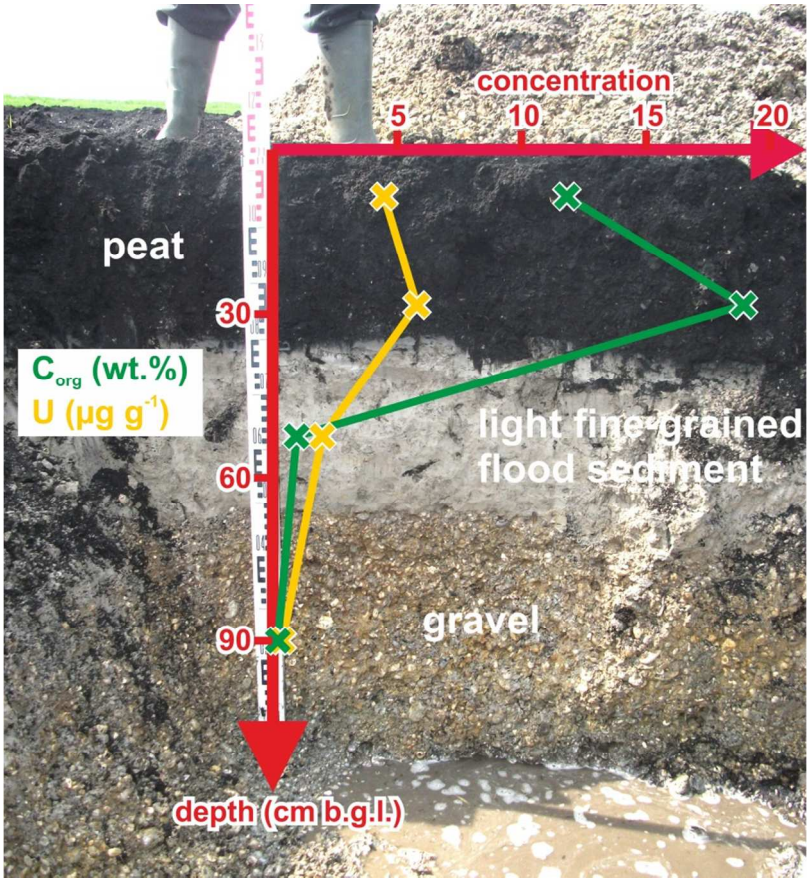

Figure S4. Profile and U/C_{org} development in trial pit 3.

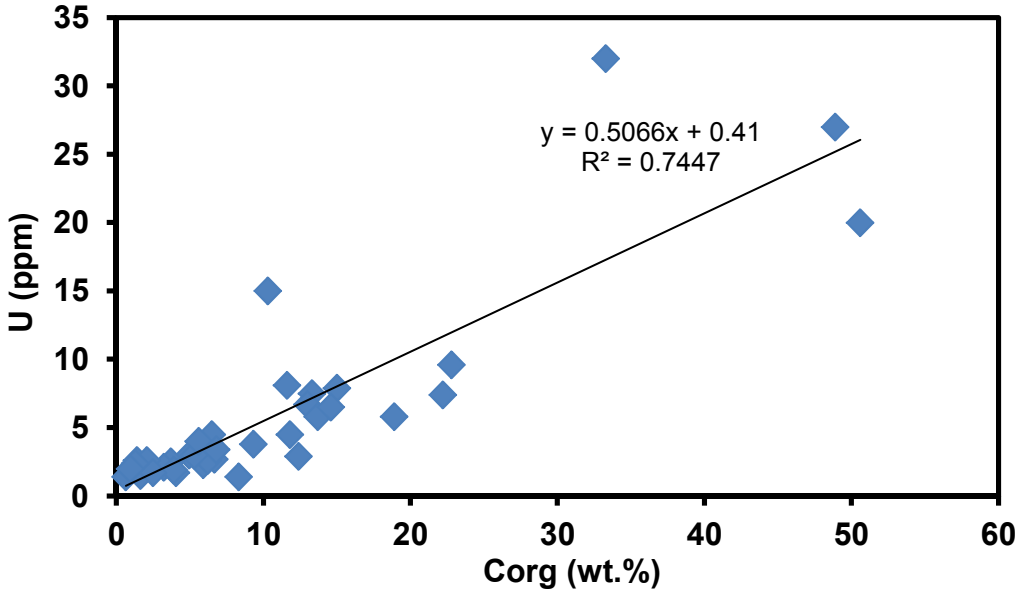

Figure S5. Scatter plot and regression of U and C_{org} in soil samples.

Table S1. Sediment geochemistry.

