Supplementary Material

1 Supplementary Figures and Tables

The supplementary material below includes additional figures of the rating curves for the stilling wells installed in Mineral Creek near Chattanooga Fen and Cement Creek near Prospect (Figure A1), as well as breakthrough and anion data (Figure A2) and OTIS with PEST model output for Mineral Creek (Figure A3) and Cement Creek (Figure A4) associated with the tracer tests. We also include supplemental figures of the concentrations of conservative elements in the hyporheic zone well clusters (Figure A5), an Eh-pH diagram for Al-bearing minerals (Figure A6), and concentration-discharge relationships (Figure A7). Tables include tracer test measurements (Table A1), vertical hydraulic gradients (Table A2), hydraulic conductivity estimates from slug test data (Table A3), saturation indices for Ca- and Na-bearing minerals (Table A4), and geochemical data for the hyporheic zone well clusters (Table A5).

1.1 Supplementary Figures

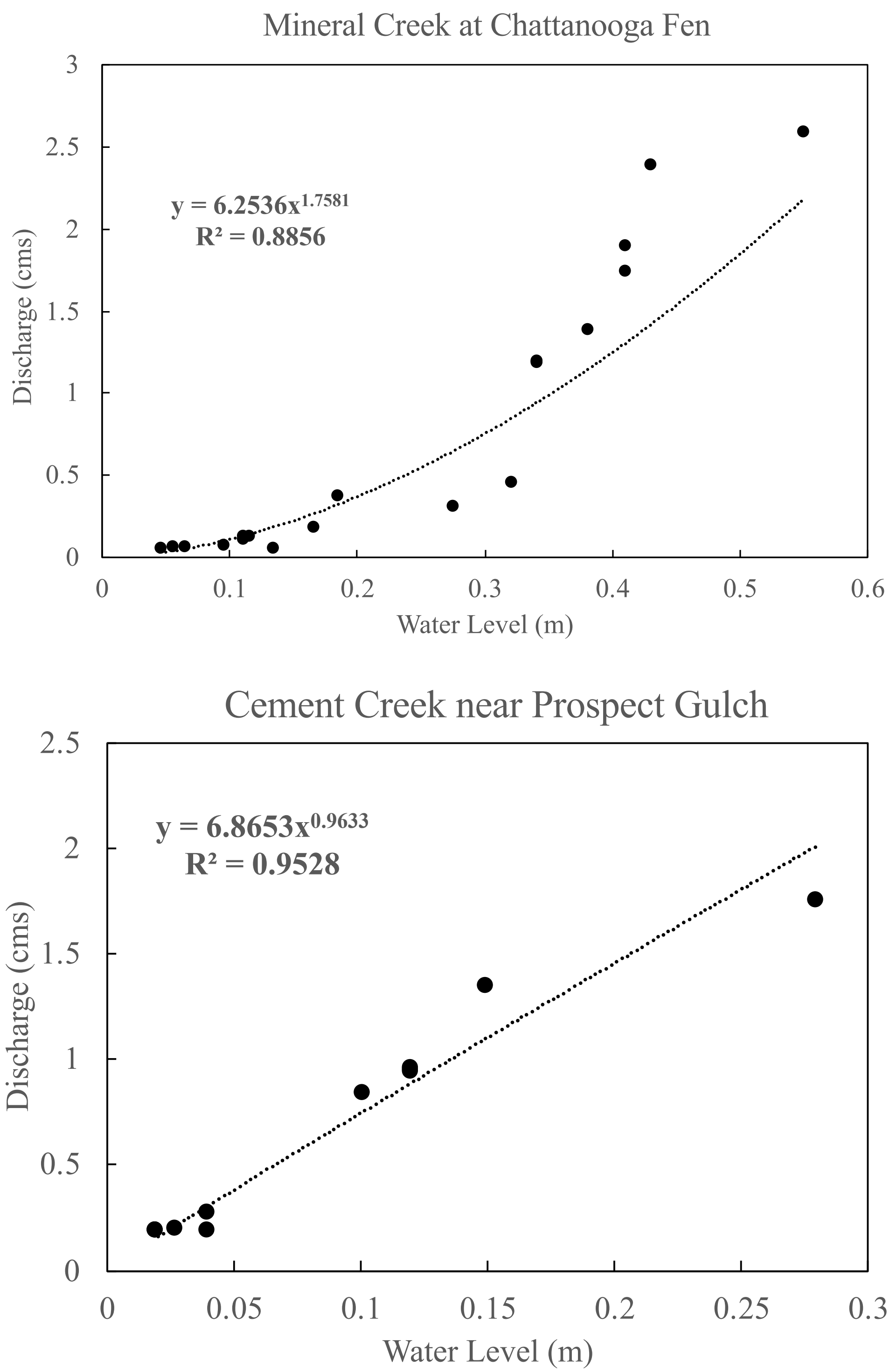

Figure A.1. Rating curves for Mineral Creek at Chattanooga Fen and Cement Creek near Prospect Gulch.

