

Supporting Information

Lagrangian Mass-Flow Investigations of Inorganic Contaminants in Wastewater-Impacted Streams

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This 20 page supporting information section includes three tables and five figures summarizing hydrological and chemical data from Boulder Creek, Colorado and Fourmile Creek, Iowa for the summer 2003 and spring 2005 Lagrangian samplings.

Table SI-1. Summary of dissolved concentration and load data for inorganic constituents measured in Boulder Creek, Colorado (BC) and Fourmile Creek, Iowa (FC) during the summer 2003 Lagrangian samplings. [Full details on analytical methods and all chemical results are presented in Barber and others (*1*); U, upstream from the wastewater treatment plant (WWTP); E, WWTP effluent; D1 and D2, downstream from the WWTP; major cations (calcium, magnesium, potassium, and sodium), major anions (alkalinity, chloride, fluoride, and sulfate), nutrients (ammonia, nitrite, nitrate, and orthophosphate), iron, and silica were measured at the U.S. Geological Survey (USGS) National Water Quality Laboratory (Denver, Colorado) and were determined as single measurements; suspended sediments were measured at the USGS Iowa Sediment Laboratory (Iowa City, Iowa) and were determined as single measurements; trace elements were determined at the USGS National Research Laboratory (Boulder, Colorado) and measurements are reported as the average and standard deviation for analysis of replicate (n=3) composite samples; --, not calculated.]

	Unit	BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Date		9/3/2003	9/3/2003	9/3/2003	9/3/2003	8/5/2003	8/5/2003	8/5/2003	8/6/2003
Time		830	915	1215	1540	1130	1245	1845	700
Distance	km	-0.1	0	3.6	7.4	-0.1	0	2.9	8.4
Discharge	m ³ s ⁻¹	1.62	0.92	2.41	1.84	0.04	0.14	0.17	0.16
Constituent									
Alkalinity	mg/L CaCO ₃	47	130	67	68	190	140	150	160
Alkalinity Load	kg/d	6,600	10,200	13,900	10,800	560	1,700	2,200	2,300
Aluminum Average	µg/L	4.9	13.0	6.6	5.8	0.9	10.8	3.3	1.2
Aluminum Standard Deviation	µg/L	2.5	1.2	0.2	0.1	0.1	0.3	0.6	0.6
Aluminum Load	g/d	680	1,050	1,380	920	2.6	130	48	17
Ammonium	mg/L N	< 0.04	8.5	1.4	0.79	< 0.04	0.31	0.15	0.03
Ammonium Load	kg/d N	--	680	290	130	--	3.9	2.2	0.4
Antimony Average	µg/L	0.10	0.25	0.14	0.15	0.30	0.56	0.51	0.50
Antimony Standard Deviation	µg/L	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00
Antimony Load	g/d	13	20	30	24	0.9	7.0	7.6	6.9
Arsenic Average	µg/L	0.40	0.40	0.48	0.59	1.7	1.1	1.7	2.3
Arsenic Standard Deviation	µg/L	0.01	0.01	0.01	0.02	0.0	0.0	0.0	0.0
Arsenic Load	g/d	56	33	100	94	5	14	25	33
Barium Average	µg/L	29	23	29	32	109	30	53	65
Barium Standard Deviation	µg/L	0	0	0	1	1	0	0	1
Barium Load	g/d	4,100	1,800	6,000	5,200	320	370	770	910

	Unit	BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Beryllium Average	µg/L	.005	0.003	0.004	0.003	0.003	< 0.003	0.003	0.003
Beryllium Standard Deviation	µg/L	0.001	--	--	--	0.000	--	0.000	--
Beryllium Load	g/d	0.6	0.2	0.7	0.4	0.009	--	0.04	0.04
Bismuth Average	µg/L	< 0.002	0.063	0.008	0.007	< 0.002	0.058	0.019	0.012
Bismuth Standard Deviation	µg/L	--	0.003	0.000	0.002	--	0.001	0.001	0.000
Bismuth Load	g/d	--	5.1	1.7	1.0	--	0.73	0.28	0.16
Boron Average	µg/L	20	196	76	78	77	297	251	242
Boron Standard Deviation	µg/L	0	3	1	1	1	7	1	1
Boron Load	g/d	2,700	15,800	15,800	12,400	230	3,700	3,700	3,400
Cadmium Average	µg/L	0.007	0.021	0.011	0.016	0.010	0.073	0.084	0.105
Cadmium Standard Deviation	µg/L	0.001	0.002	0.001	0.007	0.001	0.002	0.002	0.005
Cadmium Load	g/d	0.9	1.7	2.4	2.5	0.028	0.9	1.2	1.5
Calcium	mg/L	17	40	24	26	67	65	65	70
Calcium Load	kg/d	2,400	3,200	5,000	4,100	200	810	950	970
Cerium Average	µg/L	0.032	0.009	0.034	0.045	0.016	0.006	0.019	0.017
Cerium Standard Deviation	µg/L	0.004	0.001	0.001	0.023	0.000	0.001	0.000	0.001
Cerium Load	g/d	4.5	0.7	7.0	7.2	0.046	0.073	0.28	0.24
Cesium Average	µg/L	< 0.002	0.059	0.022	0.020	< 0.002	0.042	0.010	0.005
Cesium Standard Deviation	µg/L	--	0.002	0.001	0.001	--	0.002	0.000	0.001
Cesium Load	g/d	--	4.8	4.6	3.1	--	0.52	0.15	0.07
Chloride	mg/L	8.3	54	22	22	80	113	104	109
Chloride Load	kg/d	1,200	4,300	4,500	3,500	230	1,400	1,500	1,500
Chromium Average	µg/L	< 0.1	0.2	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1
Chromium Standard Deviation	µg/L	--	0.0	--	--	--	0.0	--	--
Chromium Load	g/d	--	18	--	--	--	3	--	--
Cobalt Average	µg/L	0.016	0.27	0.11	0.12	0.19	0.26	0.46	0.63
Cobalt Standard Deviation	µg/L	0.002	0.01	0.00	0.00	0.01	0.00	0.01	0.01
Cobalt Load	g/d	2.2	22	23	19	0.57	3.3	6.7	8.8
Copper Average	µg/L	1.5	8.4	2.8	2.6	1.7	4.4	4.4	4.5