Sample groups and sample no.	Al	Ca	Fe	K	Mg	Na	P	S	As	Co	Cr	Cu	Mn	Ni	Pb	Sb	U	V	Zn
	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	wt.%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lignitic inclusions in Tertiary sands																			
1	2.25	2.56	0.99	0.16	0.28	0.02	0.03	1.65	9.5	4	33	16	133	11	8	0.4	< 0.5	55	10
2	2.88	4.19	2.92	1.52	1.35	0.29	0.03	1.93	105	12	51	29	408	40	11	2.9	7.6	81	231
3	0.79	1.69	1.72	0.28	0.46	0.06	0.01	2.29	171	8	17	27	131	19	< 3	7.0	4.2	21	121
4	5.19	2.75	3.57	2.18	2.33	0.13	0.04	0.95	74.5	13	86	77	358	58	28	4.0	31.0	122	103
5	4.00	0.70	3.22	2.15	1.07	0.39	0.03	1.01	51.4	13	76	24	273	50	10	0.9	50.4	92	83
6	5.04	5.93	3.27	2.50	2.63	0.49	0.05	0.06	9.0	13	74	52	518	46	17	1.8	4.5	93	99
7	4.22	2.41	2.83	2.11	1.56	0.41	0.04	1.08	24.4	13	85	28	487	47	16	1.4	3.5	102	95
8	7.52	0.82	3.48	1.31	0.62	0.04	0.02	1.91	22.2	27	133	59	97	85	49	1.1	4.2	282	233
9	0.95	1.73	6.22	0.50	0.50	0.05	0.02	8.17	348	17	36	31	147	39	30	5.7	22.8	50	39
10	0.47	1.63	3.50	0.20	0.45	0.03	0.05	4.66	135	5	< 2	18	151	26	4	12.8	33.1	40	14
11	4.88	2.75	3.46	2.56	1.41	0.14	0.03	1.50	75.9	10	86	32	287	39	15	1.9	11.0	91	82
Fe-rich concretions in Tertiary sands																			
12	2.32	0.34	5.59	2.04	0.67	0.75	0.04	< 0.01	218	10	64	19	283	30	10	3.8	3.0	124	65
13	2.19	0.50	10.4	1.54	0.45	0.54	0.06	0.01	686	11	84	32	391	34	15	3.5	< 0.5	191	67
14	1.59	0.62	22.0	0.84	0.31	0.37	0.07	0.02	1800	3	266	24	608	28	9	0.6	4.8	232	63
15	4.34	2.66	11.7	0.58	0.79	0.30	0.10	< 0.01	10.2	13	163	9	6530	17	12	1.6	4.8	30	74
Cley lense in Tertiary sands																			
16	6.04	0.60	4.18	2.15	1.72	0.34	0.04	< 0.01	10.1	15	94	47	502	61	25	2.2	4.2	129	130
Pure Tertiary sands																			
17	1.64	0.55	1.27	1.06	0.23	0.47	0.02	< 0.01	< 0.5	4	15	8	307	10	5	0.5	< 0.5	20	24
18	2.50	2.41	1.98	1.66	1.22	0.73	0.03	< 0.01	7.6	4	30	7	564	14	7	0.7	< 0.5	33	36
19	1.34	6.69	1.90	0.91	0.23	0.32	0.04	< 0.01	48.2	5	15	7	557	12	6	< 0.1	< 0.5	20	21
20	3.57	0.49	2.72	1.62	0.52	0.39	0.03	< 0.01	11.7	10	71	15	831	37	17	1.0	1.5	67	59
21	2.25	0.40	1.42	1.29	0.30	0.46	0.03	< 0.01	5.5	4	29	3	1020	13	9	0.6	1.5	34	35
22	2.80	0.40	2.26	1.64	0.54	0.41	0.04	< 0.01	< 0.5	8	47	10	806	26	12	1.0	1.3	48	49
23	1.38	0.22	2.51	1.47	0.42	0.44	0.04	< 0.01	10.8	9	52	10	613	26	9	1.0	1.4	58	49
24	2.54	0.33	1.71	1.40	0.37	0.46	0.03	< 0.01	10.8	5	24	7	420	17	9	0.7	1.4	41	36
25	2.78	0.10	2.00	1.45	0.37	0.31	0.03	0.01	9.0	7	24	8	339	24	12	0.4	1.6	46	45
26	2.05	1.24	1.97	1.18	0.34	0.52	0.03	< 0.01	18.4	5	28	4	860	15	5	0.6	< 0.5	28	27
27	1.09	0.49	1.76	1.20	0.29	0.34	0.03	< 0.01	17.7	8	29	6	624	12	7	0.7	< 0.5	34	34
28	2.57	0.36	1.96	1.60	0.40	0.46	0.05	< 0.01	4.3	6	27	7	541	19	7	0.8	< 0.5	40	39
Loesses and loess loams																			
29	3.65	0.38	2.91	1.73	0.46	0.27	0.02	< 0.01	12.6	11	71	17	761	36	16	1.1	3.7	62	62
30	2.17	13.3	1.44	1.31	3.6	0.41	0.04	0.01	8.4	7	44	11	500	18	8	0.6	3.1	34	30
31	2.68	11.1	1.73	1.62	3.49	0.44	0.05	0.01	6.4	7	48	12	520	23	9	0.9	3.2	46	37
32	2.81	0.24	2.05	1.7	0.42	0.5	0.04	0.01	7.0	9	62	9	683	23	15	0.7	2.7	56	51
Alluvial gravels																			
33	2.07	0.08	2.69	1.04	0.19	0.21	0.04	0.01	20.9	6	30	14	1080	28	9	0.8	1.3	43	43
34	4.95	0.39	3.35	1.83	0.47	0.19	0.04	< 0.01	13.1	10	95	19	288	46	25	1.2	2.8	94	71
35	0.86	9.53	1.14	0.67	0.22	0.2	0.03	< 0.01	11.4	4	17	11	3010	14	6	0.5	< 0.5	14	21
36	1.64	0.32	4.98	0.85	0.19	0.14	0.08	< 0.01	95.0	9	29	19	1310	38	10	1.6	< 0.5	64	51
37	2.51	5.61	3.85	2.26	1.76	0.41	0.06	< 0.01	8.3	17	94	30	614	46	15	1.6	2.8	115	88
38	0.75	10.6	0.78	0.55	5.51	0.15	0.01	< 0.01	6.9	3	14	8	303	9	< 3	< 0.1	1.3	13	14
39	0.78	14.6	0.65	0.54	4.82	0.18	0.01	0.02	9.7	3	16	10	286	8	3	0.5	1.6	13	14
40	0.93	12.4	0.74	0.64	4.07	0.19	0.01	0.01	6.0	3	15	5	343	8	5	0.4	1.2	14	16
Alluvial valley deposits																			
41	0.95	11.9	0.82	0.63	3.16	0.22	0.02	0.01	5.4	2	15	5	300	1	4	0.4	1.5	14	16
42	0.82	13.1	0.81	0.53	3.03	0.17	0.02	0.01	14.1	2	10	6	373	9	< 3	0.5	< 0.5	13	15
43	2.24	14.9	1.2	1.11	6.47	0.2	0.02	0.02	6.7	6	48	17	207	29	9	0.3	3.3	46	32
44	2.66	7.82	1.87	1.23	1.73	0.26	0.05	0.72	33.8	10	48	25	262	40	11	0.9	10.4	61	39
45	0.68	17.0	0.79	0.42	5.25	0.16	0.02	0.02	5.7	3	12	5	338	7	4	< 0.1	2.7	12	12
46	2.34	6.3	6.05	1.89	2.63	0.13	0.04	0.07	35.4	21	84	39	830	49	25	2.8	2.5	111	74

Table S2. Soil geochemical data (soil probe samples).

