APPENDIX 1

SOLIDS COMPOSITION OF ROCK FROM PREDICTION BINS AND LIMESTONE ADDITIION TANKS

Table A.1.1. Sulfur (bins 1 - 4) and CO_2 (bin 4) analyses from samples taken from the muck boxes. Analyses by Lerch Bros.

Sample #	Bin 1/ 0.02% Sulfur	Sample #	Bin 2/ 0.22% Sulfur	Sample #	Bin 3/ 0.39% Sulfur	Sample #	Bin 4/ 0.67% Sulfur	Bin 4/ CO_2
2-20	0.005	3-18	0.08	4-10	0.20	1-13	0.29	0.60
2-10	0.006	3-17	0.10	4-13	0.20	1-15	0.33	0.28
2-4	0.01	3-21	0.13	4-15	0.22	1-19	0.42	0.09
2-6	0.01	3-6	0.13	4-2	0.23	1-5	0.45	0.17
2-9	0.01	3-19	0.13	4-14	0.23	1-3	0.46	0.42
2-14	0.01	3-20	0.14	4-4	0.24	1-1	0.47	0.31
2-16	0.01	3-8	0.18	4-11	0.24	1-14	0.48	1.24
2-18	0.01	3-10	0.18	4-7	0.25	1-18	0.50	0.24
2-19	0.01	3-4	0.19	4-21	0.28	1-23	0.54	0.67
2-21	0.01	3-13	0.19	4-3	0.29	1-6	0.58	0.15
2-22	0.01	3-1	0.20	4-20	0.29	1-8	0.59	0.28
2-23	0.01	3-7	0.20	4-17	0.30	1-22	0.64	0.22
2-25	0.01	3-3	0.21	4-22	0.32	1-24	0.66	0.33
2-7	0.02	3-14	0.21	4-19	0.33	1-11	0.69	0.71
2-8	0.02	3-12	0.21	4-12	0.34	1-7	0.74	1.43
2-11	0.02	3-9	0.21	4-24	0.36	1-25	0.75	0.32
2-12	0.02	3-25	0.22	4-25	0.36	1-12	0.76	0.29
2-15	0.02	3-2	0.25	4-1	0.39	1-20	0.77	0.30
2-24	0.02	3-22	0.26	4-23	0.41	1-16	0.79	0.34
2-13	0.03	3-11	0.32	4-6	0.49	1-19	0.80	0.09
2-17	0.03	3-23	0.32	4-16	0.50	1-10	0.94	1.66
2-1	0.04	3-5	0.33	4-18	0.51	1-17	0.94	0.21
2-5	0.05	3-15	0.37	4-9	0.61	1-2	1.02	0.15
2-3	0.07	3-16	0.40	4-5	0.81	1-9	1.04	0.23
2-2	0.08	3-24	0.46	4-8	1.47	1-4	1.09	0.68

Table A.1.2. Summary statistics for percent sulfur on the 25 initial samples taken from the muck boxes.

Statistic	Bin 1/ 0.02% S	Bin 2/ 0.22% S	Bin 3/ 0.39%S	Bin 4/ 0.67% S
N of cases	25	25	25	25
Minimum	0.005	0.08	0.20	0.29
Maximum	0.08	0.46	1.47	1.09
Median	0.01	0.21	0.32	0.66
Mean	0.02	0.22	0.39	0.67
95% CI Upper	0.03	0.26	0.50	0.76
95% CI Lower	0.01	0.19	0.28	0.58
Standard Dev.	0.019	0.095	0.266	0.223

Table A1.3. Whole rock chemistry for the 0.02% S sample of greenstone. Analysis by ACTLABS.

Sample ID	S %	SO_4 %	CO_2 %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LOI %	Total %
2-1	0.04	0.02	0.66	52.57	18.52	12.64	0.147	5.75	0.97	0.47	2.36	0.823	0.27	5.71	100.23
2-2	0.08		0.55	52.58	19.06	11.47	0.158	5.77	0.98	0.43	2.69	0.853	0.35	5.85	100.17
2-3	-0.01	0.02	0.11	54.49	18.99	10.26	0.126	5.62	0.71	0.44	2.75	0.826	0.39	5.39	99.99
2-4	-0.01		-0.05	54.00	19.59	10.27	0.118	5.69	0.75	0.39	2.77	0.868	0.45	5.48	100.37
2-5	0.04	0.02	0.51	53.37	19.24	10.99	0.167	5.67	0.79	0.40	2.83	0.861	0.32	5.69	100.33
2-6	0.02		0.15	50.85	20.56	11.19	0.125	6.09	0.80	0.42	2.98	0.924	0.49	5.81	100.25
2-7	-0.01	0.02	0.11	52.47	20.34	10.84	0.127	5.68	0.65	0.47	2.98	0.907	0.38	5.42	100.26
2-8	0.01		0.33	53.73	19.24	10.43	0.126	5.67	0.89	0.42	2.91	0.832	0.36	5.43	100.03
2-9	-0.01	0.02	0.07	53.58	19.08	10.62	0.124	5.88	0.87	0.38	2.67	0.838	0.60	5.45	100.09
2-10	-0.01		0.11	50.42	20.70	11.50	0.143	6.40	0.65	0.39	3.02	0.895	0.38	5.85	100.33
2-11	-0.01	0.02	0.11	55.14	18.60	10.27	0.125	5.40	1.14	0.39	2.59	0.800	0.72	5.18	100.34
2-12	-0.01		0.07	53.38	19.61	10.60	0.122	6.16	0.66	0.36	2.66	0.847	0.44	5.66	100.50
2-13	-0.01	0.02	0.07	50.42	20.54	11.71	0.130	6.87	0.58	0.39	2.39	0.913	0.35	6.09	100.39
2-14	-0.01		-0.05	50.82	20.20	11.52	0.125	6.75	0.55	0.40	2.50	0.908	0.37	5.95	100.09
2-15	-0.01	0.02	-0.05	52.46	19.88	11.07	0.122	6.16	0.63	0.45	2.64	0.877	0.41	5.63	100.33
2-16	0.02		0.07	52.50	19.55	11.18	0.128	6.64	0.63	0.38	2.32	0.868	0.40	5.83	100.42
2-17	-0.01	0.02	-0.05	50.25	20.47	11.71	0.140	6.81	0.62	0.42	2.62	0.911	0.39	5.97	100.31
2-18	-0.01		-0.05	51.46	20.09	11.39	0.129	6.57	0.65	0.34	2.60	0.878	0.40	5.87	100.38
2-19	-0.01	0.02	0.07	51.30	20.08	11.33	0.130	6.62	0.66	0.39	2.56	0.877	0.40	5.91	100.26
2-20	-0.01		-0.05	50.91	20.35	11.28	0.131	6.98	0.58	0.39	2.25	0.896	0.36	6.03	100.17
2-21	-0.01	0.02	0.48	52.07	19.18	11.42	0.160	6.49	0.88	0.33	2.58	0.834	0.29	6.17	100.41
2-22	-0.01		-0.05	49.91	20.58	12.06	0.136	7.36	0.50	0.40	2.06	0.913	0.30	6.28	100.50
2-23	-0.01	0.02	0.07	50.86	19.59	12.20	0.124	7.36	0.48	0.43	1.67	0.877	0.30	6.27	100.16
2-24	-0.01		-0.05	50.99	19.67	11.90	0.131	7.26	0.72	0.39	1.95	0.864	0.46	6.03	100.37
2-25	-0.01	0.02	-0.05	50.78	19.72	11.89	0.132	7.11	0.73	0.38	2.06	0.872	0.49	6.16	100.33

Table A1.4. Whole rock chemistry for the 0.20% S sample of greenstone. Analysis by ACTLABS.