	Unit	BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Copper Standard Deviation	µg/L	0.2	0.3	0.1	0.0	0.0	0.2	0.0	0.0
Copper Load	g/d	210	680	580	410	4.9	55	64	62
Dysprosium Average	µg/L	0.003	0.003	0.004	0.005	0.006	0.002	0.007	0.008
Dysprosium Standard Deviation	µg/L	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.001
Dysprosium Load	g/d	0.5	0.2	0.7	0.7	0.02	0.03	0.10	0.11
Erbium Average	µg/L	0.0024	0.0032	0.0029	0.0033	0.0045	0.0019	0.0042	0.0059
Erbium Standard Deviation	µg/L	0.0004	0.0003	0.0002	0.0007	0.0001	0.0002	0.0002	0.0004
Erbium Load	g/d	0.33	0.26	0.60	0.52	0.013	0.024	0.062	0.082
Europium Average	µg/L	0.0008	0.0004	0.0010	0.0009	0.0014	0.0003	0.0008	0.0010
Europium Standard Deviation	µg/L	0.0002	0.0002	0.0002	0.0002	0.0011	0.0000	0.0003	0.0004
Europium Load	g/d	0.11	0.03	0.21	0.14	0.004	0.004	0.012	0.014
Fluoride	mg/L	0.2	1.0	0.4	0.5	0.4	1.0	0.8	0.8
Fluoride Load	kg/d	28	81	83	80	1.2	12	12	11
Gadolinium Average	µg/L	0.005	0.15	0.045	0.041	0.007	0.057	0.051	0.054
Gadolinium Standard Deviation	µg/L	0.001	0.00	0.003	0.002	0.001	0.002	0.001	0.000
Gadolinium Load	g/d	0.6	11.8	9.3	6.6	0.02	0.71	0.75	0.76
Holmium Average	µg/L	0.0008	0.0009	0.0009	0.0010	0.0014	0.0005	0.0012	0.0020
Holmium Standard Deviation	µg/L	0.0000	0.0001	0.0001	0.0002	0.0001	0.0000	0.0000	0.0001
Holmium Load	g/d	0.11	0.07	0.18	0.16	0.004	0.006	0.018	0.028
Iron	µg/L	25	61	36	31	< 8	79	22	14
Iron Load	g/d	3,500	4,900	7,500	4,900	--	990	320	200
Lanthanum Average	µg/L	0.022	0.009	0.022	0.027	0.014	0.004	0.013	0.012
Lanthanum Standard Deviation	µg/L	0.003	0.000	0.001	0.010	0.001	0.000	0.000	0.001
Lanthanum Load	g/d	3.1	0.7	4.6	4.2	0.04	0.05	0.19	0.17
Lead Average	µg/L	< 0.09	0.37	0.19	0.25	0.16	0.71	0.51	0.46
Lead Standard Deviation	µg/L	--	0.01	0.01	0.12	0.07	0.04	0.01	0.01
Lead Load	g/d	--	30	39	39	0.5	8.8	7.5	6.4
Lithium Average	µg/L	3.9	11.5	6.2	7.1	11	18	16	16
Lithium Standard Deviation	µg/L	0.0	0.3	0.0	0.1	0	0	0	0
Lithium Load	g/d	540	930	1,300	1,100	32	220	240	220

	Unit	BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Lutetium Average	µg/L	0.0004	0.0012	0.0007	0.0009	0.0012	0.0010	0.0013	0.0016
Lutetium Standard Deviation	µg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.0002
Lutetium Load	g/d	0.06	0.09	0.15	0.14	0.004	0.013	0.019	0.023
Magnesium	mg/L	5.3	14	7.9	11	30	23	24	25
Magnesium Load	kg/d	740	1,200	1,600	1,700	89	280	350	340
Manganese Average	µg/L	10	35	18	14	10	42	40	13
Manganese Standard Deviation	µg/L	0	0	0	0	0	0	0	0
Manganese Load	g/d	1,400	2,800	3,700	2,200	30	520	590	180
Molybdenum Average	µg/L	0.8	4.2	1.8	1.9	3.1	7.3	6.6	6.5
Molybdenum Standard Deviation	µg/L	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1
Molybdenum Load	g/d	110	340	380	310	9.0	91	97	90
Neodymium Average	µg/L	0.024	0.006	0.024	0.029	0.018	0.005	0.017	0.020
Neodymium Standard Deviation	µg/L	0.002	0.000	0.000	0.008	0.001	0.000	0.001	0.001
Neodymium Load	g/d	3.4	0.5	4.9	4.6	0.05	0.07	0.26	0.27
Nickel Average	µg/L	0.3	2.1	0.9	0.9	2.0	3.6	3.8	4.6
Nickel Standard Deviation	µg/L	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Nickel Load	g/d	40	170	180	140	5.8	45	56	65
Nitrate	mg/L N	0.095	7.6	2.6	2.7	3.2	13.9	10.7	10.2
Nitrate Load	kg/d N	13	620	540	440	9.4	170	160	140
Nitrite	mg/L N	0.005	0.57	0.30	0.34	0.045	0.25	0.20	0.22
Nitrite Load	kg/d N	0.7	46	61	54	0.13	3.2	2.9	3.1
Orthophosphate	mg/L P	< 0.007	2.7	0.71	0.55	0.006	5.1	3.8	3.9
Orthophosphate Load	kg/d P	--	220	150	88	0.02	64	55	55
Potassium	mg/L	1.0	9.7	3.6	3.5	2.9	12.9	10.3	9.5
Potassium Load	kg/d	140	780	740	560	8.5	160	150	130
Praseodymium Average	µg/L	0.0056	0.0013	0.0054	0.0066	0.0036	0.0011	0.0036	0.0040
Praseodymium Standard Deviation	µg/L	0.0006	0.0001	0.0001	0.0027	0.0001	0.0000	0.0003	0.0002
Praseodymium Load	g/d	0.78	0.10	1.1	1.1	0.011	0.013	0.053	0.055

	Unit	BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Rhenium Average	µg/L	0.0095	0.031	0.016	0.017	0.029	0.056	0.050	0.050
Rhenium Standard Deviation	µg/L	0.0004	0.001	0.000	0.000	0.001	0.002	0.001	0.002
Rhenium Load	g/d	1.3	2.5	3.4	2.8	0.08	0.70	0.73	0.70
Rubidium Average	µg/L	0.77	6.7	2.6	2.5	1.0	8.2	6.1	5.4
Rubidium Standard Deviation	µg/L	0.01	0.1	0.0	0.0	0.0	0.0	0.1	0.0
Rubidium Load	g/d	110	540	550	400	2.9	102	89	75
Samarium Average	µg/L	0.0048	0.0018	0.0051	0.0059	0.0052	0.0013	0.0043	0.0054
Samarium Standard Deviation	µg/L	0.0008	0.0002	0.0005	0.0015	0.0006	0.0001	0.0005	0.0002
Samarium Load	g/d	0.66	0.14	1.05	0.94	0.015	0.016	0.063	0.076
Selenium Average	µg/L	0.17	< 0.04	< 0.04	< 0.04	1.0	1.1	1.1	1.0
Selenium Standard Deviation	µg/L	0.02	--	--	--	0.0	0.1	0.0	0.1
Selenium Load	g/d	24	--	--	--	3.0	13	16	14
Silica	mg/L	4.3	9.3	5.7	5.6	6.7	18	14	14
Silica Load	kg/d	600	750	1,180	890	20	220	200	190
Sodium	mg/L	7.3	52	21	21	31	79	68	65
Sodium Load	kg/d	1,000	4,200	4,300	3,400	92	990	990	910
Strontium Average	µg/L	155	326	213	249	203	187	195	194
Strontium Standard Deviation	µg/L	1	6	3	2	2	3	4	2
Strontium Load	g/d	22,000	26,000	44,000	40,000	600	2,300	2,900	2,700
Sulfate	mg/L	21	80	37	43	41	80	71	73
Sulfate Load	kg/d	2,900	6,400	7,800	6,800	120	990	1,040	1,020
Suspended Sediment	mg/L	11	4	13	5	111	5	34	21
Suspended Sediment Load	kg/d	1,600	380	2,900	560	5,900	130	2,700	1,600
Tellurium Average	µg/L	< 0.004	0.006	< 0.004	< 0.004	0.007	0.006	0.007	0.006
Tellurium Standard Deviation	µg/L	--	--	--	--	0.001	--	--	0.000
Tellurium Load	g/d	--	0.5	--	--	0.02	0.07	0.10	0.09
Terbium Average	µg/L	0.0005	0.0003	0.0006	0.0008	0.0010	0.0003	0.0010	0.0012
Terbium Standard Deviation	µg/L	0.0000	0.0001	0.0000	0.0002	0.0001	0.0000	0.0001	0.0001
Terbium Load	g/d	0.07	0.03	0.13	0.12	0.003	0.004	0.014	0.017