Sample groups and sample no.	pH	organic C wt.%	inorganic C wt.%	N wt.%	S wt.%	As ppm	Co ppm	Cr ppm	Cu ppm	Ni ppm	Pb ppm	Sb ppm	U ppm	V ppm	Zn ppm
Lowland moor peat															
1						71	4.4	25	21	21	12	0.58	4.4	43	33
2						18	6.9	24	10	17	13	0.33	2.1	32	39
3						28	9.0	32	13	24	17	0.52	8.7	39	54
4						110	14	32	18	20	29	0.77	5.9	64	39
5						74	8.2	30	15	20	15	0.67	4.5	42	46
6						32	6.4	28	18	19	15	0.42	2.6	40	58
7						25	<2.1	9.3	<10	8.2	<10	0.28	8.4	10	<21
8						12	5.6	30	19	25	11	0.38	6.4	44	37
9						10	8.6	43	24	33	25	0.47	5.3	57	54
10						11	4.9	23	14	18	<10	0.28	2.9	32	35
11						6.4	7.0	40	22	34	12	0.59	4.1	51	48
12	7.3	10.3	6.04	0.82	0.20	13	3.9	21	26	22	14	0.34	15	31	40
13	7.3	9.33	3.37	0.77	0.15	29	7.0	47	34	35	16	0.29	3.8	67	61
14	7.4	22.2	5.08	1.83	0.42	90	5.4	25	21	20	16	0.33	7.4	49	28
15	7.5	13.3	7.22	1.08	0.32	50	2.8	17	17	13	15	0.24	7.5	26	32
16	7.5	5.90	6.20	0.51	0.05	28	2.9	19	13	13	<10	0.16	2.3	27	28
17	7.5	13.0	7.48	1.08	0.28	28	2.7	19	17	13	12	0.23	6.7	33	29
18	7.4	22.8	4.08	1.70	0.59	97	12	32	35	36	15	0.43	9.6	53	41
19	7.4	13.7	6.93	1.21	0.27	18	3.2	14	34	13	37	0.28	5.8	18	40
calcaric-humic gleysol															
20	7.4	6.66	4.44	0.60	0.11	15	8.1	41	35	36	21	0.39	2.7	54	66
21	7.6	4.95	6.95	0.42	0.05	30	4.5	22	18	20	<10	0.21	3.0	32	33
22	7.5	6.34	5.36	0.53	0.12	32	5.9	31	30	29	12	0.26	2.9	43	45
23	7.5	8.33	5.87	0.79	0.15	69	4.2	25	23	20	15	0.31	1.4	39	37
24	7.4	6.21	5.19	0.55	0.11	28	5.1	25	19	22	<10	0.26	2.6	38	30
25	7.4	6.50	0.98	0.51	0.05	30	5.4	22	14	18	<10	0.18	4.5	34	26
26	7.3	5.29	1.72	0.47	0.05	26	7.1	42	25	32	15	0.31	3.0	61	58
27	7.6	3.70	6.90	0.30	0.05	15	5.1	27	21	24	<10	0.23	2.5	37	39
28	7.5	4.05	8.75	0.35	0.05	14	<2.1	13	12	10	<10	0.14	1.7	18	<21
29	7.5	3.24	5.83	0.28	0.05	23	6.6	32	23	29	12	0.23	2.1	43	44
30						34	5.4	27	19	17	17	0.45	1.4	37	58
31						23	5.8	30	15	25	<10	0.28	2.3	41	34
32						35	4.3	21	13	17	<10	0.27	1.9	31	30
33						34	5.8	38	19	25	18	0.39	1.2	49	46
34						10	11	56	29	39	21	0.55	2.6	76	82
gley															
35						34	10	29	13	21	13	0.46	0.8	37	56
36						7.2	2.9	13	11	11	<10	0.31	1.6	17	56
37						13	7.5	20	<10	16	<10	0.24	0.6	24	33
38						17	<2.1	14	<10	12	<10	0.25	1.4	21	<21
39						29	7.0	36	20	23	21	0.44	1.6	45	76
40						27	5.2	25	15	20	15	0.42	1.4	33	44
41						28	9.8	62	38	48	18	0.41	1.7	85	77
42						11	9.8	51	32	42	15	0.40	1.6	70	64
43						23	5.2	27	15	21	<10	0.34	1.7	39	38
44						3.7	3.2	14	<10	11	<10	0.23	1.6	20	23
45						4.5	5.0	22	13	18	<10	0.25	1.1	29	36
calcaric fluvisol															
46						4.7	4.5	19	15	17	<10	0.31	1.7	26	33
47						33	8.8	36	23	31	11	0.45	1.6	46	55
48						7.1	5.8	25	21	22	16	0.61	1.7	33	59
49						5.1	4.6	19	15	18	<10	0.26	1.9	25	28
50						5.6	4.2	18	12	15	<10	0.34	1.7	24	32
51						7.6	5.8	24	16	20	13	0.47	1.5	33	47
52						8.8	6.7	30	15	24	<10	0.35	1.0	39	48
53						5.3	4.4	18	13	17	<10	0.29	1.9	25	26
54						7.5	6.0	32	19	28	<10	0.32	1.8	44	37
calcaric arenosol															
55						2.5	<2.1	15	<10	9.7	<10	0.19	1.1	12	<21
56						4.9	4.1	24	14	19	<10	0.19	1.9	34	27
57						45	5.6	29	25	22	29	0.76	2.5	42	86
58						11	6.1	35	17	29	<10	0.22	1.5	44	40
59						27	5.6	45	13	22	17	0.33	1.2	57	52
60						16	5.5	32	22	17	22	0.60	1.3	45	83
cambisol															
61						29	8.0	46	28	33	24	0.71	2.8	69	58
62						11	10	35	15	28	15	0.36	1.1	49	52
63						8.6	8.4	30	12	23	12	0.30	0.8	40	44
64						4.7	4.4	23	14	15	15	0.31	1.1	37	52
colluvisol															
65						7.4	8.0	28	11	18	17	0.42	1.1	40	51
66						2.1	2.4	9.3	<10	6.6	<10	0.07	0.6	10	<21
top soil															
67						27	7.2	32	23	27	18	0.58	2.3	46	52
68						18	7.3	22	11	16	13	0.44	1.8	32	47
69						63	13	55	24	31	26	0.95	9.0	67	73
70						18	5.4	40	19	26	14	0.41	5.8	65	42
71						25	5.1	43	12	15	38	1.47	11	34	36
72						46	12	61	53	46	36	0.97	2.9	82	120
73						4.9	3.8	21	77	13	34	0.98	1.1	18	180
74						32	9.9	57	33	43	22	0.60	1.7	90	75
75						4.3	2.9	13	11	11	<10	0.27	1.8	19	29
76						6.9	5.0	23	18	18	10	0.40	1.9	35	42

Table S3. Soil geochemical data (trial pit samples).