Sample ID	S %	SO_4 %	CO_2 %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LOI %	Total %
3-1	0.20		0.59	60.07	14.83	10.84	0.111	5.07	1.29	0.39	1.75	0.663	0.27	5.05	100.34
3-2	0.24	0.09	0.18	59.62	14.26	11.26	0.099	6.10	0.93	0.25	1.33	0.644	0.43	5.28	100.21
3-3	0.19		0.22	59.90	15.21	10.38	0.099	5.81	0.72	0.27	1.67	0.688	0.35	5.28	100.37
3-4	0.18	0.02	0.18	65.68	13.23	9.41	0.081	3.68	0.52	0.39	1.68	0.550	0.19	4.11	99.53
3-5	0.33		-0.05	61.29	14.50	10.44	0.093	4.90	0.61	0.35	1.48	0.625	0.22	4.75	99.26
3-6	0.14	0.02	-0.05	61.48	14.25	10.17	0.095	6.02	0.70	0.26	1.26	0.645	0.42	4.93	100.23
3-7	0.20		-0.05	62.74	14.43	9.13	0.077	5.05	0.67	0.24	1.76	0.632	0.43	4.47	99.62
3-8	0.17	0.05	-0.05	58.05	15.55	11.11	0.099	6.12	0.83	0.20	1.67	0.745	0.54	5.14	100.05
3-9	0.19		-0.05	60.01	13.59	10.90	0.097	5.83	0.82	0.26	1.34	0.610	0.49	4.70	98.64
3-10	0.16	0.02	-0.05	59.56	15.23	10.71	0.096	5.92	0.64	0.25	1.53	0.691	0.44	4.92	99.98
3-11	0.22		-0.05	61.45	15.30	9.33	0.081	4.55	0.84	0.42	1.91	0.746	0.47	4.37	99.47
3-12	0.35	0.02	-0.05	61.06	13.88	9.90	0.078	6.30	0.93	0.27	1.33	0.615	0.44	5.04	99.84
3-13	0.19		0.18	60.76	14.86	10.19	0.095	5.09	1.07	0.28	1.86	0.685	0.48	4.75	100.13
3-14	0.19	0.02	0.11	60.43	15.07	10.02	0.091	5.02	0.90	0.32	1.99	0.724	0.46	4.55	99.57
3-15	0.36		0.29	62.05	14.23	9.23	0.078	4.93	0.89	0.27	1.86	0.623	0.39	4.56	99.11
3-16	0.40	0.02	0.18	60.16	14.61	10.56	0.084	5.94	0.72	0.24	1.63	0.619	0.45	5.22	100.23
3-17	0.11		0.18												
3-18	0.07	0.02	0.18	53.85	17.31	11.60	0.114	7.22	0.71	0.24	1.94	0.804	0.56	5.77	100.12
3-19	0.14		0.11	58.01	16.57	9.90	0.086	6.23	0.72	0.28	2.02	0.728	0.41	5.13	100.09
3-20	0.14	0.02	0.11	59.06	16.66	9.49	0.089	5.70	0.56	0.27	2.38	0.760	0.38	4:97	100.33
3-21	0.14		-0.05	66.11	13.56	9.11	0.084	3.51	0.44	0.23	1.99	0.532	0.29	3.73	99.58
3-22	0.24	0.02	2.70	59.39	16.84	10.26	0.104	4.56	0.50	0.24	2.64	0.703	0.28	4.91	100.43
3-23	0.32		0.29	62.11	15.85	9.36	0.092	4.03	0.56	0.31	2.52	0.672	0.31	4.53	100.33
3-24	0.44	0.02	0.15	62.47	14.80	9.39	0.089	4.24	0.61	0.28	2.22	0.688	0.40	4.36	99.54
3-25	0.23		0.29	62.85	14.32	9.49	0.099	4.36	1.18	0.29	2.07	0.611	0.76	4.26	100.29

Table A1.5. Whole rock chemistry for the 0.39% S sample of greenstone. Analysis by ACTLABS.

Sample ID	S %	SO_4 %	CO_2 %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LOI %	Total %
4-1	0.40	0.02	0.18	68.63	12.49	8.04	0.076	4.10	0.38	0.42	1.28	0.504	0.21	4.05	100.18
4-2	0.21		0.11	67.38	12.89	8.76	0.078	3.70	0.34	0.36	1.41	0.520	0.21	3.65	99.29
4-3	0.27	0.02	-0.05	63.14	15.25	8.69	0.067	4.11	0.45	0.42	2.04	0.609	0.28	4.05	99.11
4-4	0.24		-0.05	64.84	14.43	8.37	0.068	3.98	0.60	0.35	2.01	0.569	0.48	3.85	99.55
4-5	0.75	0.02	-0.05	68.58	13.34	7.88	0.058	3.10	0.37	0.39	1.98	0.486	0.24	3.66	100.07
4-6	0.48		-0.05	66.88	14.90	7.57	0.057	2.88	0.35	0.38	2.60	0.596	0.24	3.53	99.96
4-7	0.23	0.02	-0.05	70.34	13.00	6.93	0.058	2.83	0.32	0.30	2.25	0.491	0.22	3.23	99.96
4-8	1.33		-0.05	76.72	8.06	8.49	0.052	2.17	0.25	0.27	0.85	0.335	0.18	3.01	100.39
4-9	0.57	0.10	-0.05	70.65	12.06	7.10	0.052	2.91	0.34	0.29	1.88	0.515	0.24	3.26	99.31
4-10	0.19		0.07	60.98	14.81	10.40	0.083	5.65	0.70	0.39	1.49	0.672	0.48	4.54	100.28
4-11	0.22	0.02	-0.05	65.39	14.92	8.21	0.067	3.24	0.41	0.42	2.32	0.628	0.27	3.67	99.55
4-12	0.32		-0.05	68.83	12.26	8.51	0.065	3.71	0.54	0.31	1.57	0.509	0.39	3.49	100.18
4-13	0.20	0.02	-0.05	69.19	13.24	8.27	0.072	2.47	0.30	0.29	2.10	0.507	0.21	3.20	99.85
4-14	0.22		-0.05	65.93	14.66	8.66	0.071	3.37	0.45	0.41	1.95	0.647	0.29	3.65	100.08
4-15	0.22	0.04	-0.05	65.13	14.54	8.90	0.079	3.23	0.36	0.44	2.08	0.626	0.22	3.68	99.28
4-16	0.50		0.11	68.32	12.46	9.33	0.077	3.09	0.32	0.33	1.52	0.535	0.23	3.44	99.67
4-17	0.28	0.02	-0.05	66.12	13.06	9.45	0.079	3.76	0.43	0.34	1.59	0.599	0.30	3.71	99.43
4-18	0.46		-0.05	66.59	13.38	9.50	0.078	3.08	0.36	0.38	1.65	0.562	0.27	3.62	99.47
4-19	0.34	0.06	-0.05	71.54	12.15	7.81	0.071	2.59	0.25	0.34	1.79	0.439	0.16	3.04	100.18
4-20	0.28		-0.05	67.10	12.71	10.70	0.094	2.95	0.30	0.34	1.29	0.613	0.21	3.38	99.72
4-21	0.26	0.02	0.11	68.82	13.08	8.49	0.073	2.95	0.41	0.52	1.47	0.557	0.20	3.40	99.97
4-22	0.30		0.07	68.55	13.45	8.28	0.065	2.72	0.27	0.53	1.63	0.517	0.18	3.24	99.43
4-23	0.36	0.02	0.15	70.08	12.39	8.59	0.073	2.72	0.30	0.56	1.45	0.501	0.21	3.20	100.06
4-24	0.35		0.15	71.77	10.95	8.85	0.084	2.89	0.29	0.45	1.03	0.435	0.27	3.09	100.13
4-25	0.36	0.02	0.37	66.38	12.73	10.60	0.131	2.93	0.35	0.63	1.31	0.486	0.23	3.63	99.47

Table A1.6. Whole rock chemistry for the 0.67% S sample of greenstone. Analysis by ACTLABS.

Sample ID	S %	SO_4 %	CO_2 %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LOI %	Total %
1-1	0.48		0.29	66.52	12.80	9.92	0.066	3.43	0.33	0.28	1.96	0.494	0.09	3.61	99.51
1-2	0.91	0.02	0.07	66.15	12.76	10.61	0.059	3.62	0.21	0.25	1.78	0.538	0.11	3.85	99.95
1-3	0.44		0.48	63.13	13.79	11.67	0.100	3.73	0.30	0.17	1.86	0.696	0.18	4.11	99.74
1-4	1.02	0.02	0.66	64.30	12.71	11.14	0.118	3.38	0.25	0.25	1.85	0.519	0.69	4.53	99.75
1-5	0.45		0.07	64.74	13.64	10.28	0.058	4.07	0.25	0.19	1.87	0.598	0.11	3.88	99.68
1-6	0.55	0.02	0.18	62.83	14.08	10.88	0.062	4.06	0.33	0.21	2.00	0.651	0.15	4.16	99.42
1-7	0.76		1.55	62.31	12.85	12.90	0.197	3.80	0.34	0.18	1.71	0.560	0.14	5.02	100.00
1-8	0.59	0.13	0.26	61.20	14.28	11.44	0.101	4.36	0.24	0.21	1.99	0.613	0.11	4.61	99.16
1-9	0.98		0.18	66.30	12.30	10.91	0.074	3.65	0.27	0.17	1.67	0.581	0.11	4.15	100.17
1-10	0.86	0.02	1.75	65.43	11.12	12.92	0.223	3.20	0.24	0.20	1.47	0.419	0.14	4.87	100.22
1-11	0.67		0.70	65.42	12.55	11.47	0.119	3.47	0.22	0.16	1.70	0.525	0.15	4.22	100.02
1-12	0.74	0.02	0.29	68.67	12.35	9.54	0.060	2.99	0.14	0.15	1.96	0.488	0.09	3.81	100.25
1-13	0.29		0.62	62.65	13.91	11.64	0.113	3.66	0.27	0.18	1.96	0.577	0.17	4.24	99.35
1-14	0.42	0.02	1.25	63.85	13.50	11.44	0.164	3.20	0.34	0.26	2.15	0.480	0.10	4.64	100.13
1-15	0.30		0.55	68.68	12.72	8.64	0.057	2.83	0.17	0.19	2.16	0.439	0.08	3.39	99.36
1-16	0.72	0.02	0.33	69.98	11.98	9.14	0.068	2.73	0.15	0.21	1.91	0.414	0.07	3.63	100.29
1-17	0.89		0.15	67.72	12.55	9.84	0.055	3.20	0.16	0.17	1.90	0.472	0.10	3.85	100.02
1-18	0.50	0.04	0.15	67.07	13.08	9.40	0.054	3.20	0.16	0.20	2.08	0.486	0.09	3.61	99.43
1-19	0.40		-0.05	71.00	12.06	7.79	0.038	2.76	0.08	0.22	1.99	0.394	0.06	3.16	99.56
1-20	0.71	0.03	0.29	68.39	12.76	9.64	0.065	2.67	0.18	0.22	2.12	0.396	0.07	3.68	100.18
1-21	0.75		0.18	67.95	12.88	9.46	0.054	2.70	0.15	0.21	2.21	0.436	0.09	3.66	99.80
1-22	0.60	0.02	0.22	66.62	12.78	10.28	0.062	3.46	0.14	0.21	1.81	0.496	0.08	3.87	99.81
1-23	0.50		0.73	68.77	11.19	9.90	0.108	3.18	0.19	0.17	1.51	0.464	0.12	3.81	99.40
1-24	0.63	0.05	0.29	66.22	13.03	10.58	0.075	3.51	0.31	0.22	1.86	0.581	0.12	3.96	100.46
1-25	0.68		0.37	63.79	13.47	10.55	0.076	3.59	0.24	0.20	2.04	0.554	0.09	4.19	98.79

Table A1.7. Trace metal chemistry for the 0.02% S sample of greenstone (values in ppm unless otherwise noted). Analysis by ACTLABS.