	Unit	BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Thallium Average	µg/L	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Thallium Standard Deviation	µg/L	--	--	--	--	--	--	--	--
Thallium Load	g/d	--	--	--	--	--	--	--	--
Thorium Average	µg/L	0.0044	0.0038	0.0046	0.0067	0.0015	0.0042	0.0025	0.0015
Thorium Standard Deviation	µg/L	0.0001	0.0008	0.0003	0.0025	0.0006	0.0014	0.0004	0.0002
Thorium Load	g/d	0.61	0.31	0.96	1.07	0.0044	0.053	0.037	0.021
Thulium Average	µg/L	0.0004	0.0005	0.0005	0.0007	0.0008	0.0004	0.0006	0.0011
Thulium Standard Deviation	µg/L	0.0001	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0000
Thulium Load	g/d	0.05	0.04	0.11	0.10	0.0023	0.0054	0.0095	0.015
Tungsten Average	µg/L	0.18	0.23	0.21	0.22	0.01	< 0.01	0.01	0.01
Tungsten Standard Deviation	µg/L	0.00	0.01	0.01	0.01	0.00	--	0.00	0.00
Tungsten Load	g/d	24	19	44	36	0.03	--	0.09	0.12
Uranium Average	µg/L	0.68	0.91	0.81	1.17	4.2	0.5	1.5	1.4
Uranium Standard Deviation	µg/L	0.01	0.00	0.00	0.02	0.0	0.0	0.0	0.0
Uranium Load	g/d	95	74	170	190	12	6.1	22	19
Vanadium Average	µg/L	< 0.2	0.4	0.3	0.5	1.9	0.5	1.6	2.2
Vanadium Standard Deviation	µg/L	--	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Vanadium Load	g/d	--	30	73	87	5.5	5.7	24	30
Ytterbium Average	µg/L	0.0026	0.0055	0.0038	0.0046	0.0059	0.0036	0.0058	0.0080
Ytterbium Standard Deviation	µg/L	0.0002	0.0003	0.0001	0.0003	0.0006	0.0003	0.0005	0.0006
Ytterbium Load	g/d	0.37	0.44	0.79	0.73	0.017	0.045	0.085	0.111
Yttrium Average	µg/L	0.020	0.019	0.023	0.027	0.044	0.019	0.043	0.060
Yttrium Standard Deviation	µg/L	0.001	0.000	0.000	0.005	0.000	0.001	0.000	0.002
Yttrium Load	g/d	2.8	1.5	4.9	4.3	0.13	0.23	0.63	0.83
Zinc Average	µg/L	2.0	24	7.9	7.4	1.6	41	32	27
Zinc Standard Deviation	µg/L	1.2	0	0.3	0.5	0.1	1	1	0
Zinc Load	g/d	280	1,900	1,600	1,200	5	510	470	380
Zirconium Average	µg/L	0.042	0.13	0.034	0.047	0.052	0.074	0.052	0.051
Zirconium Standard Deviation	µg/L	0.036	0.02	0.004	0.009	0.003	0.003	0.002	0.004
Zirconium Load	g/d	5.9	10.2	7.1	7.4	0.15	0.92	0.77	0.71

Table SI-2. Summary of dissolved concentration and load data for inorganic constituents measured in Boulder Creek, Colorado (BC) and Fourmile Creek, Iowa (FC) during the spring 2005 Lagrangian samplings. [Full details on analytical methods and all chemical results are presented in Barber and others (*1*); U, upstream from the wastewater treatment plant (WWTP); E, WWTP effluent; D1 and D2, downstream from the WWTP; major cations (calcium, magnesium, potassium, and sodium), major anions (alkalinity, chloride, fluoride, and sulfate), nutrients (ammonia, nitrite, nitrate, and orthophosphate), iron, and silica were measured at the U.S. Geological Survey (USGS) National Water Quality Laboratory (Denver, Colorado) and were determined as single measurements; suspended sediments were measured at the USGS Iowa Sediment Laboratory (Iowa City, Iowa) and were determined as single measurements; trace elements were determined at the USGS National Research Laboratory (Boulder, Colorado) and measurements are reported as the average and standard deviation for analysis of replicate (n=4) composite samples; --, not calculated.]

Unit		BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Date		4/19/2005	4/19/2005	4/19/2005	4/19/2005	3/8/2005	3/8/2005	3/8/2005	3/8/2005
Time		855	900	1145	1630	740	745	1120	1540
Distance	km	-0.1	0	3.6	7.4	-0.1	0	2.9	8.4
Discharge	m ³ s ⁻¹	1.69	1.11	2.60	1.29	0.62	0.24	0.92	0.90
Constituent									
Alkalinity	mg/L CaCO ₃	69	136	91	92	283	183	272	281
Alkalinity Load	kg/d	10,000	13,000	20,000	10,000	15,000	4,700	21,000	22,000
Aluminum Average	µg/L	2.9	22	8.2	6.4	0.86	9.1	1.8	0.69
Aluminum Standard Deviation	µg/L	0.1	1	0.3	0.8	0.22	0.2	0.7	0.24
Aluminum Load	g/d	420	2,100	1,800	710	46	230	140	54
Ammonium	mg/L N	< 0.04	8.6	2.8	1.3	< 0.04	0.12	< 0.04	< 0.04
Ammonium Load	kg/d N	--	820	630	150	--	3.1	--	--
Antimony Average	µg/L	0.14	0.24	0.18	0.17	0.13	0.51	0.21	0.18
Antimony Standard Deviation	µg/L	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01
Antimony Load	g/d	20	23	40	19	7.0	13	17	14
Arsenic Average	µg/L	0.43	0.45	0.50	0.57	1.06	1.03	1.05	1.10
Arsenic Standard Deviation	µg/L	0.01	0.02	0.01	0.03	0.04	0.01	0.09	0.03
Arsenic Load	g/d	63	43	113	63	57	26	83	86
Barium Average	µg/L	48	39	45	45	116	43	101	101
Barium Standard Deviation	µg/L	1	1	1	1	4	0	2	2
Barium Load	g/d	7,100	3,700	10,000	5,000	6,200	1,100	8,000	7,900