Sample groups and sample no.	pH	organic C	inorganic C	N	S	As	Co	Cr	Cu	Ni	Pb	Sb	U	V	Zn
		wt.%	wt.%	wt.%	wt.%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
trial pit 1															
cf. Paper Fig. 2															
77	7.5	0.65	4.03	0.05	0.11	5.4	<2.1	9.1	<10	8	<10	<0.14	1.4	9.1	<21
78	7.5	1.40	6.21	0.05	0.17	5.3	<2.1	11	<10	8.7	<10	<0.14	2.6	13	<21
79	7.4	5.61	3.27	0.39	0.17	9.5	4.3	30	17	24	<10	0.20	4.0	38	37
80	6.8	33.3	0.37	1.75	0.70	100	7.3	22	19	43	<10	0.24	32	28	35
81	7.0	48.9	0.91	2.91	1.16	170	<2.1	<5.5	<11	13	<10	<0.14	27	5.6	<21
82	7.1	50.6	1.55	3.90	0.80	63	<2.1	9.6	15	10	<10	<0.14	20	9.8	<21
83	7.4	12.4	6.83	1.16	0.22	39	<2.1	17	12	5.7	18	0.26	2.9	43	38
84 ("Alm")	7.6	3.80	11.2	0.27	0.05	46	<2.1	<5.5	<10	<4.1	<10	<0.14	2.0	<4.1	<21
85 (Fe hydr.)	7.5	17.3	3.85	1.34	0.29	80	6.7	<5.5	<10	14	11	<0.14	23	5.4	51
86 (plant fibre)	7.1	21.5	0.53	1.20	0.43	69	7.1	34	22	33	<10	0.29	20	40	51
trial pit 2															
cf. Fig. S3															
87	7.5	2.07	5.76	0.11	0.20	7.7	<2.1	11	<10	8	<10	<0.14	2.6	10	<21
88	7.7	3.90	10.7	0.24	0.23	13	<2.1	<5.5	<10	5.1	<10	<0.14	1.9	5.5	<21
89	7.5	11.6	7.47	0.65	1.10	41	3.5	14	16	17	<11	<0.14	8.1	16	26
90	7.8	1.63	9.17	0.05	0.05	8.5	2.5	16	10	14	<10	<0.14	1.5	20	<21
91	7.7	2.48	8.82	0.17	0.05	8.1	3.0	18	13	16	<10	<0.14	1.7	23	23
92	7.5	6.79	9.31	0.48	0.16	20	3.0	12	28	21	<10	0.26	3.4	19	<21
93	7.5	15.0	0.68	1.25	0.35	44	14	70	64	64	17	0.56	7.9	94	72
94	7.4	14.6	2.86	1.30	0.27	110	8.6	29	28	29	23	1.30	6.5	48	57
trial pit 3															
cf. Fig. S4															
95	7.5	1.29	4.17	0.05	0.19	3.6	2.2	10	<10	8.9	<10	0.23	2.4	12	<21
96	7.8	0.95	7.57	0.05	0.05	1.0	2.2	11	<10	8.7	<10	0.15	2.0	16	<21
97	7.2	18.9	1.84	1.52	0.31	14	6.4	38	27	24	24	0.72	5.8	65	58
98	7.0	11.8	0.93	1.04	0.18	14	8.4	54	30	33	26	0.68	4.5	83	71

Table S4. Mineralogical composition of sediments and soils (XRD-Rietveld data).

The software BGMN was used to perform quantitative phase analysis which consists of an automatic, whole powder-pattern calculation and refinement of structural data (provided as mineral structure files of ideal phases ranging in unit cell axial lengths, developed by the Institute of Clay and Interface Mineralogy, RWTH Aachen University) against observed data. The programme performs an automated background refinement, allowing for the separation of an intensity difference curve containing the diagnostic Bragg reflections. These were allocated to mineral phases with the help of the aforementioned structure files and the database MINCRYST. Single phase structural information and sample mineralogical composition were refined aiming for minimum deviation, i.e. best fit, between model and observed data.

	Sample groups and sample no.	Mineralogical composition (wt.%)
Sediments	**Fe-rich concretions in Tertiary sands**	
	12	Qz: 55.7; Ms: 31.3; Fsp: 6.7; Cm: 5.2; Gt: 1.1
	13	Qz: 79.3; Fsp: 8.1; Cm: 4.6; Ms: 4.3; Ttn: 2.3; Gt: 1.4
	15	Qz: 54.9; Alm: 29.9; Fsp: 3.8; Ms: 3.7; Cm: 3.6; Ttn: 2.3; Gt: 1.6
	Cley lense in Tertiary sands	
	16	Qz: 35.0; Cm: 24.2; Ms: 16.4; Ttn: 8.5; Fsp: 7.4; Anh: 6.5
	Pure Tertiary sands	
	17	Qz: 82.5; Ms: 11.2; Fsp: 4.7
	Loesses and loess loams	
	29	Qz: 69.0; Ms: 13.5; Fsp: 9.1; Cm: 6.8
	30	Qz: 39.2; Dol: 26.7; Cal: 18.6; Fsp: 8.5; Ms: 5.2; Cm: 1.7
	Alluvial valley deposits	
	44	Qz: 56.4; Dol: 13.7; Ms: 8.8; Cal: 7.3; Cm: 6.9; Fsp: 6.6
Soils	**Calcaric-humic gleysol**	
	28	Cal: 88.0; Dol: 6.3; Qz: 5.7
	Gley	
	40	Qz: 35.3; Dol: 32.3; Cal: 13.5; Ms: 8.6; Fsp: 5.5; Cm: 4.4
	Calcaric fluvisol	
	49	Dol: 53.2; Cal: 17.7; Qz: 16.6; Ms: 5.9; Fsp: 4.0; Cm: 2.6
	Calcaric arenosol	
	57	Qz: 42.1; Dol: 25.4; Cal: 15.1; Ms: 8.9; Fsp: 4.5; Cm: 3.8
	Trial pit 1	
	84 ("Alm")	Cal: 99.4
	Trial pit 2	
	90	Cal: 59.0; Dol: 29.6; Qz: 9.7; Fsp: 1.7
	Trial pit 3	
	96	Dol: 60.9; Qz: 26.5; Cal: 9.1; Fsp: 3.5

Table S5. LA-ICP-MS data for sediments and soils.