Sample ID	Au ppb	As	Br	Co	Cr	Cs	Hf	Ir ppb	Mo	Rb	Sb	Sc	Se	Ta	Th	U	W	La	Ce
2-1	-5	2	-1	38	275	4.9	2.7	-5	-5	74	-0.2	28.5	-3	-1	1.4	0.7	-3	15.3	34
2-3	-5	-2	-1	37	304	5.6	2.7	-5	-5	89	0.3	29.6	-3	-1	1.3	0.8	-3	13.8	32
2-5	-5	-2	-1	38	292	5.3	2.4	-5	-5	68	-0.2	28.4	-3	-1	1.2	-0.5	-3	13.6	32
2-7	-5	-2	1	38	293	4.8	2.6	-5	-5	84	-0.2	30.6	-3	-1	1.1	-0.5	-3	15.1	35
2-9	-5	-2	-1	38	290	4.9	2.5	-5	-5	78	-0.2	29.2	-3	-1	1	-0.5	-3	13.8	31
2-11	-5	-2	-1	34	282	5.5	2.3	-5	-5	77	-0.2	28.3	-3	-1	1.1	0.6	-3	16.9	37
2-13	-5	-2	-1	41	304	4.7	2.5	-5	-5	61	0.2	30.8	-3	-1	1.4	-0.5	-3	13.8	32
2-15	-5	-2	-1	39	310	4.6	2.5	-5	-5	61	0.3	29.8	-3	-1	1	0.6	-3	12.5	30
2-17	-5	-2	-1	41	294	5.3	2.3	-5	-5	81	0.2	32.1	-3	-1	1.3	-0.5	-3	13.4	32
2-19	-5	-2	-1	40	290	5.1	2.7	-5	-5	97	-0.2	30.7	-3	-1	1.2	-0.5	-3	13	28
2-21	-5	-2	-1	37	283	5.1	2.3	-5	-5	89	-0.2	29	-3	-1	1.1	-0.5	-3	9.6	22
2-23	-5	-2	-1	46	303	3.8	2.1	-5	-5	55	-0.2	30.9	-3	-1	1	-0.5	-3	11.4	27
2-25	-5	-2	-1	41	292	4.2	2.5	-5	-5	75	0.3	30.5	-3	-1	1.1	-0.5	-3	12	29

Sample ID	Nd	Sm	Eu	Tb	Yb	Lu	Ag	Cd	Cu	Ni	Pb	Zn	Bi
2-1	15	3.7	0.9	-0.5	1.9	0.28	-0.3	-0.3	23	140	-3	92	-2
2-3	18	3.5	1	-0.5	1.9	0.28	-0.3	-0.3	16	137	-3	89	-2
2-5	16	3.5	1.1	0.5	2	0.32	-0.3	-0.3	32	136	-3	88	-2
2-7	17	3.7	1.1	-0.5	2.1	0.34	-0.3	-0.3	20	142	-3	88	-2
2-9	15	3.7	1.2	0.5	2.2	0.34	-0.3	-0.3	17	141	-3	91	-2
2-11	18	4.3	1.5	0.7	3.1	0.46	-0.3	-0.3	54	137	-3	91	-2
2-13	15	3.7	1.1	-0.5	1.8	0.28	-0.3	-0.3	13	166	-3	98	-2
2-15	13	3.3	1.1	-0.5	2.1	0.33	-0.3	-0.3	23	143	-3	85	-2
2-17	14	3.5	1	-0.5	1.9	0.29	-0.3	-0.3	17	153	-3	99	-2
2-19	12	3.4	0.9	0.6	1.8	0.28	-0.3	-0.3	12	145	-3	95	-2
2-21	12	2.7	0.8	-0.5	1.4	0.25	-0.3	-0.3	19	138	-3	99	-2
2-23	15	3.1	0.9	-0.5	1.6	0.25	-0.3	0.6	12	172	-3	103	-2
2-25	15	3.7	1.4	-0.5	4	0.6	-0.3	-0.3	11	156	-3	97	-2

Table A1.8. Trace metal chemistry for the 0.20% S sample of greenstone (values in ppm unless otherwise noted). Analysis by ACTLABS.

Sample ID	Au ppb	As	Br	Co	Cr	Cs	Hf	Ir ppb	Mo	Rb	Sb	Sc	Se	Ta	Th	U	W	La	Ce
3-2	-5	8	-1	47	470	2.5	2.5	-5	-5	43	0.2	20.6	-3	-1	2.7	0.8	-3	23.1	49
3-4	-5	5	-1	29	334	2.4	4.2	-5	-5	37	-0.2	16.7	-3	1	3.5	0.7	-3	21.8	51
3-6	-5	7	-1	38	413	2.9	2.5	-5	-5	48	-0.2	20.7	-3	-1	2.6	1	-3	16.5	37
3-8	-5	7	-1	38	470	2.7	3.1	-5	-5	57	0.3	21.8	-3	-1	3.9	1	-3	23.8	54
3-10	-5	8	-1	38	394	2.9	3.2	-5	-5	58	-0.2	20.7	-3	-1	3.2	0.8	-3	20.9	46
3-12	-5	8	-1	38	462	2.1	2.7	-5	-5	35	0.2	19.4	-3	-1	3.2	0.8	-3	27.7	62
3-14	-5	8	-1	34	403	2.7	4.5	-5	-5	64	-0.2	19.5	-3	-1	3.8	1	-3	31.5	72
3-16	-5	9	-1	35	400	2.6	3.2	-5	-5	55	-0.2	19.6	-3	-1	3	0.9	-3	21.2	48
3-18	-5	4	-1	40	428	3.8	2.7	-5	-5	60	-0.2	25.9	-3	-1	2.2	-0.5	-3	14.8	33
3-20	6	7	-1	37	335	3.3	2.8	-5	-5	66	0.2	23.4	-3	-1	3.1	1.1	-3	18.7	41
3-22	-5	11	-1	36	350	3	3.7	-5	-5	79	-0.2	22.2	-3	-1	4.1	1	-3	22.7	50
3-24	-5	17	-1	44	362	2.6	2.5	-5	-5	68	0.2	19.9	-3	-1	2.6	0.6	-3	17.2	38

Sample ID	Nd	Sm	Eu	Tb	Yb	Lu	Ag	Cd	Cu	Ni	Pb	Zn	Bi
3-2	22	5.1	1.1	0.7	2.1	0.32	-0.3	-0.3	123	188	-3	114	-2
3-4	21	5.4	1.1	-0.5	4.3	0.64	-0.3	-0.3	70	146	6	106	-2
3-6	18	4.2	1.1	-0.5	2	0.3	-0.3	-0.3	175	201	-3	110	-2
3-8	25	5.5	1.3	-0.5	2	0.31	-0.3	-0.3	97	205	-3	131	-2
3-10	23	4.9	1.1	-0.5	2.2	0.34	-0.3	0.8	151	233	-3	121	-2
3-12	31	6.2	1.4	-0.5	1.7	0.26	-0.3	-0.3	122	179	-3	94	-2
3-14	35	7.3	1.7	0.7	2.1	0.31	-0.3	-0.3	83	221	7	108	-2
3-16	23	4.8	1.2	0.7	3.5	0.56	-0.3	-0.3	91	180	-3	106	-2
3-18	16	3.8	0.9	-0.5	1.6	0.23	-0.3	-0.3	65	216	-3	106	-2
3-20	21	4.4	1.1	-0.5	1.8	0.27	-0.3	-0.3	96	192	-3	104	-2
3-22	24	5	1.1	0.6	2.3	0.33	-0.3	-0.3	110	156	13	114	-2
3-24	19	4	1	-0.5	1.7	0.25	-0.3	-0.3	131	171	-3	97	-2

Table A1.9. Trace metal chemistry for the 0.39% S sample of greenstone (values in ppm unless otherwise noted). Analysis by ACTLABS.