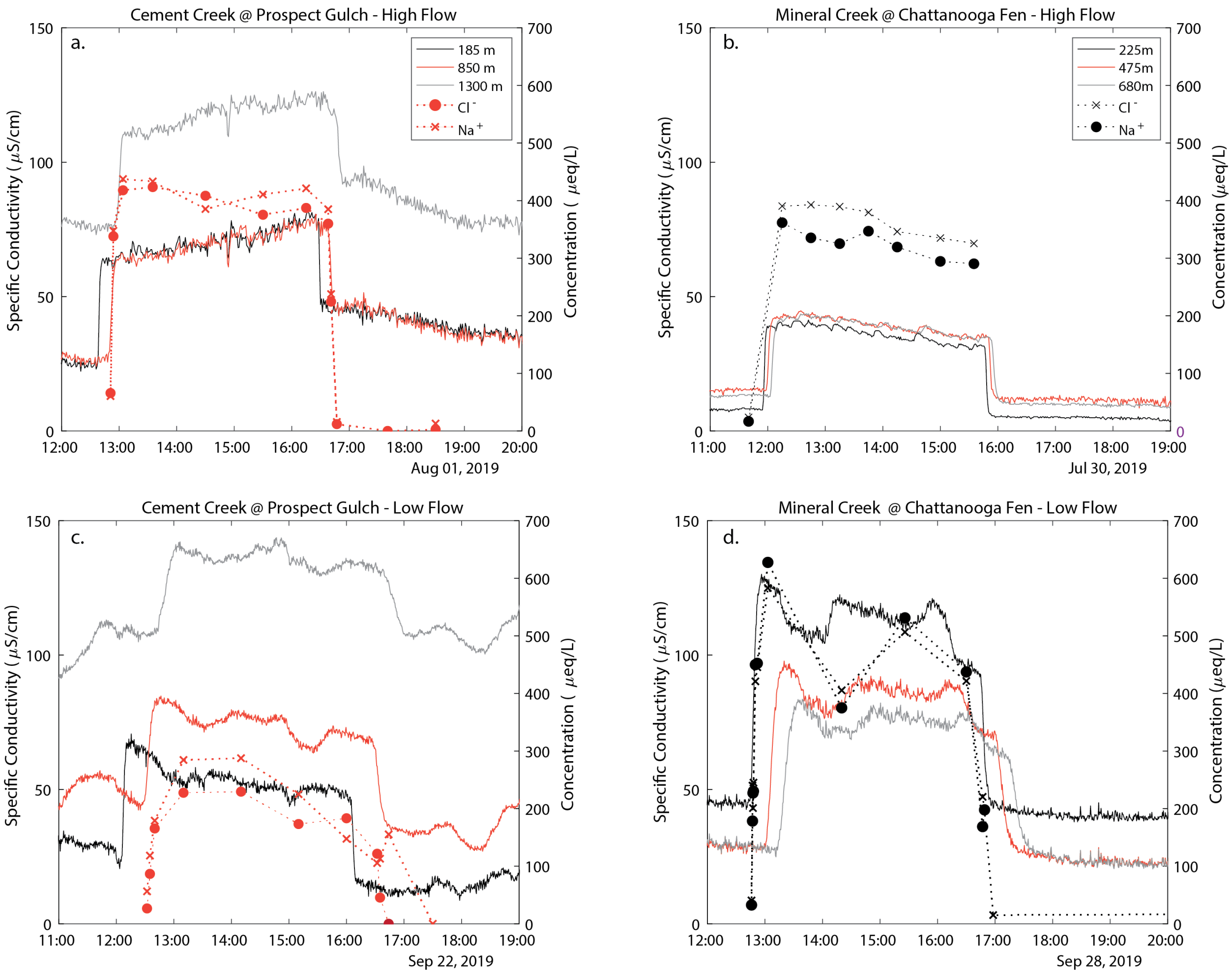

Figure A2. Specific conductivity (solid lines) and Na and Cl concentrations (dashed lines) during continuous salt tracer injection tests at high and low flow. Distances represent the distance downstream from the injection site. Conductivity presented here was adjusted for background (i.e. the upstream fluid conductivity was subtracted from conductivity measurements made downstream of the injection).