	Si	Al	Ca	Fe	Mn	As	Cr	Ni	Pb	Th	U	V	Zn
LOD	1.4	11	5000	95	7.1	33	48	8.0	0.9	0.2	0.2	6.0	39
Sample group and point analysis no.	wt.%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Lignitic sediment													
5-1	81.5	98025	8130	104243	597	1302	350	203	402	22.2	299	384	351
5-2	54.9	106642	7370	87791	336	822	264	139	104	21.2	219	348	260
5-3	62.9	128006	5185	86898	441	626	269	139	298	16.8	138	313	329
5-4	96.3	120214	16264	138320	706	3557	286	146	599	23.7	243	602	439
10-1	5.1	8733	< 5000	68419	119	456	< 48	55	9.1	4.9	62.5	89	< 39
10-2	12.9	26245	200897	41184	256	319	71	41	10.5	5.4	40.5	94	76
10-3	11.3	15139	< 5000	105684	270	536	59	110	15.0	5.7	60.7	116	87
10-4	< 1.4	4124	< 5000	66441	105	521	< 48	45	2.8	4.6	61.6	97	< 39
10-5	< 1.4	4270	8114	27965	175	159	< 48	19	2.3	1.0	41.6	47	< 39
10-6	< 1.4	2760	20003	13847	165	178	< 48	15	0.9	0.6	25.6	32	< 39
Fe-rich concretion													
14-1	11.0	n.a.	9290	*	81	16376	6462	97	4.8	0.3	8.5	607	174
14-2	8.1	n.a.	8689	*	246	18721	878	91	4.7	0.3	9.6	439	185
14-3	10.1	n.a.	7547	*	451	15391	1313	119	6.2	0.6	9.8	505	259
14-4	11.0	n.a.	5901	*	171	11087	5283	60	2.6	0.3	6.9	1210	251
14-5	6.4	n.a.	< 5000	*	99	10888	91	39	6.4	1.1	5.2	384	93
14-6	44.2	n.a.	< 5000	*	91	2961	74	19	1.3	2.3	1.7	123	76
* too high for quantification with used standard													
Lowland moor peat													
80-1	41.9	26647	13528	9440	94	32	< 48	40	8.6	2.5	8.9	65	70
80-2	36.7	27139	12601	25315	249	428	< 48	32	10.8	3.0	4.3	85	69
80-3	25.1	42820	48996	22003	257	160	114	87	18.3	6.8	52.5	110	65
80-4	24.1	36565	49789	15127	198	100	692	148	21.2	4.9	53.0	92	147
80-5	32.9	55647	38828	14809	290	< 33	144	79	20.5	11.6	26.7	111	71
80-6	29.5	54244	53733	18974	221	144	109	84	16.3	6.2	51.3	135	85
97-1	18.2	12922	13614	5626	59	< 33	< 48	< 8	9.0	1.0	1.1	31	< 39
97-2	12.6	29599	42554	23790	276	47	62	37	26.7	4.6	7.3	110	66
97-3	20.0	49956	52138	23993	1284	< 33	90	47	38.2	6.2	9.8	150	74
97-4	18.1	40169	42444	19007	1533	< 33	83	38	33.7	6.6	7.1	130	65
97-5	23.3	47245	39555	29504	476	40	88	49	48.0	6.6	10.6	191	73
97-6	18.6	38610	58572	19260	1344	< 33	67	47	31.2	6.9	11.0	117	42

Table S6. Hydrochemistry data: Quaternary aquifer.