Sample ID	Au ppb	As	Br	Co	Cr	Cs	Hf	Ir ppb	Mo	Rb	Sb	Sc	Se	Ta	Th	U	W	La	Ce ppm
4-1	-5	7	-1	28	311	2.4	3.5	-5	-5	36	0.2	15.4	-3	-1	3	0.7	-3	17.5	39
4-3	7	14	1	30	326	2.6	3.6	-5	-5	65	-0.2	19.3	-3	-1	3.5	1.1	-3	22.4	48
4-5	-5	15	-1	27	288	1.8	4.2	-5	-5	54	-0.2	13.8	-3	1	4.3	1.4	-3	26.6	58
4-7	7	20	-1	30	282	2.5	3.7	-5	-5	72	-0.2	14.5	-3	-1	3.6	0.9	-3	24.2	54
4-9	-5	20	-1	30	343	2.5	3.3	-5	-5	64	-0.2	14.9	-3	-1	2.7	-0.5	-3	19.6	45
4-11	5	18	-1	35	341	2.5	4.1	-5	-5	79	-0.2	18.8	-3	-1	3.8	-0.5	-3	25.2	54
4-13	-5	37	-1	37	306	2.4	4.1	-5	-5	61	-0.2	16.3	-3	-1	3.2	-0.5	-3	18.9	42
4-15	-5	11	-1	35	328	2.7	4.7	-5	-5	63	-0.2	19.3	-3	-1	3.9	1.1	-3	23.8	53
4-17	-5	15	-1	41	352	2.2	3.7	-5	-5	52	0.3	19.0	-3	-1	4.0	1.3	-3	24.4	54
4-19	-5	16	-1	33	256	2.3	5.4	-5	-5	59	0.3	13.6	-3	-1	4.8	1.5	-3	29.0	62
4-21	-5	9	-1	35	289	1.8	4.0	-5	-5	51	-0.2	16.6	-3	-1	3.5	0.8	-3	20.5	46
4-23	-5	12	-1	29	297	1.6	4.5	-5	-5	55	0.3	15.4	-3	-1	3.5	1.0	-3	22.4	52
4-25	-5	27	-1	28	305	1.6	4.2	-5	-5	58	0.2	15.3	-3	-1	4.1	1.1	-3	23.1	49

Sample ID	Nd	Sm	Eu	Tb	Yb	Lu	Ag	Cd	Cu	Ni	Pb	Zn	Bi
4-1	19	4.3	0.9	-0.5	2.7	0.41	-0.3	-0.3	51	127	-3	81	-2
4-3	24	5.0	1.1	-0.5	2.3	0.35	-0.3	-0.3	60	133	-3	82	-2
4-5	27	5.4	1.1	-0.5	2.4	0.39	-0.3	-0.3	72	118	-3	78	-2
4-7	24	5.3	1.0	-0.5	2.5	0.38	-0.3	-0.3	68	110	-3	74	-2
4-9	22	4.2	0.9	-0.5	2.4	0.37	-0.3	-0.3	84	115	-3	71	-2
4-11	26	5.6	1.1	0.7	2.4	0.37	-0.3	-0.3	65	155	-3	85	-2
4-13	21	4.3	0.9	0.5	2.8	0.45	-0.3	-0.3	72	153	-3	86	-2
4-15	25	5.6	1.1	0.7	3.3	0.49	-0.3	-0.3	53	163	-3	87	-2
4-17	26	5.7	1.1	0.7	2.8	0.41	-0.3	-0.3	124	187	-3	95	-2
4-19	31	6.3	1.2	0.6	3.3	0.50	-0.3	-0.3	57	121	-3	88	-2
4-21	21	5.0	1.0	0.7	3.2	0.48	-0.3	-0.3	66	160	-3	88	-2
4-23	23	5.4	1.1	-0.5	2.7	0.42	-0.3	-0.3	67	142	-3	84	-2
4-25	25	5.4	1.0	0.6	3.0	0.44	-0.3	-0.3	71	136	-3	83	-2

Table A1.10. Trace metal chemistry for the 0.67% S sample of greenstone (values in ppm unless otherwise noted). Analysis by ACTLABS.

Sample ID	Au ppb	As	Br	Co	Cr	Cs	Hf	Ir ppb	Mo	Rb	Sb	Sc	Se	Ta	Th	U	W	La	Ce
1-2	-5	6	-1	24	95	2.2	5.7	-5	-5	63	0.3	16.1	-3	1	5	1	-3	33.5	72
1-4	-5	6	-1	23	120	2.2	6	-5	-5	66	0.3	15.3	-3	-1	4.8	1.4	-3	30.3	67
1-6	-5	5	-1	31	123	1.9	5.3	-5	-5	72	0.3	20.7	-3	-1	3.8	1.1	-3	23.3	54
1-8	5	5	-1	27	179	2.8	4.5	-5	-5	60	0.3	18.8	-3	-1	3.3	0.8	-3	22.8	52
1-10	-5	4	-1	21	127	1.6	5.2	-5	-5	51	0.3	12.8	-3	-1	4.4	0.8	-3	27.4	62
1-12	-5	3	-1	21	97	2	6.6	-5	-5	69	0.3	13.7	-3	1	5.2	1.3	-3	36.3	80
1-14	-5	2	-1	20	129	3	7.5	-5	-5	75	0.2	13.6	-3	1	5.6	1.5	-3	35.5	79
1-16	-5	4	-1	18	123	2.2	6.6	-5	-5	66	0.3	11.4	-3	1	5.2	1.5	-3	35.1	78
1-18	-5	4	-1	19	97	2.6	7.6	-5	-5	69	0.2	14.6	-3	-1	5.7	1.2	-3	34.9	77
1-20	-5	3	-1	18	106	2.3	7.8	-5	-5	67	0.3	11.2	-3	1	6	1.4	-3	41.4	91
1-22	-5	4	-1	21	90	1.9	7.1	-5	-5	71	-0.2	15	-3	1	5.5	1.3	-3	34.3	76
1-24	-5	5	-1	25	131	2.3	5.8	-5	-5	60	0.3	17.1	-3	-1	4.3	0.8	-3	26	59

Sample ID	Nd	Sm	Eu	Tb	Yb	Lu	Ag	Cd	Cu	Ni	Pb	Zn	Bi
1-2	35	7.5	1.4	0.9	4.4	0.66	-0.3	0.4	100	67	-3	158	-2
1-4	32	7	1.2	1.1	5.3	0.81	-0.3	-0.3	77	68	3	158	-2
1-6	25	5.7	1	0.8	4	0.62	-0.3	-0.3	88	92	5	163	-2
1-8	23	5.4	0.9	0.6	3	0.47	-0.3	-0.3	52	119	-3	189	-2
1-10	30	6.6	1.1	0.8	4.2	0.63	-0.3	-0.3	57	67	-3	174	-2
1-12	39	8.7	1.6	1.2	6.1	0.95	-0.3	-0.3	69	60	4	145	-2
1-14	39	8.8	1.5	1.5	8.1	1.22	-0.3	-0.3	47	73	-3	143	-2
1-16	36	8.4	1.5	1.3	6.7	1.01	-0.3	-0.3	46	63	7	140	-2
1-18	37	8.6	1.5	1.3	6.4	0.97	-0.3	-0.3	55	59	-3	157	-2
1-20	44	10	1.7	1.2	6.7	1.01	-0.3	-0.3	46	62	-3	147	-2
1-22	37	8.2	1.4	1	5.3	0.79	-0.3	-0.3	58	61	-3	169	-2
1-24	28	6.3	1	0.8	4.4	0.65	-0.3	-0.3	62	78	-3	144	-2

Table A1.11. Particle size distribution of field bins (percent).

SIZE FRACTION	BIN 1 PERCENT	BIN 2 PERCENT	BIN 3 PERCENT	BIN 4 PERCENT
+ 12"	12.2	8.7	3.0	7.9
- 12" / +6"	10.6	8.9	6.2	6.1
- 6" / +21/2"	21.4	23.3	12.5	11.1
- 21/2" / +3/4"	33.0	32.7	30.9	32.7
-3/4" / +1/4"	11.4	10.5	22.1	19.3
-1/4" / +10	5.2	6.2	12.1	11.7
-10 / +35	3.8	6.2	8.4	6.9
-35 / +100	1.5	2.3	3.1	2.4
-100 / +200	0.3	0.4	0.7	0.7
-200	0.5	0.8	1.0	1.2

Table A1.12. Whole rock analyses as a function of particle size for the greenstone prediction bins. Analysis by ACTLABS.