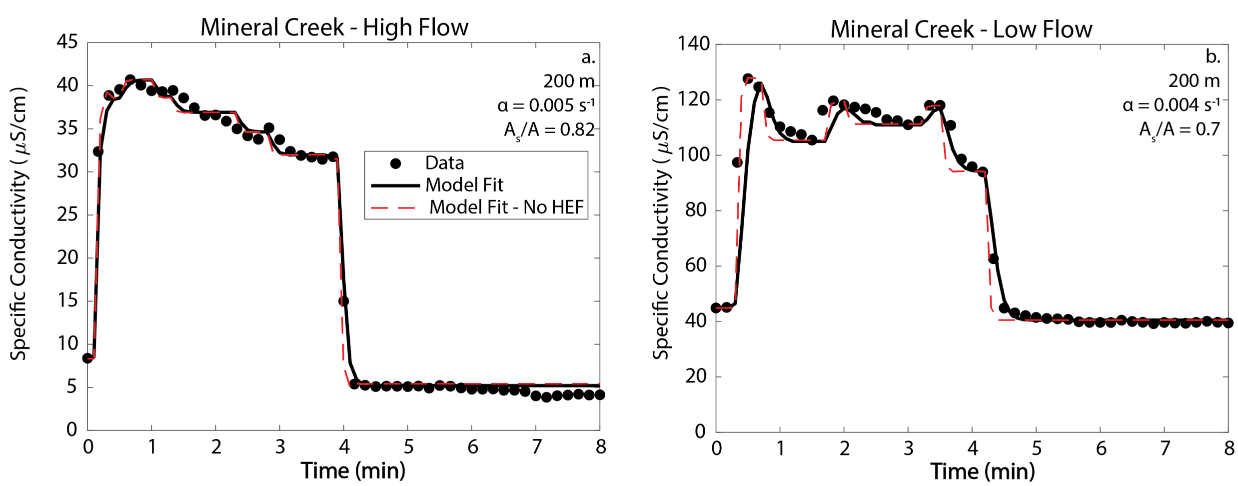

Figure A3. Model fits from OTIS with PEST (solid black lines) and fluid electrical conductivity (black circles) measured 200 m downstream of the tracer injection site in Mineral Creek. Red dashed lines represent model fits when hyporheic exchange has negligible effects (e.g. $\alpha = 1.00 \times 10^{-20}\ s^{-1}$ and $A_s = 1.00$

x 10^{-20} m^2). Conductivity presented here was adjusted for background (i.e. the upstream fluid conductivity was subtracted from conductivity measurements made downstream of the injection).

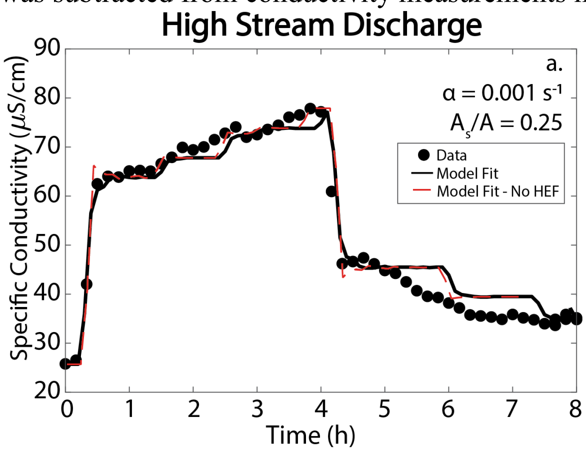

Figure A4. Model fits from OTIS with PEST (solid black lines) and fluid electrical conductivity (black circles) measured 200 m downstream of the tracer injection site in Cement Creek. Red dashed lines represent model fits when hyporheic exchange has negligible effects (e.g. $\alpha = 1.00 \times 10^{-20}$ s^{-1} and $A_s = 1.00 \times 10^{-20}$ m^2). Conductivity presented here was adjusted for background (i.e. the upstream fluid conductivity was subtracted from conductivity measurements made downstream of the injection).