Sample no.	pH -	temp °C	eC µS/cm	Eh mV	O2 mg/l	DOC mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	HCO3 mg/L	Cl mg/l	SO4 mg/l	NO3 mg/l	Fe mg/l	As mg/l	Cu mg/l	Mn mg/l	Sr mg/l	V mg/l	Zn mg/l	U µg/l
1	7.0	11.5	895			4.7	155	30	21.0	0.7	458	45	95	<0.5	2.90	0.027	<0.001	0.300	0.36	0.0001	<0.01	2.2
2	7.0	12.7	650		2.9	1.0	104	27	9.4	2.2	370	25	40	18	<0.01	0.002	0.002	<0.001	0.18	0.0002	<0.01	6.9
3	7.0	12.3	742		0.1	1.0	119	28	8.8	8.6	386	32	41	48	<0.01	<0.001	0.001	0.012	0.20	<0.0001	<0.01	3.3
4	7.3	10.5	683		6.7	0.9	101	33	7.6	0.7	309	34	47	57	0.01	<0.001	0.002	0.002	0.14	<0.0001	<0.01	3.4
5	7.0	11.4	662		2.0	1.4	107	26	11.6	2.8	363	27	45	21	<0.01	<0.001	0.001	<0.001	0.24	0.0001	<0.01	8.8
6	7.2	10.5	726		10.1	0.5	118	30	9.5	2.3	387	22	33	71	<0.01	<0.001	<0.001	0.001	0.22	0.0003	<0.01	1.0
7	7.1	10.3	759		9.8	0.6	106	30	32.5	1.2	369	36	41	67	<0.01	<0.001	0.001	<0.001	0.21	0.0002	<0.01	1.4
8	7.1	10.1	776		9.4	0.6	122	35	8.2	0.9	360	29	54	92	<0.01	<0.001	0.001	<0.001	0.24	0.0002	<0.01	1.8
9	7.2	10.5	672		3.4	0.9	111	28	9.4	3.2	381	23	42	25	<0.01	<0.001	0.003	<0.001	0.29	0.0001	<0.01	3.7
10	7.0	12.5	806		7.4	0.7	134	31	10.1	1.2	415	32	44	82	0.03	<0.001	<0.001	0.090	0.26	0.0003	<0.01	0.9
11	7.1	10.4	709		10.0	0.5	113	32	6.1	0.9	342	29	40	63	<0.01	<0.001	<0.001	0.001	0.23	0.0002	<0.01	1.3
12	7.1	11.8	700		4.3	1.0	115	27	11.7	2.3	381	27	46	27	<0.01	<0.001	<0.001	<0.001	0.30	<0.0001	<0.01	12
13	7.1	13.6	666		1.7	1.6	108	25	11.2	2.9	357	27	40	29	<0.01	0.001	0.001	<0.001	0.25	0.0002	<0.01	7.0
14	7.1	12.4	673		4.2	1.5	110	25	11.3	2.4	357	28	39	34	<0.01	<0.001	0.001	<0.001	0.26	0.0002	<0.01	9.3
15	7.0	11.7	691		1.8	1.4	113	26	9.9	3.2	381	26	44	27	<0.01	<0.001	<0.001	<0.001	0.27	0.0001	<0.01	6.7
16	7.1	12.7	720		1.2	1.2	119	28	9.9	2.9	394	27	52	23	<0.01	<0.001	<0.001	0.002	0.28	<0.0001	0.01	8.8
17	7.1	12.0	706		5.0	1.3	118	26	11.3	3.1	381	28	49	25	<0.01	<0.001	<0.001	<0.001	0.31	<0.0001	<0.01	12
18	7.5		547		6.2	<0.5	83	29	2.8	1.5	357	11	20	<0.5	0.50	<0.001	0.001	0.043	0.34	<0.0001	0.07	<0.1
19	7.1	10.9	648		3.8	0.7	96	24	14.1	7.7	333	36	24	32	<0.01	0.004	0.003	<0.001	0.20	0.0003	0.01	1.3
20	7.1	12.0	735		2.7	1.2	123	27	9.9	3.4	397	27	48	33	<0.01	<0.001	0.001	<0.001	0.27	<0.0001	<0.01	6.7
21	7.1	12.6	721		2.0	1.1	121	26	10.1	2.7	391	28	55	22	<0.01	<0.001	<0.001	0.002	0.28	<0.0001	<0.01	7.7
22	7.0	12.7	713		1.8	1.6	113	28	11.0	3.5	387	30	35	36	<0.01	<0.001	0.003	0.003	0.26	0.0002	0.01	4.4
23	6.9	11.3	879		6.2	1.0	134	31	17.7	5.3	433	50	43	44	<0.01	<0.001	0.003	0.001	0.33	0.0002	0.03	2.8
24	7.0	13.2	727		2.3	1.6	116	29	12.0	3.4	384	29	41	39	<0.01	<0.001	0.006	<0.001	0.26	0.0001	0.01	4.6
25	6.9	11.6	860		6.7	2.8	154	32	10.2	1.2	455	31	94	23	<0.01	<0.001	0.003	<0.001	0.43	0.0001	0.01	14
26	7.0	13.0	725		5.5	2.1	120	26	10.8	3.1	378	27	45	44	<0.01	<0.001	0.001	0.002	0.30	<0.0001	<0.01	7.5
27	7.0	12.7	681		3.0	1.7	109	28	11.7	2.3	369	27	46	26	<0.01	<0.001	0.001	<0.001	0.33	<0.0001	<0.01	10
28	6.7	13.6	1028		0.1	2.0	139	37	28.1	22.8	430	74	66	79	0.05	0.002	0.002	0.200	0.27	0.0004	0.03	3.5
29	7.1	12.6	727		2.2	1.6	112	27	19.3	2.5	369	39	51	27	<0.01	<0.001	0.002	<0.001	0.29	0.0001	<0.01	9.0
30	7.1	10.8	911		0.8	3.0	112	27	36.6	4.8	360	71	34	31	<0.01	0.0025	0.001	0.010	0.43	<0.0001	<0.01	2.3
31	7.0	12.0	755		5.2	1.6	112	26	30.0	3.2	391	45	29	42	0.02	<0.001	0.003	0.002	0.28	0.0001	<0.01	4.3
32	7.1	12.9	677		3.1	1.5	111	22	17.0	3.7	378	32	34	24	<0.01	0.001	0.006	<0.001	0.26	0.0001	0.06	9.3
33	7.0		730			1.6	118	29	13.0	3.2	400	31	51	25	<0.01	0.002	0.003	<0.001	0.25	0.0003	0.01	8.6
34	7.0		760			1.6	131	26	14.2	2.4	412	33	57	22	<0.01	<0.001	0.012	0.003	0.31	<0.0001		14
35	7.2	11.3	725		7.7	1.3	115	25	19.4	2.7	363	39	50	29	<0.01	<0.001	0.014	<0.001	0.28	<0.0001	0.04	9.2
36	7.1	11.7	731		6.9	1.5	115	26	19.4	2.6	369	41	47	33	<0.01	<0.001	0.001	<0.001	0.31	0.0001	<0.01	7.0
37	7.0	12.3	731		4.7	1.2	110	26	22.2	2.5	384	40	28	42	<0.01	<0.001	<0.001	<0.001	0.32	<0.0001	<0.01	3.2
38	7.2		727			1.6	118	27	14.0	2.5	372	33	53	29	<0.01	0.001	0.015	0.002	0.31	0.0002	0.1	7.5
39	7.1	14.6	757		1.8	2.0	121	26	20.7	2.6	391	43	59	6.1	0.50	<0.001	0.001	0.300	0.32	<0.0001		10
40	7.5	16.5	457		0.5	<0.5	57	26	7.2	1.3	211	25	38	22	<0.01	<0.001	<0.001	<0.001	0.15	0.0001	<0.01	0.9
41	7.1	12.7	717		3.8	1.7	116	25	16.8	3.1	357	37	43	30	0.02	0.001	0.002	0.002	0.29	0.0002	<0.01	11
42	6.7	13.0	870		1.1	7.4	168	22	14.4	0.9	473	41	94	<0.5	3.80	0.031	<0.001	0.200	0.35	0.0003	<0.01	0.8
43	6.9	10.8	872		3.0	1.0	129	45	10.6	4.4	470	33	46	64	0.01	<0.001	<0.001	<0.001	0.26	0.0002	<0.01	1.8
44	7.0	12.7	740		5.6	0.8	106	26	29.9	3.0	378	47	27	37	0.01	<0.001	0.001	0.002	0.35	0.0002	<0.01	2.9
45	6.9	11.0	822		0.1	4.5	136	22	31.0	1.7	409	54	73	8.3	0.01	0.002	0.003	0.200	0.28	0.0003	<0.01	17
46	7.2	7.9	738		6.7	2.2	114	27	12.1	2.0	397	42	33	33	<0.01	<0.001	0.004	<0.001	0.26	0.0002	<0.01	19
47	7.4	10.0	660		9.7	1.0	94	27	15.2	2.4	348	32	26	51	<0.01	<0.001	0.002	<0.001	0.25	0.0001	<0.01	3.0
48	7.4	9.2	653		9.6	1.4	96	26	14.0	2.2	351	33	27	48	0.01	<0.001	0.002	0.002	0.24	0.0001	0.09	4.6
49	7.1	7.4	713		0.5	4.9	143	20	7.9	0.8	445	15	36	33	<0.01	<0.001	0.004	0.400	0.19	<0.0001	<0.01	17