Mesh Size	S %	S^{2-} [1] %	SO_4 %	CO_2 %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	LOI %	TOTAL[2] %
0.02% Sulfur Bin																
+2½	0.04	0.02	0.05	-0.05	50.43	21.22	11.59	0.114	6.61	0.42	0.67	1.85	0.942	0.29	6.45	100.59
+3/4	0.04	0.02	0.05	-0.05	52.18	19.34	11.66	0.129	6.74	0.43	0.34	2.42	0.783	0.28	5.96	100.27
+1/4	0.06	0.06	-0.05	-0.05	51.41	19.08	12.20	0.180	6.09	0.90	0.46	2.53	0.878	0.35	5.63	99.72
+10	0.04	0.04	-0.05	0.37	53.89	18.33	11.38	0.117	5.67	1.00	0.53	2.55	0.829	0.36	5.79	100.44
+35	0.05	0.05	-0.05	0.81	54.41	18.33	10.83	0.115	5.44	1.06	0.62	2.52	0.763	0.38	5.73	100.20
+100	0.05	0.05	-0.05	1.00	54.17	17.66	10.31	0.108	5.10	1.25	0.82	2.50	0.751	0.33	6.04	99.04
+200	0.07	0.07	-0.05	1.03	53.34	17.88	10.60	0.114	5.21	1.61	0.95	2.41	0.799	0.33	6.38	99.63
-200	0.08	0.06	0.05	1.50	50.68	18.64	11.15	0.122	5.49	1.83	0.84	2.56	0.679	0.33	7.33	99.65
0.20% Sulfur Bin																
+2½	0.80	0.80	-0.05	-0.05	75.83	8.18	9.48	0.081	2.60	0.10	0.09	0.76	0.133	0.06	2.89	100.20
+3/4	0.41	0.41	-0.05	0.07	66.39	14.99	8.31	0.075	2.38	0.33	0.20	2.89	0.594	0.21	3.51	99.88
+1/4	0.73	0.73	-0.05	-0.05	60.94	14.56	11.01	0.095	5.32	0.64	0.30	1.61	0.617	0.30	4.98	100.37
+10	0.27	0.27	-0.05	0.81	61.05	14.68	9.61	0.086	4.39	1.65	0.49	2.15	0.660	0.33	5.05	100.14
+35	0.25	0.25	-0.05	0.92	60.06	15.55	9.16	0.079	4.27	1.52	0.42	2.28	0.657	0.33	5.04	99.37
+100	0.26	0.26	-0.05	1.72	57.30	16.74	9.42	0.081	4.30	2.12	0.56	2.50	0.743	0.29	6.07	100.12
+200	0.28	0.28	-0.05	2.13	52.49	17.78	10.23	0.087	4.83	3.16	0.60	2.61	0.836	0.33	7.15	100.09
-200	0.25	0.23	0.05	2.90	50.39	18.29	10.15	0.088	4.67	3.85	0.57	2.78	0.776	0.33	8.25	100.14
0.39% Sulfur Bin																
+2½	0.25	0.25	-0.05	-0.05	47.89	14.90	17.03	0.097	9.74	1.31	0.03	0.18	0.857	0.95	6.41	99.39
+3/4	0.50	0.50	-0.05	-0.05	78.51	8.12	6.51	0.047	2.61	0.14	0.13	1.04	0.267	0.10	2.56	100.05
+1/4	0.28	0.28	-0.05	-0.05	68.71	12.55	8.42	0.062	3.29	0.52	0.34	1.64	0.555	0.32	3.50	99.92
+10	0.29	0.29	-0.05	0.37	67.56	13.47	8.12	0.063	3.24	0.77	0.44	1.85	0.529	0.26	3.94	100.24
+35	0.33	0.33	-0.05	0.33	64.82	15.22	8.41	0.064	3.20	0.61	0.59	2.26	0.593	0.26	4.11	100.13
+100	0.31	0.26	0.15	0.40	60.77	17.37	8.74	0.070	3.36	0.79	0.80	2.59	0.699	0.25	5.00	100.45
+200	0.60	0.60	-0.05	1.10	56.80	17.52	11.49	0.096	3.45	0.93	0.55	3.12	0.769	0.12	5.66	100.49
-200	0.55	0.52	0.10	1.10	54.76	18.48	11.46	0.100	3.48	1.05	0.49	3.37	0.718	0.12	6.14	100.17
0.67% Sulfur Bin																
+2½	0.90	0.90	-0.05	-0.05	75.36	11.59	5.99	0.018	1.65	0.06	0.20	2.54	0.222	0.04	2.78	100.45
+3/4	0.25	0.25	-0.05	-0.05	73.04	10.62	7.57	0.045	3.27	0.18	0.18	1.25	0.480	0.13	3.04	99.81
+1/4	0.75	0.70	0.15	-0.05	68.43	12.28	9.38	0.043	3.33	0.16	0.22	1.82	0.460	0.08	3.64	99.85
+10	0.63	0.58	0.15	0.29	66.98	12.90	10.14	0.065	3.18	0.32	0.25	2.01	0.489	0.09	4.00	100.41
+35	0.46	0.46	-0.05	0.22	64.55	14.28	9.97	0.066	3.28	0.29	0.29	2.33	0.524	0.09	4.05	99.71
+100	0.43	0.43	-0.05	0.48	60.06	16.54	10.51	0.073	3.43	0.54	0.46	2.90	0.650	0.10	4.82	100.08
+200	0.34	0.29	0.15	0.66	57.49	18.31	9.26	0.075	3.64	1.14	0.89	2.80	0.783	0.27	5.78	100.43
-200	0.32	0.32	-0.05	0.66	57.32	18.26	9.17	0.076	3.47	1.23	0.84	2.94	0.746	0.26	5.93	100.24

[1] Determined by difference. Less than values are assumed to be 0.

[2] Total for parameters SiO_2 through LOI.

Negative values indicate less than the reporting limit.

Table A1.13. Page 1 of 2. Trace metal analyses as a function of particle size for the greenstone prediction bins. Analysis by ACTLABS. Concentrations in mg/L unless indicated otherwise.

Mesh Size	Ag	Au ppb	As	Bi	Br	Co	Cr	Cd	Cu	Cs	Hf	Ir ppb	Mo	Ni	Pb	Rb
0.02% Sulfur Bin																
+2½	-0.3	-5	-2	-2	-1	44	338	-0.3	19	3.8	3.4	-5	-5	191	-3	68
+3/4	-0.3	-5	-2	-2	-1	44	256	0.4	34	5.3	2.9	-5	-5	144	-3	86
+1/4	-0.3	5	-2	-2	-1	50	309	-0.3	291	5.3	2.9	-5	-5	199	-3	90
+10	0.3	5	-2	-2	-1	40	326	-0.3	24	3.8	4.0	-5	-5	140	-3	90
+35	0.4	-5	-2	-2	-1	38	272	-0.3	30	5.1	2.9	-5	-5	138	-3	76
+100	0.5	-5	4	-2	2	39	313	-0.3	51	4.9	4.0	-5	-5	136	19	108
+200	0.4	-5	5	-2	3	39	234	-0.3	43	5.6	3.7	-5	-5	133	17	97
-200	0.4	13	5	-2	4	41	254	-0.3	55	8.0	4.1	-5	-5	143	11	84
0.20% Sulfur Bin																
+2½	0.9	-5	4	-2	-1	6	120	-0.3	59	1.7	7.4	-5	-5	30	-3	30
+3/4	0.6	6	8	-2	-1	31	289	-0.3	112	4.2	5.0	-5	-5	95	-3	107
+1/4	0.6	-5	11	-2	-1	47	354	-0.3	177	3.3	4.1	-5	-5	210	-3	79
+10	0.5	-5	12	-2	-1	38	408	-0.3	77	3.0	4.9	-5	-5	156	-3	94
+35	0.6	-5	12	-2	-1	38	362	-0.3	110	3.3	4.6	-5	-5	161	-3	79
+100	0.8	-5	14	-2	2	40	412	-0.3	142	3.9	5.2	-5	-5	166	15	93
+200	0.9	6	18	-2	3	41	360	-0.3	187	4.8	6.0	-5	-5	178	12	86
-200	1.0	11	21	-2	2	39	335	-0.3	170	4.9	6.2	-5	-5	181	17	94
0.39% sulfur Bin																
+2½	0.3	5	26	-2	-1	62	699	-0.3	27	2.0	3.9	-5	-5	251	-3	-20
+3/4	0.6	6	12	-2	-1	25	155	-0.3	121	-0.5	3.3	-5	-5	79	4	-20
+1/4	0.5	5	12	-2	-1	32	314	-0.3	156	2.0	3.9	-5	-5	189	-3	61
+10	0.6	-5	13	-2	-1	33	325	-0.3	82	2.9	4.9	-5	-5	150	-3	77
+35	0.7	-5	15	-2	-1	35	302	-0.3	107	3.8	5.8	-5	-5	157	14	93
+100	0.9	6	17	-2	-1	37	368	-0.3	165	3.7	7.2	-5	-5	161	10	76
+200	1.6	-5	8	-2	4	30	93	-0.3	85	4.3	12.5	-5	-5	91	27	121
-200	1.8	-5	10	-2	5	29	104	0.3	98	4.7	13.4	-5	-5	90	28	124
0.67% Sulfur Bin																
+2½	1.2	-5	-2	-2	-1	9	93	-0.3	63	2.8	11.1	-5	-5	33	-3	113
+3/4	0.5	5	-2	-2	-1	19	154	-0.3	54	1.9	4.9	-5	-5	60	7	43
+1/4	0.9	10	4	-2	-1	26	116	-0.3	105	2.0	7.2	-5	-5	67	-3	76
+10	0.8	-5	4	-2	-1	25	159	-0.3	75	2.1	7.5	-5	-5	63	-3	85
+35	1.1	-5	3	-2	-1	23	110	-0.3	67	2.7	8.8	-5	-5	64	4	103
+100	1.2	-5	5	-2	4	25	153	-0.3	75	3.6	10.5	-5	-5	71	-3	108
+200	0.8	52	27	-2	1	41	305	-0.3	149	4.2	8.5	-5	-5	149	25	100
-200	0.8	72	29	-2	-1	40	291	-0.3	171	4.5	8.1	-5	-5	142	20	108

Negative values indicate less than the reporting limit.

Table A1.13. Page 2 of 2. Trace metal analyses as a function of particle size for the greenstone prediction bins. Analysis by ACTLAB Concentrations in mg/L unless indicated otherwise.