Unit		BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Beryllium Average	µg/L	< 0.009	< 0.009	0.014	< 0.009	< 0.009	< 0.009	< 0.009	< 0.009
Beryllium Standard Deviation	µg/L	--	--	--	--	--	--	--	--
Beryllium Load	g/d	--	--	3.0	--	--	--	--	--
Bismuth Average	µg/L	< 0.003	0.115	0.017	0.012	0.001	0.046	0.004	< 0.003
Bismuth Standard Deviation	µg/L	--	0.004	0.001	0.002	--	0.001	0.001	--
Bismuth Load	g/d	--	11.0	3.7	1.3	0.04	1.18	0.32	--
Boron Average	µg/L	32	241	108	94	29	259	78	61
Boron Standard Deviation	µg/L	2	3	4	2	1	4	1	1
Boron Load	g/d	4,800	23,000	24,000	10,000	1,600	6,600	6,200	4,700
Cadmium Average	µg/L	0.006	0.033	0.016	0.017	0.011	0.045	0.024	0.026
Cadmium Standard Deviation	µg/L	0.001	0.002	0.002	0.003	0.002	0.001	0.001	0.003
Cadmium Load	g/d	0.9	3.2	3.5	1.9	0.6	1.1	1.9	2.1
Calcium	mg/L	24	56	38	38	114	108	108	113
Calcium Load	kg/d	3,600	5,400	8,500	4,300	6,100	2,800	8,600	8,800
Cerium Average	µg/L	0.092	0.015	0.070	0.070	0.026	0.005	0.018	0.018
Cerium Standard Deviation	µg/L	0.003	0.002	0.002	0.002	0.001	0.000	0.001	0.001
Cerium Load	g/d	14	1.4	16	7.8	1.4	0.12	1.4	1.4
Cesium Average	µg/L	< 0.003	0.18	0.075	0.082	< 0.003	0.023	< 0.003	< 0.003
Cesium Standard Deviation	µg/L	--	0.00	0.001	0.001	--	0.001	--	--
Cesium Load	g/d	--	17	17	9.1	--	0.58	--	--
Chloride	mg/L	32	75	47	43	49	121	64	59
Chloride Load	kg/d	4,700	7,100	10,600	4,800	2,600	3,100	5,000	4,600
Chromium Average	µg/L	< 0.4	0.5	< 0.4	0.5	< 0.4	1.0	0.5	< 0.4
Chromium Standard Deviation	µg/L	--	0.0	--	0.0	--	0.3	--	--
Chromium Load	g/d	--	45	--	52	--	25	41	--
Cobalt Average	µg/L	0.070	0.26	0.16	0.17	0.086	0.27	0.17	0.18
Cobalt Standard Deviation	µg/L	0.003	0.01	0.00	0.00	0.002	0.00	0.00	0.01
Cobalt Load	g/d	10	25	36	19	4.6	6.9	14	14
Copper Average	µg/L	1.6	14.9	5.4	4.3	1.2	2.0	1.2	1.3

Unit		BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Copper Standard Deviation	µg/L	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0
Copper Load	g/d	230	1,400	1,200	480	63	51	96	98
Dysprosium Average	µg/L	0.0088	0.0024	0.0066	0.0062	0.0067	0.0025	0.0051	0.0061
Dysprosium Standard Deviation	µg/L	0.0011	0.0009	0.0004	0.0011	0.0003	0.0001	0.0004	0.0002
Dysprosium Load	g/d	1.3	0.23	1.5	0.69	0.36	0.06	0.40	0.47
Erbium Average	µg/L	0.0057	0.0026	0.0050	0.0037	0.0043	0.0028	0.0041	0.0046
Erbium Standard Deviation	µg/L	0.0006	0.0005	0.0004	0.0003	0.0006	0.0004	0.0002	0.0005
Erbium Load	g/d	0.83	0.24	1.13	0.41	0.23	0.071	0.33	0.36
Europium Average	µg/L	0.0029	0.0009	0.0019	0.0022	0.0017	0.0010	0.0022	0.0021
Europium Standard Deviation	µg/L	0.0007	0.0004	0.0004	0.0002	0.0019	0.0004	0.0008	0.0005
Europium Load	g/d	0.43	0.08	0.42	0.25	0.088	0.026	0.17	0.17
Fluoride	mg/L	0.3	1.0	0.5	0.5	0.4	1.3	0.6	0.5
Fluoride Load	kg/d	44	96	112	56	20	33	45	37
Gadolinium Average	µg/L	0.011	0.14	0.062	0.048	0.007	0.26	0.060	0.034
Gadolinium Standard Deviation	µg/L	0.001	0.00	0.001	0.001	0.000	0.00	0.003	0.001
Gadolinium Load	g/d	1.6	14	14	5.3	0.4	6.6	4.7	2.7
Holmium Average	µg/L	0.0017	0.0008	0.0015	0.0016	0.0014	0.0007	0.0012	0.0014
Holmium Standard Deviation	µg/L	0.0001	0.0001	0.0004	0.0001	0.0001	0.0001	0.0002	0.0001
Holmium Load	g/d	0.24	0.08	0.34	0.18	0.073	0.019	0.092	0.111
Iron	µg/L	40	81	56	51	6.4	10	9.8	8.9
Iron Load	g/d	5,900	7,700	12,600	5,700	340	260	780	690
Lanthanum Average	µg/L	0.067	0.027	0.053	0.052	0.021	0.004	0.016	0.016
Lanthanum Standard Deviation	µg/L	0.004	0.001	0.001	0.002	0.001	0.000	0.001	0.001
Lanthanum Load	g/d	9.8	2.6	11.9	5.8	1.1	0.1	1.2	1.2
Lead Average	µg/L	0.071	0.52	0.24	0.24	0.014	0.32	0.082	0.051
Lead Standard Deviation	µg/L	0.004	0.01	0.00	0.06	0.001	0.01	0.002	0.008
Lead Load	g/d	10	50	54	27	0.8	8.1	6.5	4.0
Lithium Average	µg/L	9.5	14.2	11.1	11.3	9.0	13.8	10.4	10.1
Lithium Standard Deviation	µg/L	0.1	0.4	0.2	0.1	0.2	0.1	0.3	0.3
Lithium Load	g/d	1,400	1,400	2,500	1,300	480	350	820	790

Unit		BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Lutetium Average	µg/L	0.0011	0.0008	0.0011	0.0010	0.0009	0.0008	0.0008	0.0009
Lutetium Standard Deviation	µg/L	0.0001	0.0001	0.0001	0.0002	0.0001	0.0002	0.0001	0.0001
Lutetium Load	g/d	0.17	0.08	0.25	0.11	0.048	0.020	0.062	0.072
Magnesium	mg/L	10	19	14	15	33	32	32	33
Magnesium Load	kg/d	1,500	1,800	3,000	1,700	1,800	830	2,500	2,600
Manganese Average	µg/L	24	36	33	28	24	83	50	52
Manganese Standard Deviation	µg/L	1	0	1	1	0	1	1	1
Manganese Load	g/d	3,500	3,500	7,400	3,100	1,300	2,100	3,900	4,100
Molybdenum Average	µg/L	0.84	4.8	2.3	2.2	1.5	3.7	1.9	1.8
Molybdenum Standard Deviation	µg/L	0.03	0.2	0.1	0.1	0.0	0.1	0.1	0.0
Molybdenum Load	g/d	120	460	510	240	81	96	150	140
Neodymium Average	µg/L	0.067	0.006	0.050	0.053	0.023	0.005	0.019	0.019
Neodymium Standard Deviation	µg/L	0.004	0.001	0.003	0.001	0.000	0.001	0.001	0.002
Neodymium Load	g/d	9.8	0.6	11.1	6.0	1.2	0.1	1.5	1.5
Nickel Average	µg/L	0.54	2.0	1.1	1.0	0.39	5.5	1.5	1.2
Nickel Standard Deviation	µg/L	0.02	0.0	0.0	0.0	0.17	0.1	0.1	0.2
Nickel Load	g/d	80	190	240	110	21	140	120	96
Nitrate	mg/L N	< 0.06	9.0	3.3	3.3	17	11	15	15
Nitrate Load	kg/d N	--	860	740	370	910	270	1,200	1,200
Nitrite	mg/L N	< 0.008	0.35	0.23	0.33	0.023	0.18	0.056	0.052
Nitrite Load	kg/d N	--	34	52	37	1.2	4.6	4.4	4.1
Orthophosphate	mg/L P	< 0.006	3.4	1.2	0.92	0.017	4.7	0.84	0.60
Orthophosphate Load	kg/d P	--	330	260	100	0.9	122	66	46
Potassium	mg/L	1.9	13	5.9	5.0	2.3	3.0	3.0	2.4
Potassium Load	kg/d	270	1,220	1,330	560	120	80	230	180
Praseodymium Average	µg/L	0.017	0.0016	0.013	0.012	0.0049	0.0010	0.0037	0.0040
Praseodymium Standard Deviation	µg/L	0.001	0.0001	0.000	0.001	0.0002	0.0002	0.0002	0.0001
Praseodymium Load	g/d	2.5	0.15	2.8	1.4	0.26	0.03	0.29	0.32