50	7.5	9.9	669		9.6	0.8	93	28	19.2	2.5	351	41	29	46	0.01	<0.001	0.004	0.003	0.29	0.0002	0.01	3.2
51	7.4	9.8	650		9.5	1.1	91	28	16.1	2.2	320	37	28	47	<0.01	<0.001	0.002	<0.001	0.25	0.0003	<0.01	3.9
52	7.0	10.1	864		0.3	3.3	135	33	18.8	1.1	436	48	110	<0.5	2.30	0.004	<0.001	0.600	0.29	<0.0001	<0.01	1.4
53	7.2	9.5	722		5.9	2.1	109	31	10.8	2.4	357	33	40	57	<0.01	<0.001	0.002	0.001	0.26	0.0001	<0.01	11
54	7.2	8.8	726		4.0	1.8	124	26	12.9	2.4	366	31	54	50	<0.01	<0.001	0.002	0.003	0.27	<0.0001	0.01	9.0
55	7.0	8.3	822		0.7	2.6	148	31	11.8	1.9	433	29	100	26	<0.01	<0.001	0.001	0.200	0.29	<0.0001	<0.01	18
56	7.0	7.4	949	330	0.5	5.5	167	28	23.5	0.8	464	60	100	0.58	0.03	<0.001	0.003	0.500	0.32	0.0001	<0.01	14
57	7.1	9.1	765	420	4.6	2.2	124	29	10.6	2.6	381	34	45	55	<0.01	<0.001	0.002	0.004	0.27	<0.0001	<0.01	10
58	7.2	8.1	806	410	1.5	2.8	146	24	18.1	2.5	394	36	48	61	<0.01	0.001	0.002	<0.001	0.26	<0.0001	<0.01	14
59	7.9	11.3	627	440		1.4	89	27	9.8	3.2	320	16	24	48	<0.01	<0.001	0.006	0.002	0.21	<0.0001	0.04	3.3
60	7.3	9.5	810	420	9.5	0.9	111	27	29.8	2.6	351	72	30	42	<0.01	<0.001	0.003	0.002	0.26	0.0001	0.04	3.7
61	7.4	10.1	809	370	9.2	1.1	111	27	29.6	2.6	360	69	29	43	0.02	<0.001	0.013	0.002	0.26	0.0001	0.03	3.8
62	7.3	8.9	591	450	3.4	0.9	95	25	5.4	0.8	299	27	37	31	<0.01	<0.001	0.003	<0.001	0.17	<0.0001	0.05	2.5
63	7.4	9.3	618	440	9.7	0.6	86	26	11.2	2.8	308	25	26	45	<0.01	<0.001	0.001	<0.001	0.21	<0.0001	<0.01	3.1
64	7.2	8.3	807	400	7.4	1.0	108	27	30.0	2.7	357	73	29	44	<0.01	<0.001	0.002	<0.001	0.25	0.0001	0.01	3.8
65	7.2	7.9	727	420	4.0	1.7	116	28	11.2	2.0	357	36	49	32	<0.01	<0.001	0.001	<0.001	0.20	<0.0001	<0.01	8.1
66	7.5	11.3	662	430		1.5	100	25	14.6	2.7	333	29	26	48	<0.01	<0.001	0.005	0.002	0.25	0.0001	0.02	3.0
67	7.3	8.2	684	410	9.5	1.6	109	24	12.7	2.6	339	31	29	54	<0.01	<0.001	0.001	<0.001	0.23	<0.0001	<0.01	14
68	7.4	12.9	685	450	9.7	0.9	105	24	16.5	2.3	336	38	27	45	<0.01	<0.001	0.002	0.012	0.25	<0.0001	1.1	3.4
69	7.4	7.8	667	440	8.6	1.4	106	27	10.1	2.3	354	30	35	27	<0.01	0.001	0.002	<0.001	0.21	<0.0001	0.01	11
70	7.6	12.5	757	430	8.2	2.0	121	27	16.4	3.0	357	36	53	57	<0.01	0.001	0.01	<0.001	0.27	0.0001	0.01	10
71	7.3	9.4	694	420	8.7	1.0	103	25	19.1	2.3	339	39	28	46	<0.01	<0.001	0.002	<0.001	0.25	<0.0001	<0.01	3.8
72	7.3	9.5	731	420	7.5	1.2	107	25	23.8	2.4	342	48	30	46	<0.01	<0.001	0.002	<0.001	0.24	<0.0001	<0.01	3.6
73	6.9	11.5	780		1.1	1.8	116	24	39.1	7.7	403	66	48	18	<0.01	<0.001	0.004	0.002	0.27	0.0002	<0.01	6.2
74	7.3	9.9	722		7.3	1.5	106	31	8.8	2.4	387	26	55	26	<0.01	<0.001	0.001	0.002	0.25	<0.0001	<0.01	10
75	7.1	11.5	725		6.1	1.4	122	27	10.0	2.1	403	26	48	37	<0.01	<0.001	0.011	0.001	0.22	<0.0001	0.08	10
76	7.2	9.9	733		4.7	1.3	120	29	9.2	2.5	412	28	55	25	0.10	<0.001	0.001	0.005	0.25	0.0002	0.03	8.6
77	7.2	9.7	684		6.5	0.8	102	28	13.7	2.3	363	31	31	34	<0.01	<0.001	0.001	0.001	0.24	<0.0001	<0.01	10
78	7.1	9.9	729		5.9	0.8	104	25	27.6	2.2	342	46	29	45	<0.01	<0.001	0.002	0.001	0.23	<0.0001	0.1	4.0
79	7.0	10.4	740		5.3	1.6	120	27	14.2	2.5	397	34	41	40	<0.01	0.001	0.002	0.002	0.26	0.0002	<0.01	12
80	7.1	10.3	751		6.4	1.9	121	28	15.5	2.7	375	34	42	45	<0.01	0.001	0.002	0.001	0.24	0.0002	<0.01	10
81	7.1	12.5	752		6.1	1.9	124	27	14.5	2.6	372	43	39	37	<0.01	<0.001	0.008	0.003	0.26	<0.0001	0.02	14
82	7.1	9.7	775		4.2	1.2	126	29	9.2	3.1	320	38	55	87	0.02	0.003	0.002	0.011	0.17	0.0004	<0.01	4.3
83	7.1	14.9	735		4.0	1.2	121	27	9.3	2.5	378	25	45	30	0.01	<0.001	0.026	0.005	0.25	<0.0001	1.1	8.1
84	6.9	9.5	1010		0.1	4.7	167	24	44.8	1.3	418	76	140	<0.5	0.03	0.001	0.002	0.600	0.32	<0.0001	<0.01	17
85	7.1	9.0	733		2.9	1.3	128	28	9.0	3.1	394	27	55	23	0.09	<0.001	<0.001	0.002	0.25	0.0002	0.18	8.8
86	6.9	10.6	753		0.1	6.5	135	30	9.7	1.0	506	24	22	<0.5	0.20	0.001	0.001	0.200	0.19	0.0002	0.02	4.5
87	7.3	8.4	651		7.1	1.6	101	25	12.0	2.3	326	30	41	17	<0.01	<0.001	0.014	<0.001	0.27	<0.0001	0.01	11
88	7.0	10.0	799		0.1	2.3	133	26	17.7	2.3	393	41	54	44	<0.01	<0.001	0.002	0.029	0.29	<0.0001	<0.01	15
89	7.2	10.6	656		6.9	1.8	108	25	9.3	2.0	364	24	37	27	<0.01	<0.001	0.001	<0.001	0.21	0.0002	<0.01	8.2
90	7.2	11.0	745		4.0	1.6	120	29	9.1	2.3	401	26	56	28	<0.01	<0.001	0.002	<0.001	0.28	<0.0001	<0.01	8.9
91	7.2	9.7	659		4.0	1.3	105	25	12.3	2.5	344	30	36	31	<0.01	<0.001	<0.001	<0.001	0.28	0.0001	<0.01	5.6
92	7.1	11.9	701		3.8	1.4	113	29	10.3	2.3	390	25	38	31	<0.01	<0.001	<0.001	<0.001	0.21	0.0001	<0.01	3.6
93	7.2	10.6	757		5.7	1.1	120	26	19.0	2.3	361	41	62	34	<0.01	<0.001	<0.001	<0.001	0.30	<0.0001	<0.01	10
94	6.9	9.9	929		0.1	5.1	162	28	22.7	0.8	469	53	110	<0.5	1.70	0.031	<0.001	0.500	0.34	0.0002	<0.01	10
95	7.2	12.7	760		0.8	1.7	122	27	17.8	2.0	374	38	69	31	<0.01	0.002	0.002	<0.001	0.27	0.0002	<0.01	12
96	6.9	11.4	1072		0.5	4.5	146	27	74.4	1.0	454	124	79	<0.5	0.60	0.005	<0.001	0.300	0.34	0.0001	<0.01	4.2
97	7.5					1.5								38								11
98	7.2	10.5	812	330	3.9	5.0	146	24	13.5	2.0	421	32	70	38	0.08	0.008	0.001	0.600	0.23	0.0006	<0.01	29
99	7.2	8.4	801	440	6.5	4.8	142	23	11.3	2.6	391	35	68	45	0.05	0.02	0.002	0.200	0.23	0.0008	<0.01	24
100	7.2	12.3	906	410	3.9	20.3	170	37	4.8	3.6	513	28	110	3.0	0.03	0.028	0.003	0.100	0.32	0.0024	<0.01	96