Mesh Size	Sb	Sc	Se	Ta	Th	U	W	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
0.02% Sulfur Bin																
+2½	0.2	29.2	-3	-1	1.0	-0.5	-3	87	17.4	42	22	4.7	1.8	0.7	3.2	0.47
+3/4	0.2	30.4	-3	-1	1.3	1.0	-3	96	11.5	29	16	3.4	1	-0.5	1.8	0.26
+1/4	0.3	30.6	-3	-1	1.5	-0.5	-3	97	12.7	29	13	3.3	1.1	0.6	1.8	0.27
+10	0.3	28.6	-3	-1	2.0	-0.5	-3	84	14.6	33	18	3.7	1.2	-0.5	2.2	0.35
+35	0.5	27.4	-3	-1	1.8	0.9	-3	91	15.0	36	16	3.7	1.2	-0.5	2.2	0.34
+100	0.9	26.1	-3	-1	2.2	0.9	3	101	16.2	36	21	3.8	1.2	0.6	2.3	0.35
+200	1.3	25.7	-3	-1	3.2	-0.5	-3	92	17.6	39	20	3.9	1.1	0.6	2.3	0.35
-200	1.9	26.0	-3	1	2.9	0.7	-3	104	17.5	40	21	3.8	1.2	0.6	2.5	0.37
0.20% Sulfur Bin																
+2½	-0.2	3.6	-3	-1	6.9	1.8	-3	97	46.6	101	45	9.3	1.7	1.5	8	1.31
+3/4	-0.2	20.7	-3	-1	2.9	0.9	-3	86	14.3	33	13	3.5	1.1	-0.5	2.8	0.41
+1/4	0.4	21.0	-3	-1	4.0	1.8	-3	104	18.3	43	16	4.3	1.3	0.7	2.9	0.44
+10	0.4	21.2	-3	-1	4.0	1.8	-3	98	20.4	46	21	4.6	1.4	-0.5	2.5	0.37
+35	-0.2	22.1	-3	-1	3.8	1.4	10	95	23.2	54	24	5.1	1.3	0.6	2.6	0.41
+100	0.8	22.9	-3	1	4.4	2.0	4	116	28.5	60	29	5.6	1.5	0.8	2.9	0.45
+200	1	25.1	-3	-1	5.6	1.1	6	115	34.9	79	33	6.8	1.7	0.9	3.3	0.49
-200	1.4	25.1	-3	-1	5.0	1.4	-3	131	32.4	68	27	6.3	1.6	-0.5	3.2	0.50
0.39% sulfur Bin																
+2½	0.3	25.9	-3	-1	6.3	2.0	-3	136	19.9	48	27	6.5	1.9	-0.5	1.9	0.28
+3/4	0.3	10.0	-3	-1	2.8	0.8	-3	78	18.9	43	20	3.7	1.3	-0.5	2.1	0.33
+1/4	-0.2	16.8	-3	-1	4.9	1.6	4	93	28.7	63	24	5.5	1.5	-0.5	2.8	0.43
+10	0.3	17.3	-3	-1	4.7	1.9	-3	93	23.5	50	26	4.9	1.3	0.7	2.9	0.43
+35	0.2	18.9	-3	-1	5.6	1.5	-3	93	30.4	68	29	6.2	1.5	0.8	3.3	0.50
+100	0.9	21.5	-3	1	7.1	1.7	-3	124	38.7	86	44	7.5	1.8	0.9	3.8	0.57
+200	1.5	22.0	-3	2	8.7	2.2	-3	194	49.2	111	39	10.5	2.2	1.7	8.2	1.25
-200	1.8	23.6	-3	2	10.1	2.4	-3	190	45.8	98	45	10.0	2.1	1.6	8.8	1.37
0.67% Sulfur Bin																
+2½	-0.2	4.2	-3	3	8.1	1.6	-3	88	62.8	126	66	13.0	2.5	2.1	8.3	1.35
+3/4	-0.2	15.7	-3	-1	3.3	-0.5	-3	121	26.2	58	30	5.4	1.1	0.8	4	0.60
+1/4	0.4	14.7	-3	1	5.2	1.8	-3	132	31.4	70	33	6.9	1.4	0.9	5	0.78
+10	0.3	16.0	-3	1	5.6	1.4	-3	132	30.8	71	34	6.8	1.5	1.0	4.9	0.75
+35	0.2	17.1	-3	2	6.7	1.4	-3	139	37.7	85	39	8.3	1.8	1.5	6.9	1.09
+100	0.6	20.7	-3	2	8.2	1.9	-3	157	44.5	100	40	9.6	2	1.6	7.6	1.16
+200	1.5	23.2	-3	-1	7.5	2.4	-3	107	46.3	99	42	8.8	2	1.0	4.3	0.66
-200	1.5	22.3	-3	-1	7.3	1.4	4	114	45.9	98	50	8.7	2.1	1.1	4.2	0.65

Negative values indicate less than the reporting limit.

Table A1.14. Sobek method for determination of neutralization potentials from the 0.67% total sulfur (bin 4) muck box samples.

Sample	pH after HCL	mLs to pH 7.0	pH 7.0 NP	mLs to pH 8.3	pH 8.3 NP	mLs back to pH 8.3	pH 8.3 Final NP[1]
1-1	2.09	16.4	9.0	ns	ns	ns	7.2 est.
1-2	2.04	16.9	7.75	ns	ns	ns	5.95 est.
1-3	2.10	16.9	7.75	ns	ns	ns	5.95 est.
1-4	2.19	16.7	8.25	ns	ns	ns	6.45 est.
1-5	2.06	16.5	8.75	ns	ns	ns	6.95 est.
1-6	ns	16.35	9.125	ns	ns	ns	7.3 est.
1-7	2.02	15.9	10.25	ns	ns	ns	8.45 est.
1-8	2.02	16.8	8.0	ns	ns	ns	6.2 est.
1-9	2.01	16.0	10.0	ns	ns	ns	8.2 est.
1-10	1.93	16.5	8.75	17.3	6.75	17.4	6.5
1-11	1.93	16.6	8.5	17.3	6.75	17.4	6.5
1-12	2.11	17.3	6.75	18.0	5.0	18.1	4.75
1-13	2.01	17.0	7.5	17.5	6.25	17.6	6.0
1-14	1.96	15.7	10.75	16.3	9.25	16.4	9.0
1-15	1.96	17.3	6.75	17.7	5.75	17.8	5.5
1-16	1.98	16.7	8.25	17.2	7.0	17.3	6.75
1-17	1.96	16.9	7.75	17.3	6.75	17.4	6.5
1-18	1.99	18.1	4.75	18.6	3.5	18.7	3.25
1-19	2.00	16.6	8.5	18.2	4.5	18.3	4.25
1-20	1.96	16.8	8.0	17.4	6.5	17.5	6.25
1-21	1.96	17.2	7.0	17.8	5.5	17.9	5.25
1-22	1.97	16.6	8.5	17.2	7.0	17.3	6.75
1-23	1.92	17.2	7.0	17.8	5.5	17.9	5.25
1-24	1.96	16.9	7.75	17.4	6.5	17.5	6.25
1-25	1.95	16.2	9.5	17.3	6.75	17.4	6.5
Blank	1.64	20.1	0	ns	ns	ns	ns

Mean NP at pH 7.0 = 8.2 kg $CaCO_3$/t
Mean NP at pH 8.3 = 5.95 kg $CaCO_3$/t
Mean NP at pH 8.3 using est. values = 6.32 kg $CaCO_3$/t
Calculated NP = 10.5 kg $CaCO_3$/t
1-NP after 24 hours

Table A1.15. Particle size distribution for rock used in field limestone addition tanks and limestone (percent passing). Analysis by Lerch Brothers, Inc.

FRACTION	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Limestone
2"	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1 ½"	97.1	97.3	91.3	90.1	88.9	95.3	100.0
1"	68.2	77.4	80.2	72.6	77.5	82.4	100.0
1/2"	43.3	40.5	53.2	52.4	61.7	54.8	100.0
1/4"	31.5	27.2	37.5	36.2	43.8	42.0	100.0
4M	27.1	22.9	32.4	31.1	37.8	37.8	100.0
10M	16.7	14.2	19.6	18.7	23.1	25.3	87.9
20M	12.6	10.8	14.4	13.6	16.9	19.5	57.1
28M	10.8	9.3	12.0	11.4	14.1	17.0	41.8
35M	9.5	8.2	10.2	9.9	12.1	15.3	30.2
48M	7.8	6.7	6.9	7.9	9.6	13.3	18.5
65M	6.2	5.5	5.1	6.3	7.6	11.6	9.0
100M	5.4	4.6	4.7	5.2	6.3	10.4	4.5
200M	3.4	2.8	2.5	3.1	3.7	8.2	1.4

NOTE: All samples were dry screened with the exception of Tank 6 which was wet screened for comparison.

Table A1.16. Whole rock chemistry (percent) of field limestone addition tanks. Analyses by ACTLABS, Inc.

Parameter	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Limestone
S	0.56	0.40	0.50	0.46	0.55	0.48	0.01
S^{2-} [2]	0.54	0.34	0.48	0.44	0.53	0.46	0
SO_4^{2-} as S	0.016	0.06	0.02	0.016	0.02	0.02	0.016
CO_2	0.40	0.37	0.22	0.44	0.44	0.48	41.56[3]
Al_2O_3	13.86	13.09	12.53	13.12	13.28	13.00	0.47
CaO	0.41	0.37	0.26	0.46	0.32	0.43	27.63
Fe_2O_3	10.65	8.83	8.61	9.38	10.30	9.31	0.87
K_2O	1.86	2.03	1.95	1.91	1.85	2.09	0.29
MgO	3.59	2.96	2.91	3.26	3.41	2.89	18.82
MnO	0.068	0.065	0.053	0.089	0.065	0.059	0.081
Na_2O	0.36	0.38	0.30	0.39	0.34	0.38	<0.01
P_2O_5	0.15	0.12	0.10	0.12	0.13	0.21	0.03
SiO_2	64.70	68.40	69.30	65.96	65.38	67.32	9.68
TiO_2	0.587	0.458	0.452	0.522	0.519	0.514	0.026
LOI	4.19	3.73	3.62	3.89	4.02	3.72	41.95
TOTAL[2]	100.42	100.44	100.08	99.11	99.60	99.92	99.78

1 - Determined by difference. Less than values are assumed to be 0.
2 - For parameters from Al_2O_3 through LOI2.
3 - Analysis by Lerch Brothers Inc. and determined by LOI.