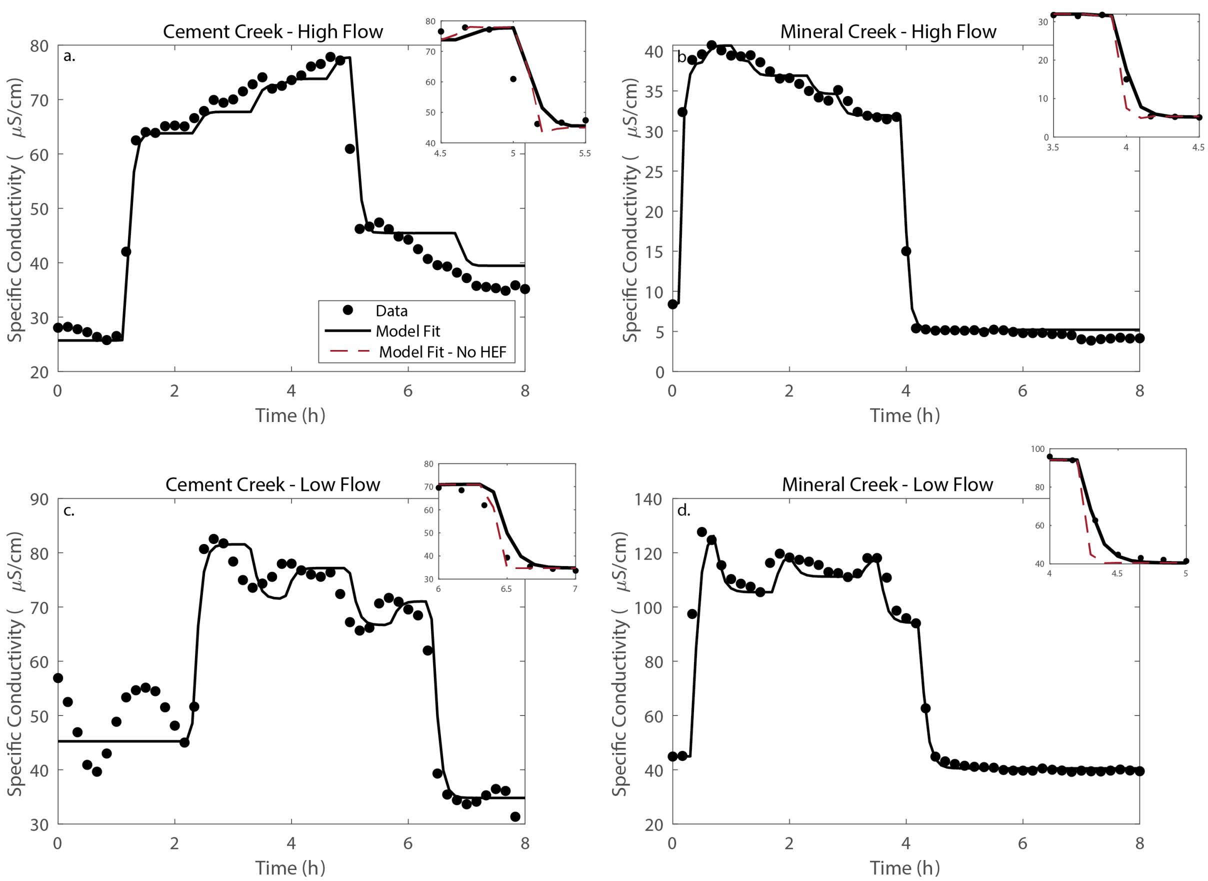

Figure A5. Same model fits as in figures A3 and A4 that includes a comparison of the no exchange simulation (red dashed lines) to the best fit hyporheic exchange model (solid black) line in the insets. The insets only highlight the falling limb of the breakthrough curve.