Table S7. Hydrochemistry data: Tertiary aquifer.

Sample	pH	temp	eC	Eh	O2	DOC	Ca	Mg	Na	K	HCO3	Cl	SO4	NO3	Fe	As	Cu	Mn	Sr	V	Zn	U
no.	-	°C	µS/cm	mV	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/L	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l
101	7.3	10.9	501		0.2	0.5	71	29	5.9	0.9	348	1.0	14	<0.5	0.20	0.001	<0.001	0.049	0.64	<0.0001	<0.01	0.4
102	7.5	10.7	584		9.2	0.5	85	26	4.9	0.6	247	40	25	62	<0.01	<0.001	<0.001	<0.001	0.20	0.0003	<0.01	3.7
103	7.4	10.3	441		0.6	<0.5	73	20	3.0	0.6	314	2.0	20	2.2	0.04	0.002	<0.001	0.044	0.18	<0.0001	0.01	1.5
104	7.2	10.2	770		9.0	0.5	118	31	8.5	0.8	311	34	46	107	<0.01	0.001	<0.001	<0.001	0.14	0.0002	<0.01	1.8
105	7.5	11.0	604		1.0	0.7	87	28	4.3	1.1	287	16	62	0.05	1.10	0.0025	<0.001	0.050	0.47	<0.0001	<0.01	0.5
106	7.6	9.7	522		0.9	0.5	82	28	3.7	0.9	280	22	60	0.05	0.20	0.002	<0.001	0.006	0.14	<0.0001	<0.01	5.7
107	7.6	9.4	505		1.8	<0.5	78	29	3.6	0.8	319	5.8	34	7.4	<0.01	<0.001	<0.001	0.002	0.13	<0.0001	<0.01	3.0
108	7.1	8.9	772		1.5	0.7	128	36	6.4	1.1	386	48	73	15	0.10	<0.001	0.022	0.060	0.24	<0.0001	0.12	6.0
109	7.5	10.1	797		10.7	0.7	108	35	19.3	0.7	326	61	42	76	0.01	0.001	0.007	<0.001	0.14	0.0002	0.03	1.5
110	7.4	10.8	512		0.3	<0.5	82	28	2.9	1.1	409	1.5	4.4	<0.5	0.80	0.01	<0.001	0.070	0.56	<0.0001	<0.01	0.2
111	7.4	12.5	525	190	0.1	<0.5	80	31	3.1	0.9	394	1.5	2.8	<0.5	0.50	<0.001	<0.001	0.060	0.75	<0.0001	0.03	0.3
112	7.3					<0.5								<0.5								0.9
113	7.6					<0.5								<0.5								0.4
114	7.3					0.8								<0.5								1.3