Table A1.17. Page 1 of 2. Trace metal analysis of field limestone addition tanks. Analysis by ACTLABS, Inc.; concentrations in ppm.

Parameter	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Limestone
Ag	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
As	5	3	6	3	5	4	2
Au	<5	<5	<5	<5	6	5	<5
Bi	<2	<2	<2	<2	<2	<2	<2
Br	<1	<1	<1	<1	<1	<1	7
Cd	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Co	26	20	21	22	24	22	2
Cr	105	75	65	75	71	76	5
Cs	2.2	2.7	2.0	2.4	2.1	2.5	<0.5
Cu	67	36	44	45	44	45	7
Hf	5.5	6.6	6.3	5.9	6.6	6.5	<0.5
Mo	<5	<5	<5	<5	<5	<5	<5
Ni	97	69	69	82	76	75	3
Pb	<3	<3	6	<3	5	<3	<3
Rb	68	67	63	57	54	71	<20
Sb	0.3	0.3	0.3	0.3	0.3	0.3	<0.2
Se	<3	<3	<3	<3	<3	<3	<3
Ir	<5	<5	<5	<5	<5	<5	<5
Ta	<1	<1	<1	1	1	<1	<1
W	<3	<3	<3	<3	<3	<3	<3
Zn	158	132	132	147	149	135	17

Table A1.17. Page 2 of 2. Trace metal analysis of field limestone addition tanks. Analysis by ACTLABS, Inc.; concentrations in ppm.

Parameter	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Limestone
Ce	57	76	74	63	72	73	6
La	26.9	34.8	33.2	28.1	32.7	33.3	2.4
Lu	0.66	0.85	0.76	0.84	0.82	0.86	<0.05
Nd	27	33	35	31	34	36	<5
Sc	18.1	13.6	13.6	16.2	16.3	15.4	0.5
Tb	0.8	1.1	0.9	0.9	1.0	1.2	<0.5
Th	4.0	5.6	4.9	4.7	4.7	4.9	<0.5
U	1.1	1.3	1.7	0.9	1.1	1.2	0.9
Yb	4.3	5.5	4.9	5.4	5.2	5.5	0.2
Sm	6.0	7.5	7.3	6.2	7.2	7.4	0.4
Eu	1.2	1.5	1.4	1.2	1.3	1.5	0.1

APPENDIX 2

FIELD TEST PILES: PRECIPITATION, FLOW, REACTION CONDITIONS

Table A2.1.	2000 precipitation data.
Table A2.2.	2001 precipitation data.
Attachment A2.1.	Bin field notes.
Attachment A2.2.	Bin flow estimates.
Attachment A2.3.	Dissolved oxygen and temperature field notes for bins.
Attachment A2.4.	Limestone addition field notes.

Table A2.1. Daily precipitation data for 2000. Precipitation data from the DNR Hibbing Research Site.

Day	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
1					.16			.62	.03		.07	
2										.15	.70	
3											.06	
4												
5									.82	.06		
6									.63		.15	
7								.38			.96	
8					1.45						.04	
9								.28				
10							1.84					
11									.24			
12					.29	2.22	.82					
13						.40	.15				.15	
14								.25				
15					.12							
16						.90				1.52		
17								.02				
18								.20	.01			
19						.46	.02					
20									.08			
21						.94		.13				
22					.18							
23						.72						
24												
25									.25			
26					.11	.25	.38					
27										1.29	.40	
28								.48				
29								.09				
30						.15				.10		
31							.12	1.56				
Total	.56	.45	.64	.75	2.31	6.04	3.33	4.01	2.06	3.12	2.53	

Annual total = 22.39, Annual average for Hibbing = 26.93

Table A2.2. Daily precipitation data for 2001. Precipitation data from the DNR Hibbing Research Site.

Day	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
1					.18	.33						.02
2							.11					
3							.20					
4												
5												.38
6				.19	.69						.04	
7					.03	.07		.15			.25	
8								.46		.18		
9				1.93	.24				.55			
10												
11										1.15		
12				.84						.67	.09	
13					.26							
14								.51				
15					.01		.03	.20		.48		.02
16				.56			.36				.01	
17						.16	.02	.33				
18						.01	.54		.08	.06	.09	
19							.03					
20					1.19				.01			
21					.78							
22					.33					.31		
23				1.24	.02				.93	.22		.45
24				.01		.01				.04	1.05	
25												
26												
27												
28					.92					.21		
29							.65	.39				
30				.31			.02	.01			.15	
31				.23			.96					
Total	.31	.23	.19	5.31	4.65	.58	2.90	2.05	1.57	3.32	1.68	.87

Annual total = 23.66, Annual average for Hibbing = 26.93

2000

7/18/00 - Started filling bin 1 (low sulfur, 0.02) and finished on 7/21.

7/21/00 - Started filling bin 4 (high sulfur, 0.67) and finished on 7/25.

8/1/00 - After a downpour of 0.67" of rain bin 4 received no flow and bin 1 about 200-300 mLs.

8/2/00- Attempted to measure O_2 and temperature. O_2 meter was giving some strange readings, unsure if the pump was not strong enough or O_2 meter not working.

8/8/00 - .38" of rain: bin 4 had about 4 ½" of leachate in the sump, bin 1 had about ¾" of leachate in the sump, no water dripping. The flow totalizers and meters are not working, there appears to be a problem with the electrical wiring. Installed new flow totalizers in bins 1 and 4.

8/9/00 - AM: bin 4 had no change in water volume since 8/8, the leachate bin 1 was up to the bottom of the second float switch (3" from top of the sump).

8/14/00 - AM rain gage = .25". No flow to Bin 4, still had only about 4" of water in sump and about 60 mLs in collection bottle. Bin 1 had about 4 ½" of water in sump (meter read 60) and approximately 200 mL in collecting sample bottle. The flow totalizer in bin 1 appears to be working and was calibrated. Collected baseline grab samples from the sumps of bins 1 and 4 for nutrients (500 mL) and metals (250 mL). Both bins had some algal growth in the sump and on the pipe fixtures. Bin 4 pH = 8.74, SC = 550, Bin 1 pH = 8.06, SC = 1450.

8/15/00 - 0.30" rain from PM on 8/14. Bin 4 water level the same in sump, SC = 500. Bin1 water nearing the trip switch (8:20 AM) and water dripping from inlet pipe at about 15 to 20mL/30 sec. SC = 1200. More water in the collection bottle than 8/14 which indicates that there was flow but the meter read zero after being reset during calibration.
8/17/00 - 0.02" rain

8/18/00 - 0.20" rain in AM. Bin 4 water level is up to the gravity overflow pipe. Bin 1 has very little water in sump, and water dripping in from stockpile which indicates that the pump had tripped. Water in collecting bottle was 3/4" higher than previous date. Neither flow totalizer is working, still having electrical problems. Meters read 0. Used YSI probe to compare the CG 502 oxygen probe. Some trials produced the same numbers and other trials did not. A more detailed comparison will be performed at a later date.

8/21/00 - Bins 1 and 4 both received flow but flow instrumentation was still out of order. Cleaned the level sensors in both sumps to remove organic film that may affect the sensor. This will have to part of the routine maintenance check.

8/22/00 - 0.13" of rain, flow instrumentation is still out of order and will have to be shipped to the company for repair.

8/25/00 - Bin 4: the water level is ½ way up on the bottom sump switch. Bin 1: the water level is ½ inch above the bottom sump switch, some water in collection bottle.

8/28/00 - Heavy downpour Friday evening (8/25) resulting in 0.48" rain. Bin 1: (1435) sump water 3/4" above bottom sump switch and bin is flowing at a slow drip. Sample collection bottle was full, replaced with new bottle. Brown slime covering bottom of sump, with clumps of green algae present. Meter reads 0. Bin 4: 1 1/4" water in the sump with about 100 mL in the collection bottle. No flow. Slight oil sheen on surface of water. Meter not functioning yet.

8/29/00 - 0.09" rain from previous evening. Bin 1: Water in the sump measured 1" more than on 8/28 and the collection bottle had about mLs of water which indicates that the pump had been triggered. Bin 4: Replaced collection bottle to measure pH and SC. Sampled metals and nutrients from bin 1, not enough water to sample bin 4.

8/31/00 - 1.56" rain between 8/30 PM and 8/31 AM, also heavy mist off and on all day. Replaced sample bottle in bin 1.

9/1/00 - Bin 4: Water is ½ way between sump switches, water dripping into sump. Sample bottle is 3/4 full which indicates that the pump had triggered. Meter not working yet. Bin 1: Water is ½ way between switches, water dripping into sump. Sample bottle is approximately 1/5 full which indicates that the pump had triggered, meter still reads zero.

9/5/00 - 0.82" rain over the weekend. Bin 4: There is about 2" of water in the sump and the collection bottle is full (2000 mLs). Flow rate at 1247 was 31 mL/min. Bin 1: There is 2 ½" water in the sump and the collection bottle is full (2000 mLs). Flow rate was 15.5 mL/min. Bin 3: Started loading with the 0.39% S rock. Loaded 2 truck loads into the bin and took 4 samples from each load once they were placed in the bin. One random sample from the east side of the pile, one from the west, one from the north, and one from the south.