		BC	BC	BC	BC	FC	FC	FC	FC
Unit		U	E	D1	D2	U	E	D1	D2
Rhenium Average	µg/L	0.011	0.042	0.024	0.024	0.023	0.040	0.028	0.027
Rhenium Standard Deviation	µg/L	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.002
Rhenium Load	g/d	1.6	4.0	5.3	2.6	1.2	1.0	2.2	2.1
Rubidium Average	µg/L	1.1	8.1	3.6	3.1	0.29	7.3	1.5	1.0
Rubidium Standard Deviation	µg/L	0.0	0.2	0.1	0.0	0.00	0.1	0.0	0.0
Rubidium Load	g/d	160	770	820	350	15	190	120	77
Samarium Average	µg/L	0.012	0.002	0.009	0.009	0.006	0.002	0.004	0.005
Samarium Standard Deviation	µg/L	0.001	0.000	0.001	0.001	0.000	--	0.001	0.001
Samarium Load	g/d	1.7	0.2	2.1	1.0	0.30	0.04	0.32	0.36
Selenium Average	µg/L	< 0.08	0.13	0.12	< 0.08	3.1	1.5	2.8	2.9
Selenium Standard Deviation	µg/L	--	0.06	0.04	--	0.1	0.0	0.1	0.0
Selenium Load	g/d	--	12	28	--	170	38	220	230
Silica	mg/L	6.7	10.2	7.9	6.8	17	17	18	17
Silica Load	kg/d	990	980	1,800	760	920	450	1,400	1,400
Sodium	mg/L	22	70	39	37	25	30	31	25
Sodium Load	kg/d	3,200	6,700	8,800	4,100	1,300	770	2,400	1,900
Strontium Average	µg/L	227	448	310	353	228	179	221	227
Strontium Standard Deviation	µg/L	2	6	3	1	6	0	2	2
Strontium Load	g/d	33,000	43,000	70,000	39,000	12,000	4,600	17,000	18,000
Sulfate	mg/L	28	108	59	65	29	89	43	38
Sulfate Load	kg/d	4,100	10,300	13,200	7,200	1,500	2,300	3,400	3,000
Suspended Sediment	mg/L	11	--	13	5	111	5	34	21
Suspended Sediment Load	kg/d	1,600	--	2,900	560	5,900	130	2,700	1,600
Tellurium Average	µg/L	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	0.01	0.02
Tellurium Standard Deviation	µg/L	--	--	--	--	0.00	--	0.00	--
Tellurium Load	g/d	--	--	--	--	0.4	--	0.7	1.4
Terbium Average	µg/L	0.0014	0.0004	0.0009	0.0011	0.0008	0.0004	0.0007	0.0009
Terbium Standard Deviation	µg/L	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0000	0.0001
Terbium Load	g/d	0.21	0.036	0.20	0.12	0.045	0.009	0.053	0.070

Unit		BC U	BC E	BC D1	BC D2	FC U	FC E	FC D1	FC D2
Thallium Average	µg/L	0.005	0.021	< 0.003	0.005	0.017	< 0.003	0.007	< 0.003
Thallium Standard Deviation	µg/L	--	0.015	--	--	--	--	--	--
Thallium Load	g/d	0.7	2.0	--	0.6	0.9	--	0.5	--
Thorium Average	µg/L	0.048	0.080	0.062	0.066	0.004	0.052	0.011	0.017
Thorium Standard Deviation	µg/L	0.005	0.046	0.008	0.010	0.002	0.021	0.004	0.004
Thorium Load	g/d	7.1	7.6	14	7.3	0.18	1.3	0.87	1.3
Thulium Average	µg/L	0.0010	0.0004	0.0008	0.0007	0.0007	0.0004	0.0007	0.0008
Thulium Standard Deviation	µg/L	0.0002	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0002
Thulium Load	g/d	0.14	0.042	0.18	0.076	0.036	0.011	0.053	0.065
Tungsten Average	µg/L	0.13	0.051	0.12	0.14	0.004	< 0.004	0.004	0.005
Tungsten Standard Deviation	µg/L	0.01	0.003	0.01	0.00	0.001	--	0.000	0.000
Tungsten Load	g/d	19	4.9	27	16	0.2	--	0.3	0.4
Uranium Average	µg/L	1.3	1.7	1.6	2.1	6.2	1.0	5.1	5.4
Uranium Standard Deviation	µg/L	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0
Uranium Load	g/d	190	160	370	230	330	25	400	420
Vanadium Average	µg/L	0.28	0.37	0.44	0.56	1.7	0.66	1.6	1.6
Vanadium Standard Deviation	µg/L	0.04	0.02	0.05	0.06	0.3	0.04	0.3	0.0
Vanadium Load	g/d	42	36	100	63	91	17	127	123
Ytterbium Average	µg/L	0.0065	0.0043	0.0069	0.0058	0.0050	0.0042	0.0047	0.0049
Ytterbium Standard Deviation	µg/L	0.0005	0.0005	0.0004	0.0006	0.0004	0.0003	0.0002	0.0003
Ytterbium Load	g/d	0.95	0.41	1.5	0.65	0.27	0.11	0.37	0.39
Yttrium Average	µg/L	0.046	0.023	0.038	0.037	0.061	0.015	0.050	0.058
Yttrium Standard Deviation	µg/L	0.002	0.000	0.001	0.002	0.002	0.000	0.001	0.002
Yttrium Load	g/d	6.7	2.1	8.5	4.1	3.2	0.4	3.9	4.5
Zinc Average	µg/L	1.3	38	14	11	0.9	34	7.5	4.3
Zinc Standard Deviation	µg/L	0.2	0	0	0	0.2	0	0.1	0.1
Zinc Load	g/d	200	3,600	3,200	1,200	48	870	590	340
Zirconium Average	µg/L	0.077	0.48	0.14	0.17	0.070	0.23	0.13	0.15
Zirconium Standard Deviation	µg/L	0.012	0.15	0.01	0.00	0.010	0.05	0.02	0.02
Zirconium Load	g/d	11	46	32	19	3.7	5.8	10.4	11.5

Table SI-3. Measured discharge at site i (Q_i), calculated discharge at site i (Ω_i), discharge discrepancy at site i (e_i), measured chloride mass flow at site i ($M_{i,Cl}$), calculated chloride mass flow at site i ($\Theta_{i,Cl}$), and chloride mass flow discrepancy at site i ($\varepsilon_{i,Cl}=M_{i,Cl}/\Theta_{i,Cl}$) for the Boulder Creek, Colorado and Fourmile Creek, Iowa downstream sites D1 and D2 during the summer 2003 and spring 2005 Lagrangian samplings.

Stream	Sampling	Site	Q_i $\text{m}^3 \text{s}^{-1}$	Ω_i $\text{m}^3 \text{s}^{-1}$ ^a	e_i ^b	$M_{i,Cl}$ kg d^{-1}	$\Theta_{i,Cl}$ kg d^{-1} ^c	$\varepsilon_{i,Cl}$ ^d
Boulder Creek	Summer 2003	D1	2.41	2.38	1.02	4470	5170	0.87
		D2	1.84	1.43	1.29	3470	3340	1.04
	Spring 2005	D1	2.60	2.80	0.93	10600	11000	0.97
		D2	1.29	1.39	0.93	4770	5410	0.88
Fourmile Creek	Summer 2003	D1	0.17	0.18	0.95	1530	1570	0.98
		D2	0.16	0.17	0.95	1520	1450	1.05
	Spring 2005	D1	0.92	0.86	1.06	5040	5510	0.91
		D2	0.90	0.91	0.99	4630	4980	0.93

^a. Calculated according to eq. 1 in manuscript.