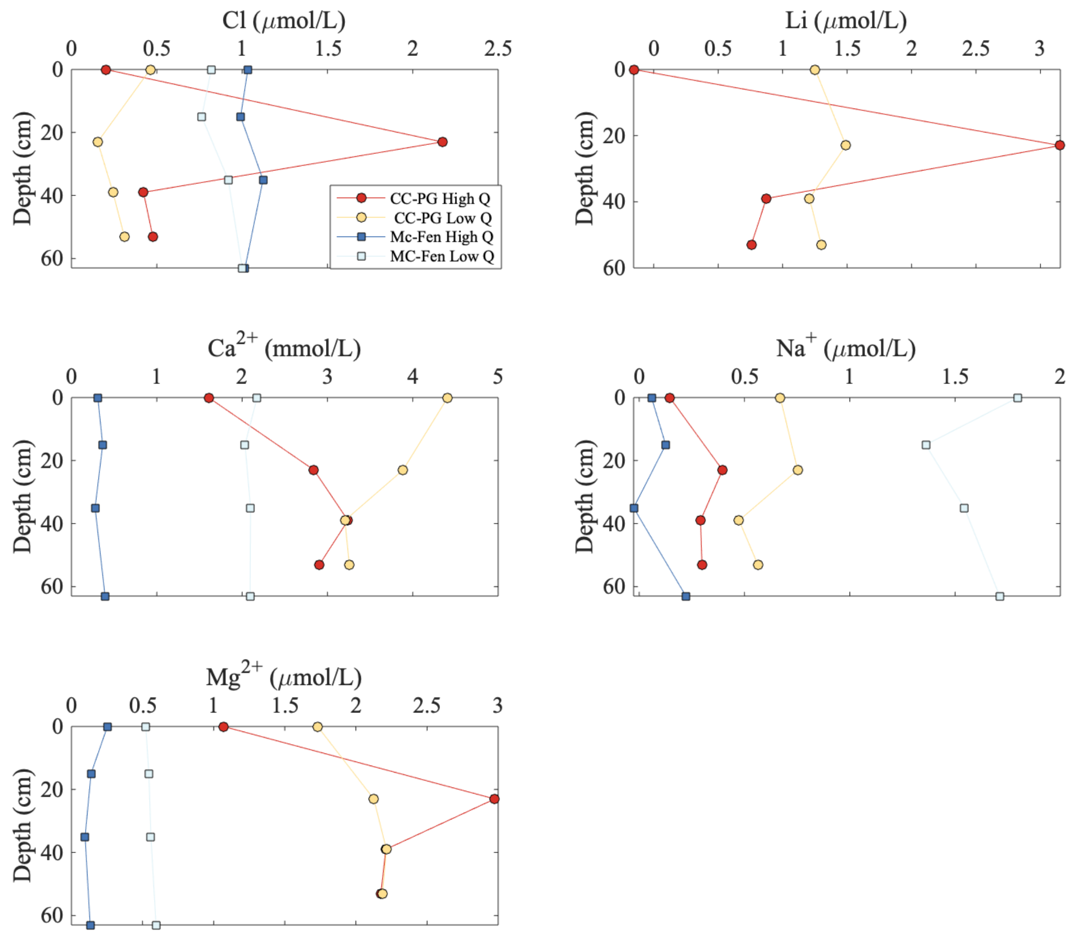

Figure A6. Depth profiles for conservative elements in the hyporheic zone well clusters at MC-Fen (blue squares) and CC-PG (red and yellow circles). Samples presented here were collected during high and low streamflow in 2019.

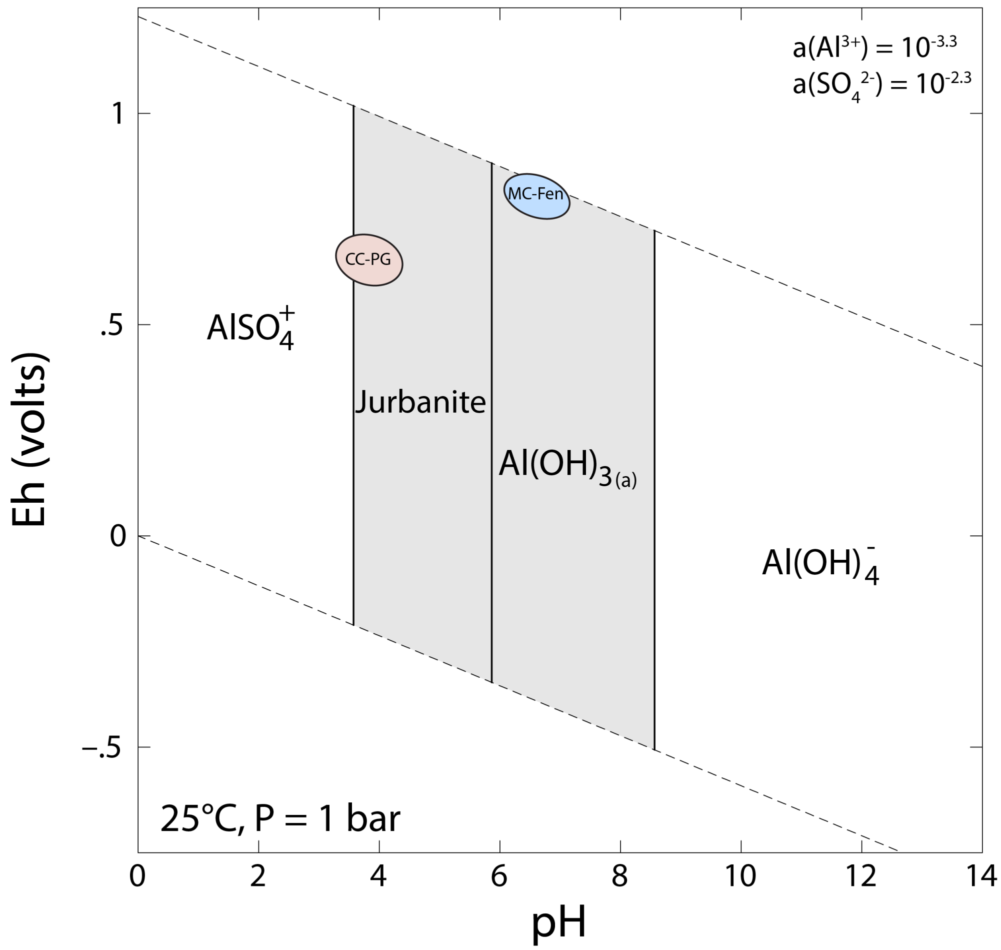

Figure A7. Eh-pH diagram calculated in Geochemist's Workbench for dissolved Al and Al-bearing minerals. Colored circles represent the range of measured pH and Eh values calculated at high and low from the hyporheic zone well clusters in 2019.