^b. Calculated according to eq. 7 in manuscript.

^c. Calculated according to eq. 2 in manuscript.

^d. Calculated according to eq. 9 in manuscript.

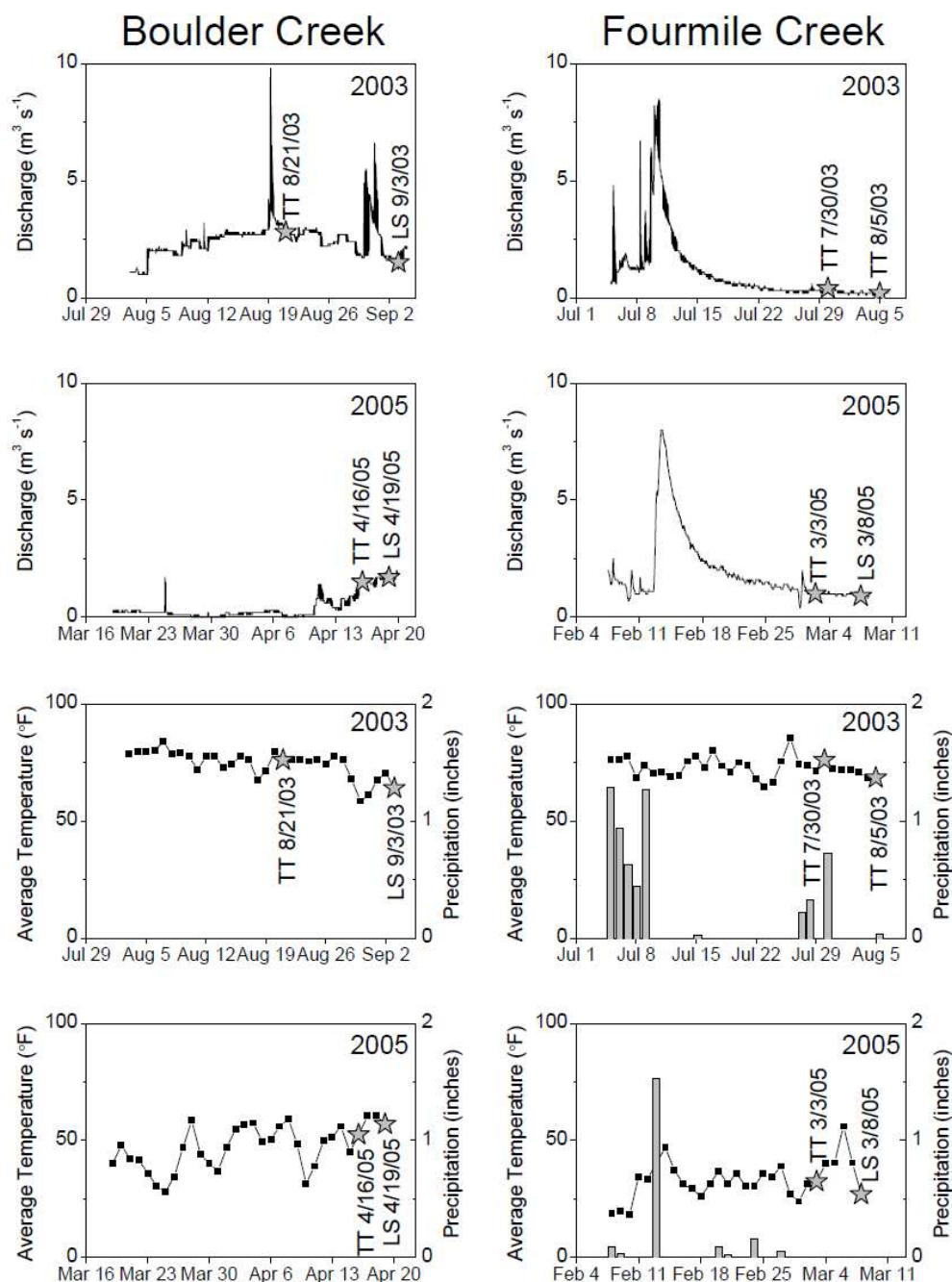


Figure SI-1. Stream flow, precipitation, and temperature in Boulder Creek, Colorado and Fourmile Creek, Iowa during the summer 2003 and spring 2005 tracer tests and Lagrangian sampling events. [Stream flow data from the U.S. Geological Survey Boulder Creek 75th Street gaging station (#06730200) and the Fourmile Creek gaging station (#05485605); precipitation and temperature obtained from wunderground.com (accessed October 15, 2010). The Boulder Creek data is from the Broomfield airport (KBJC) weather station near Boulder, Colorado. The Fourmile Creek is from the Ankeny regional airport (KIKV) weather station near Ankeny, Colorado].

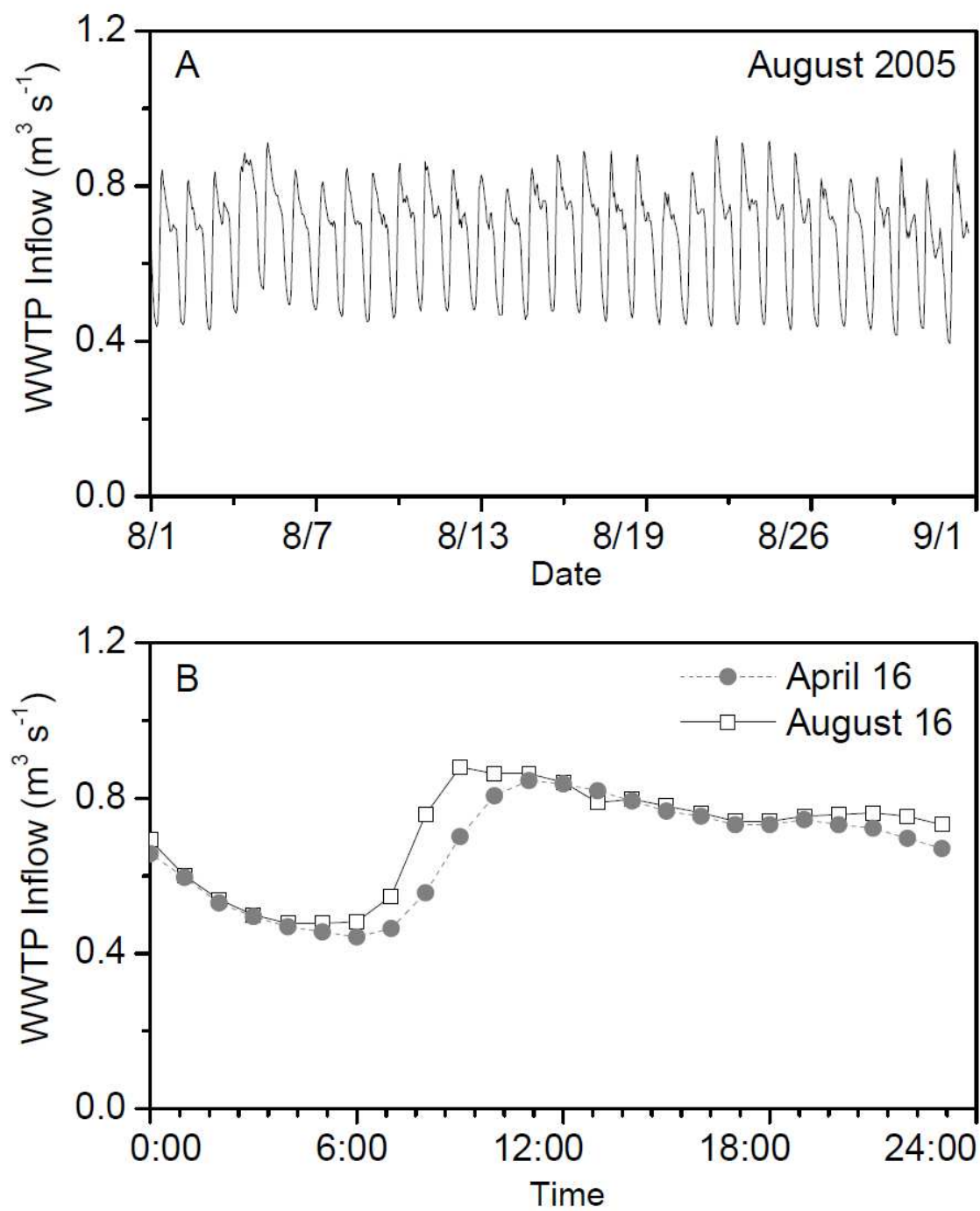


Figure SI-2. Daily variability of sewage inflow volume to the Boulder, Colorado wastewater treatment plant (WWTP) during (A) the month of August 2005, and (B) April 16 and August 16, 2005. [Source of data; City of Boulder, Colorado]

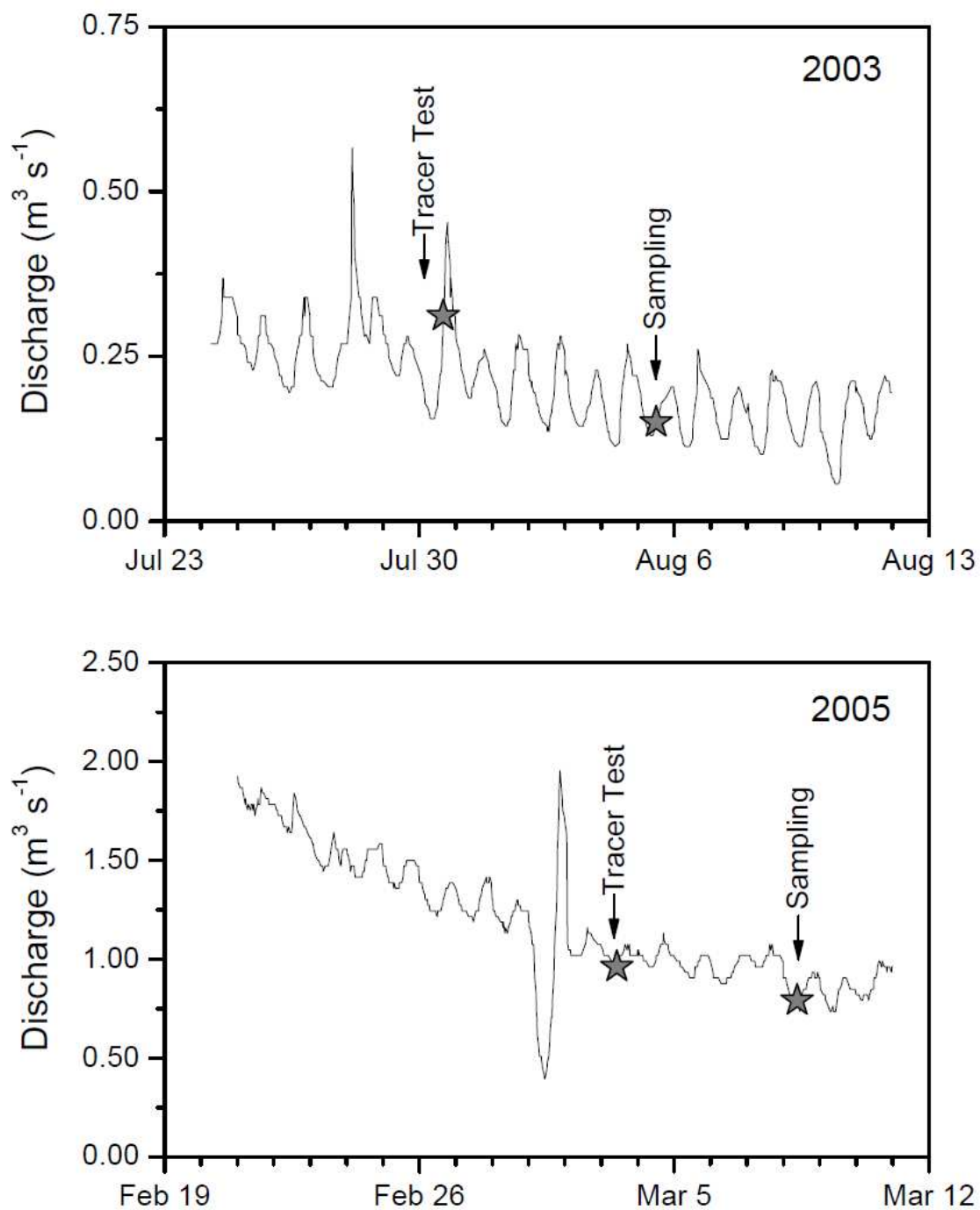


Figure SI-3. Hourly hydrographs for the U.S. Geological Survey Fourmile Creek, Iowa gaging station (#05485605) during the period of the summer 2003 and spring 2005 tracer experiments and Lagrangian samplings.