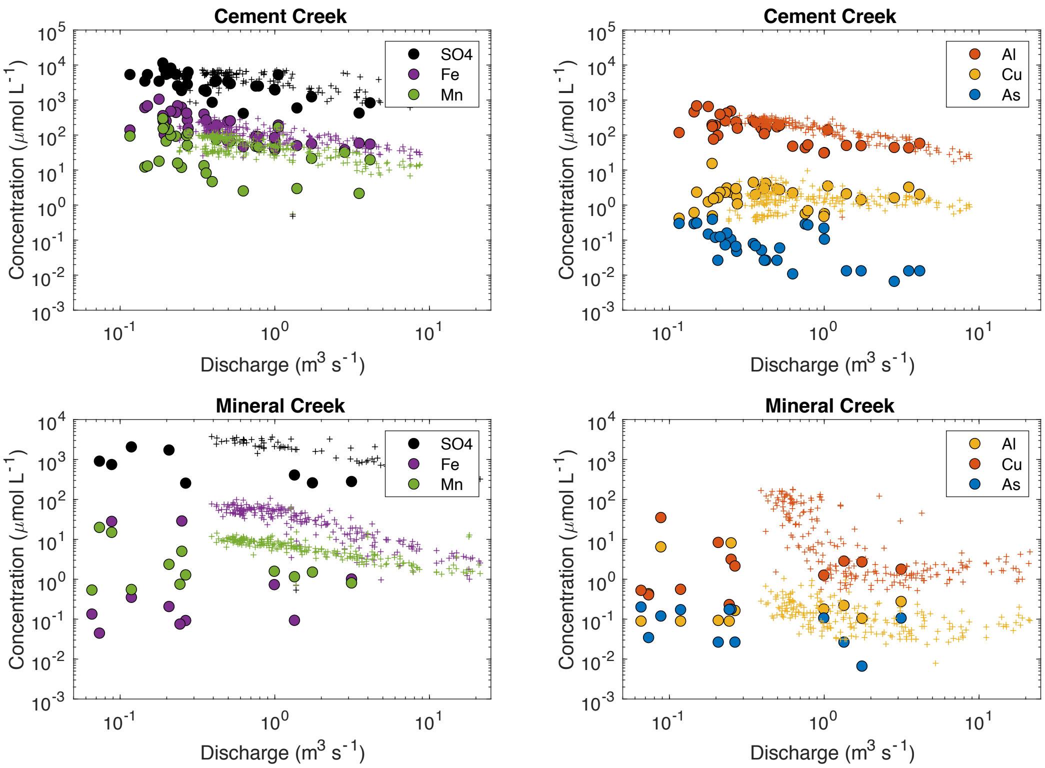

Figure A8. Concentration-discharge relationships for Cement Creek and Mineral Creek in log-log space. Solid circles represent samples collected at CC-PG and MC-Fen, including new and historical data. Crosses represent historical data compiled by the Animas River Stakeholders Group at USGS stream gages located at the outlets of Cement and Mineral Creeks (CC48 and MC34).

1.2 Supplementary Tables

Table A1. Stream measurements and tracer test conditions for the high and low discharge tracer tests at Mineral Creek.

	Cement Creek		Mineral Creek	
	July 31, 2019[a]	September 21, 2019	1-Aug-19	28-Sep-19
Streamflow (m3/s)	1.34	0.184	2.2	0.1
Stream Width (m)	6.7	5.6	8.1	5
Mean Stream Depth (m)	0.32	0.12	0.35	0.14
Stream Area (m^2)	1.6	0.6	2.7	0.86
pH	4.6	3.6	6.9	6.5
Temperature (°C)	8.2	6.2	8.9	9.6
Background Stream Electrical Conductivity (µS/cm)	288	601	120	450
Average increase in EC after injection (µS/cm)	30	45	30	75

[a] Slug tests for hydraulic conductivity were conducted on June 10, 2020 at high flow. All other measurements made on July 31.

[b] Values represent duplicate slug tests.

Table A2. Vertical hydraulic gradients at high and low flow in Cement Creek and Mineral Creek well clusters.

Date	**Time**	**Flow Regime**	**Depth to bottom of screen (m)**	**Water Level (mbgl)[a]**	**Height of water above screen, hp (m)**	**Hydraulic head, h, (m)**	**Vertical Hydrauli c Gradient (Deep)**	**Vertial Hydrauli c Gradient (Shallow)**
			z		*hp*	*h*	*dh/dz*	*dh/dz*
			Mineral Creek					
6/20/19	15:00	High Flow	0.27	-0.18	0.45	0.71	1.10	2.50
			0.39	-0.24	0.63	1.02		
			0.60	-0.21	0.81	1.41		
9/27/19	10:30	Low Flow	0.27	0.08	0.19	0.45	1.18	2.49
			0.39	0.02	0.37	0.76		
			0.60	0.02	0.58	1.18		
			Cement Creek (from Rickel et al.,n.d.)					
7/18/19	17:00	High Flow	0.28	-0.24	0.52	0.8	1.18	2.25
			0.4	-0.21	0.61	1.01		
			0.58	-0.185	0.765	1.345		
7/31/19	9:30	High Flow	0.28	-0.155	0.435	0.715	1.14	1.95
			0.39	-0.16	0.55	0.94		
			0.58	-0.113	0.693	1.273		
9/21/19	16:20	Low Flow	0.28	-0.08	0.36	0.64	0.93	1.92
			0.4	-0.09	0.49	0.89		
			0.58	-0.1	0.68	1.26		

[a]Negative value indicates water level in the well is higher than the streambed.

Table A3. Hydraulic conductivity estimates based on slug test data and two high permeability models.

Site	Well Depth (cm)	Date	Stream Discharge ($m^3 s^{-1}$)	High-K Bouwer & Rice Model (m/s)	High-K Hvorslev Model (m/s)
Cement Creek at Prospect Gulch	44	9/22/19	0.18	4×10^{-5}	5×10^{-5}
		11/11/19	0.19	5×10^{-5}	7×10^{-5}
		6/10/20	0.94	7×10^{-5}	1×10^{-4}
				9×10^{-5}	1×10^{-4}
Mineral Creek	68	9/28/19	0.11	9×10^{-5}	1×10^{-4}
		6/9/20	1.50	1×10^{-4}	1×10^{-4}
				9×10^{-5}	1×10^{-4}

[a] Measurements from September and June 2019 for Cement Creek previously published in Rickel et al., n.d.

Table A4. Saturation indices of Ca- and Na-bearing minerals calculated in PHREEQC.

Site	Depth	Flow Regime	Calcite	Albite	Anhydrite
Cement Creek	0	High Flow 2019	-4.13	-7.60	-1.57
	23		-1000	-7.28	-1.18
	39		-1000	-7.91	-1.07
	53		-1000	-8.81	-1.14
	0	Low Flow 2019	-1000	-13.7	-0.89
	23		-1000	-11.0	-0.95
	39		-1000	-10.1	-1.02
	53		-1000	-10.5	-1.04
	0	High Flow 2020	-1000	-6.96	-1.66
	23		-1000	-9.25	-1.30
	39		-1000	-7.23	-1.15
	53		-1000	-8.83	-1.23
Mineral Creek	0	High Flow 2019	-3.34	-4.64	-2.89
	15		-2.86	-4.08	-2.77
	35		-2.74	-4.90	-2.97
	63		-2.80	-4.27	-2.75
	0	Low Flow 2019	-2.37	-4.95	-1.44
	15		-2.05	-5.55	-1.45
	35		-2.15	-4.90	-1.37
	63		-2.19	-6.08	-1.44
	0	High Flow 2020	-2.23	-4.56	-2.84
	15		-2.21	-4.36	-2.70
	35		-2.21	-4.86	-2.83
	63		-2.08	-5.16	-2.72

Table A5. Hyporheic zone chemistry sampled from hyporheic zone well clusters during high and low flow conditions.

Flow Regime	Depth cm	Fraction	pH	DO mg/L	Alkalinity mg/L $CaCO_3$	Fe^{2+a} mg/L	Al uM	As uM	Co uM	Cu uM	Fe uM	Mn uM	Ni uM	Pb uM	SO_4^{2-} uM	Zn^{213} uM
					Cement Creek at Prospect Gulch											
High Flow (July 31, 2019)	0	Unfiltered	4.60	8.7	11.7	1.25	51.1	0.21	0.20	0.67	85.7	38.4	0.03	0.13	NA	15.7
	28		3.93	7.6	0	1.47	319	0.30	0.29	0.09	427	42.6	0.10	0.07	NA	3.77
	44		3.78	1.1	0	> 3	521	0.44	0.66	0.09	970	23.4	0.33	0.15	NA	13.2
	58		3.61	1.7	0	> 3	496	0.47	0.60	0.09	861	27.8	0.29	0.18	NA	14.0
	0	< 0.2 µm					31.6	0.11	0.22	0.57	70.4	38.5	0.03	0.08	1.98	15.9
	28						313	0.22	0.27	0.09	408	42.3	0.05	0.07	4.36	3.75
	44						535	0.37	0.66	0.09	927	23.3	0.34	0.10	5.57	13.3
	58						463	0.33	0.59	0.09	717	27.0	0.28	0.11	4.93	13.6
Low Flow (Sept 21, 2019)	0	Unfiltered	3.56	3.7	0	> 3	156	0.42	0.40	0.65	243	115	0.23	0.11	NA	38.3
	28		4.04	2.0	0	> 3	326	0.40	0.43	0.97	263	89.6	0.26	0.51	NA	27.8
	44		3.99	2.2	0	> 3	542	0.34	0.59	0.09	939	29.5	0.38	0.12	NA	15.0
	58		3.90	8.3	0	2.6	550	0.54	0.62	0.19	858	47.5	0.41	0.12	NA	20.9
	0	< 0.2 µm					118	0.30	0.32	0.42	140	93.9	0.17	0.08	5.37	31.2
	28						304	0.26	0.50	1.13	225	77.5	0.30	0.48	5.40	31.5
	44						592	0.32	0.64	0.09	1010	33.4	0.45	0.07	5.82	16.8
	58						546	0.37	0.60	0.16	792	45.8	0.38	0.11	5.99	20.0
High Flow (June 10, 2020)	0	Unfiltered	4.69	9.1	0.0	1.7	43.1	0.3	NA	0.89	73.7	28.9	0.12	< 0.02	NA	NA
	28		3.64	2.7	0.0	> 3.0	341	0.48	NA	0.23	473	22.9	0.28	0.11	NA	13.8
	44		4.11	2.7	0.0	2.7	659	0.66	NA	0.09	1206	22.8	0.52	< 0.02	NA	14.3
	58		3.89	2.0	0.0	> 3.0	525	0.63	NA	0.09	850	25.3	0.44	< 0.02	NA	16.0
	0	< 0.2 µm					32.8	0.19	NA	0.49	48.7	16.9	0.09	< 0.02	1.71	9.7
	28						319	0.33	NA	0.27	428	23.9	0.31	0.14	3.77	13.2
	44						452	0.53	NA	0.09	818	15.1	0.37	< 0.02	5.88	9.60
	58						277	0.51	NA	0.09	431	14.2	0.25	< 0.02	4.57	8.29