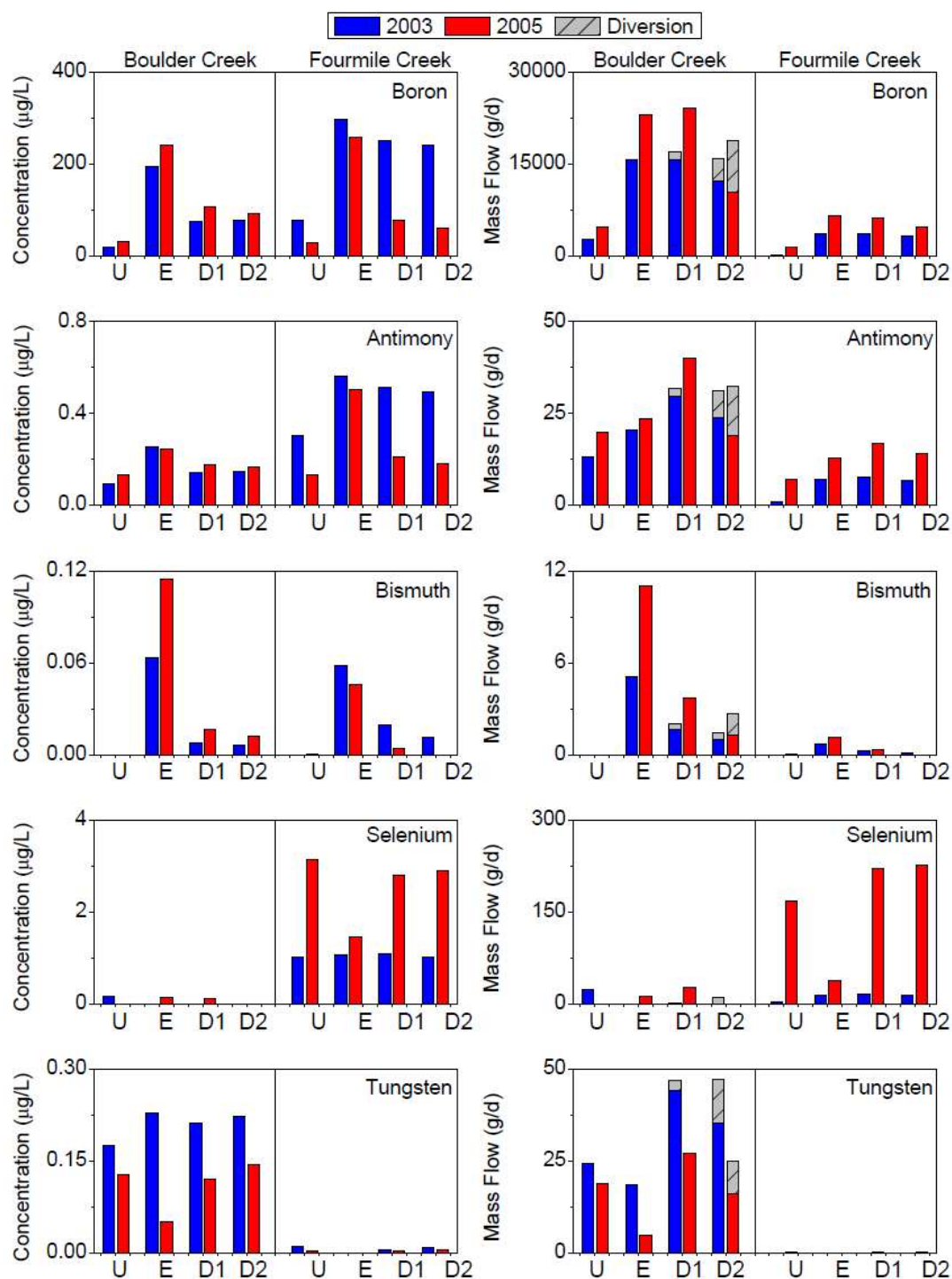


Figure SI-4. Concentrations and mass flows of select inorganic constituents at Boulder Creek, Colorado and Fourmile Creek, Iowa upstream sites (U), wastewater treatment plant effluents (E), and downstream sites (D1 and D2) during the summer 2003 and spring 2005 Lagrangian sampling. Mass loads for Boulder Creek sites D1 and D2 are corrected for losses through the diversions (shown as hatched shading).

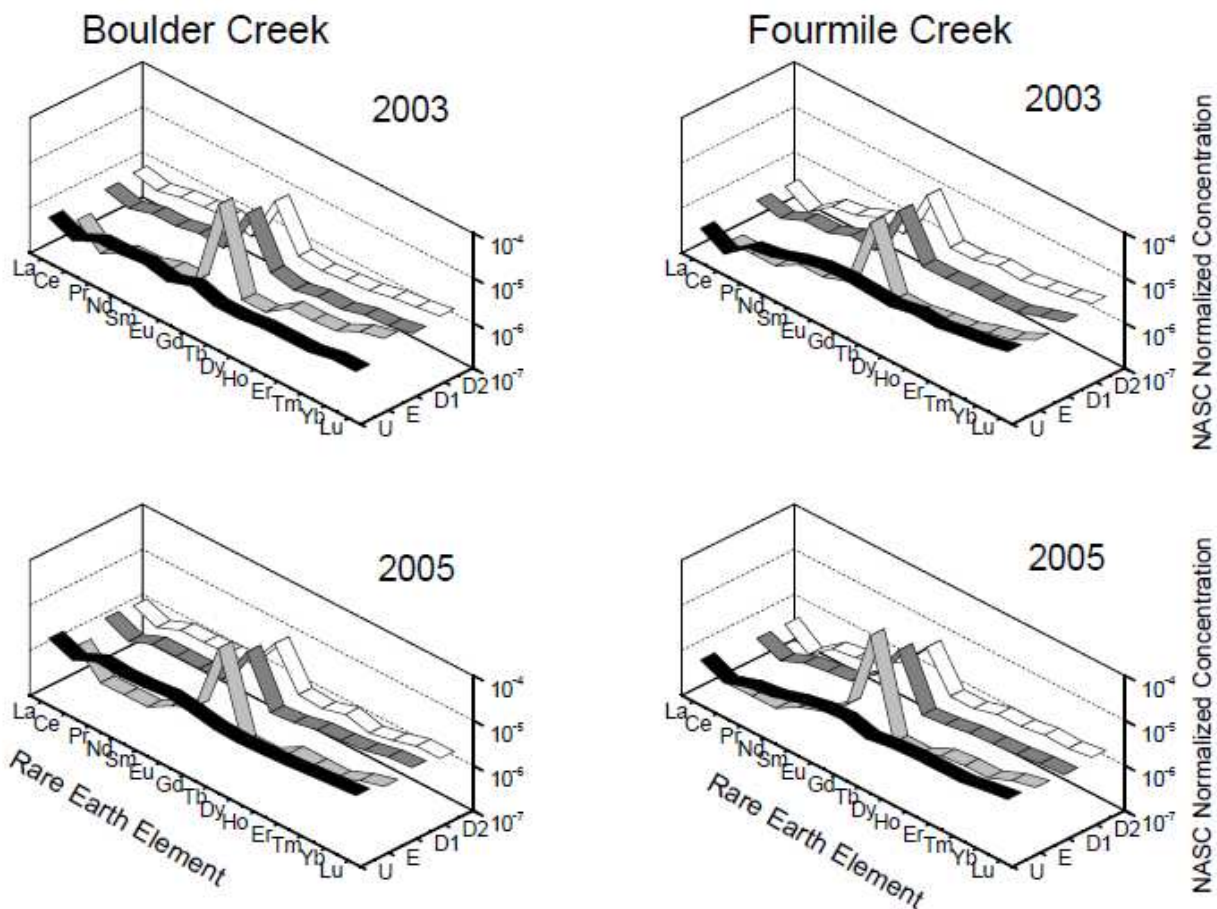


Figure SI-5. Rare earth element concentrations normalized to the North American Shale Composite (NASC; 2) for the summer 2003 and spring 2005 Lagrangian samplings in Boulder Creek, Colorado and Fourmile Creek, Iowa. [U=upstream from wastewater treatment plant (WWTP); E=WWTP effluent; D1 and D2=downstream from WWTP outfall; atomic symbols from lowest to highest atomic number are La=lanthanum, Ce=cerium, Pr=praseodymium, Nd=neodymium, Sm=samarium, Eu=europium, Gd=gadolinium, Tb=terbium, Dy=dysprosium, Ho=holmium, Er=erbium, Tm=thulium, Yb=ytterbium, Lu=lutetium]

References

1. Barber, L.B.; Keefe, S.H.; Flynn, J.L.; Schnoebelen, D.J.; Brown, G.K.; Furlong, E.T.; Glassmeyer, S.T.; Gray, J.L.; Kolpin, D.W.; Meyer, M.T.; Sandstrom, M.W.; Taylor, H.E.; Zaugg, S.D. Lagrangian sampling of wastewater treatment plant discharges into Boulder Creek, Colorado and Fourmile Creek, Iowa during the summer of 2003 and spring of 2005 – Hydrological and chemical data. U.S. Geological Survey Data Series Report 2011-xxxx, Washington, DC, 2011.
2. Gromet, L.P.; Dymek, R.F.; Haskin, L.A.; Korotev, R.L. The North American shale composite - its compilation, major and trace element characteristics. *Geochim. Cosmochim. Acta* **1984**, *48*, 2469-2482.