Flow Regime	Depth	Fraction	pH	DO	Alkalinity	Fe^{2+a}	Al	As	Co	Cu	Fe	Mn	Ni	Pb	SO_4^{2-}	Zn^{213}
	cm			mg/L	mg/L $CaCO_3$	mg/L	uM	uM	uM	uM	uM	uM	uM	uM	uM	uM
							Mineral Creek at Chattanooga Fen									
High Flow (June 20, 2019)	0	Unfiltered	6.17	10	N.A.	N.A.	3.82	0.11	0.02	0.35	4.68	0.93	0.03	0.06	NA	2.34
	20		6.48	6.4	11.4	0.03	6.27	0.11	0.03	0.76	18.0	2.99	0.03	0.13	NA	3.46
	40		6.62	7.4	12.3	0.14	2.08	0.18	0.02	0.29	3.68	0.46	0.03	0.02	NA	2.79
	68		6.42	9.1	11.9	0.06	41.9	0.25	0.19	3.86	127	18.5	0.03	1.23	NA	6.06
	0	< 0.2 µm					1.79	0.11	0.02	0.28	1.02	0.81	0.03	0.02	0.28	2.31
	20						0.59	0.11	0.02	0.19	0.26	0.04	0.03	0.02	0.32	2.78
	40						0.32	0.11	0.02	0.12	0.14	0.00	0.03	0.02	0.32	1.96
	68						0.58	0.12	0.02	0.13	0.29	0.30	0.03	0.02	0.32	1.68
Low Flow (Sept 27, 2019)	0	Unfiltered	6.18	9	15.6	0.05	0.60	0.16	0.02	0.09	0.33	0.52	0.03	0.04	NA	3.09
	20		6.53	8.7	14	0.02	1.03	0.19	0.02	0.09	3.27	0.43	0.03	0.04	NA	7.14
	40		6.49	9.2	12.6	0.01	0.25	0.11	0.02	0.09	1.03	0.12	0.03	0.02	NA	6.02
	68		6.50	9.5	11.6	< 0.01	40.2	0.27	0.09	3.81	87.0	9.73	0.03	0.98	NA	10.9
	0	< 0.2 µm					0.56	0.17	0.02	0.09	0.35	0.55	0.03	0.02	2.07	3.59
	20						0.04	0.19	0.02	0.09	0.08	0.01	0.03	0.02	2.13	6.67
	40						0.04	0.24	0.02	0.09	0.25	0.03	0.03	0.03	2.00	6.07
	68						0.04	0.18	0.02	0.09	0.06	0.05	0.03	0.02	2.16	6.28
High Flow (June 27, 2019)	0	Unfiltered	7.36	6.8	8.3	0	3.15	0.17	NA	0.20	3.60	1.05	0.04	0.05	NA	2.50
	20		7.17	8.3	9.8	0	0.77	<0.11	NA	<0.15	1.19	0.09	0.03	<0.02	NA	3.43
	40		7.19	7.8	9.2	0	<0.15	<0.11	NA	<0.15	0.34	<0.01	<0.02	<0.02	NA	2.14
	68		7.20	6.8	10.2	0	3.53	0.17	NA	0.46	7.10	0.83	0.04	0.10	NA	2.44
	0	< 0.2 µm					0.67	0.14	NA	<0.15	0.58	0.57	<0.02	<0.02	0.36	1.55
	20						<0.15	0.16	NA	<0.15	0.23	<0.01	<0.02	<0.02	0.33	3.35
	40						<0.15	<0.11	NA	<0.15	0.09	<0.01	<0.02	<0.02	0.30	2.02
	68						<0.15	<0.11	NA	<0.15	0.10	<0.01	0.03	<0.02	0.33	1.93
		Det Limit					*0.04*	*0.11*	*0.02*	*0.09*	*0.03*	*0.00*	*0.02*	*0.02*	*0.46*	*0.04*