9/7/00 - 0.63" rain. Bin 4: There is about 6" of water in the sump and the collection bottle almost ½ full, Flow rate is at 155 mLs/ 30 sec. Bin 1: There is a little over 6" of water in sump and the collection bottle is 1/4 full, flow rate is at 140 mLs/30 sec. Bin 3: Pile is complete. Took rock samples as described on 9/5.

9/11/00 - 0.24" rain over weekend. Bin 4: There is about 2 ½" of water in the sump and the collection bottle is full (exchanged for new bottle). Flow rate is at 14 mLs/min. Bin 1: There is about 4" of water in the sump and the collection bottle is 3/4 full (exchanged for new bottle). Flow rate is at 9 mLs/min. There is a considerable amount of algae present in the sump. Bin 3: Received some flow (water in the sump is to the top of the bottom sump switch), Bin is not currently flowing. Sump needs cleaning due to the presence of algae.

9/12/00 - Bin 4: There is 7" water in the sump and the collection bottle is full (exchanged for new bottle) Flow is at 1.5 mLs/min. Bin 1: There is about 6" of water in sump and the collection bottle is full (exchanged for new bottle). Pile is not currently flowing. Still having problems troubling shooting the electrical problem. Bin 3: No flow.

9/15/00 - Bin 4: 3" of water in the sump, no flow. Bin 1: About 1" of water in the sump, no flow.

9/18/00 - Started filling bin 2. Took additional rock samples using the same procedure as bin 3.

9/19/00 - Bin 4: Water level in the sump is unchanged from 9/15, no water in the collection bottle, and the bin is not flowing. There is some green algae starting appear in the sump. Bin 1: Water level in the sump is unchanged from 9/15, no water in the collection bottle, and the bin is not flowing. There is brown/green algae present in the sump. Bin 2: Pile is complete.

9/26/00- Bin 4: 2 ½ to 2 3/4" water in sump (0911), meter read 98, accidentally hit sump switch, now 1 1/4" (water half way up to sump inlet pipe). Grey plastic shavings from meter box in sump, collection bottle about 1" water. Bin 3- dry with grey shavings. Bin 2 - 1 3/4" water in sump, collection bottle empty. Bin 1 - 5 1/4" water in sump, collection bottle a <1" with grey shavings.

10/6/00 - Bin 4 - 1" water in sump, and 1" water in collecting bottle, Bin 3 - empty, Bin 2 - 1 5/8" water in sump, collection bottle empty, Bin 1 - 6 3/4" water in sump, >1 " water in collecting bottle.

10/11/00 - Same as 9/26, switched collection bottles (1126) on bins1 (100 mL) and 4 (250 mL) to sample SC, and pH. Power to pumps off and collection bottles disconnected.

10/17/00 - Power still off so water is not collecting in bottles. Rained (1.52") over weekend, so collected grab samples of sumps from the 4 bins. All still flowing (1020) Bin 4 - 33 mL/min, Bin 3 - 25 mL/min, Bin 2 - 15 to 17 mL/min, Bin 1 - 25 mL/min. Bins 1 and 4 had a greenish tint to water and some algae on sump fixtures, and Bins 1, 3, and 4 had grey shavings in sump from drilling of electrical boxes. Bin 4 also had algae in sump.

10/27/00 - 1.29" rain on 10/26. All bins flowing. At 0930 bin 4 - 87 mL/min, Bin 3 - 93 mL/min, Bin 2 - 78 mL/min, Bin 1 - 76 mL/min. At 1430 Bin 4 - 71 mL/min, Bin 3 - 71 mL/min, Bin 2 - 72 mL/min, and Bin 1 - 67 mL/min.

11/1/00 - 0.7" rain. No evidence of erosion. Bin 4 - 150 mL/10 sec (960 mL/min), Bin 3 - 160mL/ 13 sec (688 mL/min) , Bin 2 - 160 mL/13 sec (688 mL/min), Bin 1 - 160 mL/ 10 sec (900 mL/min). Meters working.

Attachment A2.1. Page 4 of 8. Field notes on waste characterization bins.

11/6/00 - more rain last week, 0.15". Strong flow, all pumps about ½ to3/4 full, 100 to 200 mL in collection bottles (except #2, valve to bottle was closed). Flow meter reading Bin 4 - 11, Bin 3 - 171, Bin 2 - 170, Bin 1 - 156.

11/7/00 - 0.96"rain. Tripped each bin sump so that could get an instantaneous sample from inlet pipe (water in collection bottle had been diluted as a result of sump calibration). Changed number on meters from 1200 to 1150 (1415), noted that sump screens needed cleaning from plastic chips and algae.

11/8/00 - 0.4"rain. Flow and volume measurements taken. Cleaned sumps and flow meter screens.

11/9/00 - Freezing rain/snow overnight. Meter and flow measurements (1545). Changed collection bottle. Still flowing 15 to 20 mL/min.

11/13/00 - Rain snow mix over the weekend. Meter and flow measurements (1345). Still flowing 12 to 14 mL/min.

11/14/00 - Meter and flow measurements (1050). Bins still flowing 2 to 22 mL/min.

11/16/00 - Meter and flow measurements (1300). Bins flowing 5 to 6 mL/min.

11/20/00 - No flow, bins starting to slush and freeze. Switched collection bottles for spring.

11/22/00 - Removed remaining water and cleaned bins for winter, also drained sump pumps.

11/22 to 12/4 - Water flowing at some point in bins 2 through 4.

12/4/00 - Meter readings Bin 3 -1296, Bin 4 - 635.

2001

3/22/01 - Warm temperatures led to flow in some tanks (Bin 2,3). Snow left only on north side of bins.

3/23/01 - Flow in Bins 2 - 4, ranged from 16 - 4 mL/min. Weather turning cool again.

3/27/01 - Electrical disturbance in Bin 2. Reset meter to zero. Sump was nearly full prior to trip for reset test. No flow in bins.

4/2/01 - Slow (~1mL/min) flow in Bins 2 and 3. Snow previous night and AM. Snow remains on north side of rock piles.

Attachment A2.1. Page 5 of 8. Field notes on waste characterization bins.

4/4/01 - Bin 2 - ¾" from tripping, tripped sump to see if meter was working. Meter read 13 after trip.

4/6/01 - There is standing water in bin 3 with a film on the surface. The outlet pipe must be frozen.

4/9/01 - Bin 4 - standing water in bin (ice in pipe), exchanged bottles from Bins 2 & 3 because they were full.

4/10/01 - Switched collection bottle in Bin 1 .

4/11/01 - Bin 4 output pipe still frozen, pumped about 1/2 gal of hot water in to thaw pipe (at 1100). Pipe began to flow, after a few minutes flow was 250 mL/9 sec. 1 trip resulted in a meter reading of 654. At 1300 the meter read 908, at 1520 meter read 1531.

4/12/01 - Bin 4 changed collection bottle.

4/19/01 - Bin 2 changed collection bottle.

4/20/01 - Bins 1, 3, and 4 changed collection bottles.

4/25/01 - Collected samples for analysis.

5/4/01 - Checked calibration of meter to sump. Power outage caused erroneous readings.

5/7/01 - Checked calibration of meter/sump again, cleaned all screens (clogged with algae, insects).

5/10/01 - Collected samples for analysis. All outlets are still dripping.

5/23/01 - Collected samples for analysis.

6/4/01 - Cleaned algae from sumps, forgot to disconnect sample bottle on Bins 2- 4 when cleaning.

6/8/01 - Put new collection jars in bins due to contamination of algae when cleaning on 6/4.

6/15/01 - Collected samples for analysis.

6/21/01 - Measured oxygen and temperature of rock piles.

7/11/01 - Measured oxygen and temperature of rock piles.

7/13/01 - Cleaned sumps and pumped out water.

7/19/01 - The cover on Bin 2 flew open during a storm the previous evening. Noticed that there is algae (red) &/or possible mold (black spots) in most of the tubing from pump to overflow pipe, also a little green algae tubing to collection jars.

7/24/01 - Measured oxygen and temperature of rock piles.

7/30/01 - Rain AM, mist and fog.

7/31/01 - Cleaned algae from pump screens, overcast, humid.

8/1/01 - Thunderstorms previous evening, 0.96 in rain. Wind may have blown tiny rock particles around, also slight erosional activity between bins. Humidity 100% (all week). Steady flow still at 1045. Sumps in bins 1 and 4 stained brown with a little algae, bin 2 very green, bin 3 lots of filamentous-like algae. Changed collection jars on bins 1, 2, and 4 (in refrigerator for analysis). Bin 3 collection jar was only half full.

8/2/01 - Collected flow from overnight and added to yesterdays collection jars for analysis (bins 1, 2, and 4). Collected sample jar from bin 3 for analysis. Measured oxygen of piles with YSI. Calibrated YSI (@ 25C in lab while probe in chamber).

8/8/01 - Thunderstorms 4:30 - 5AM, heavy winds, rain = 0.15 in. Visual inspection of bins: Bin 1 - sump brown with green filaments of algae, Bin 2 - sump thick green filaments of algae, Bin 3 - sump green algae, not as thick as sump 2, Bin 4 - sump stained ark brown with some green algae. All sumps flowing at a rapid drip. Thunderstorms again at 4:30 PM.

8/9/01 - Thunderstorms at 12:30 AM, heavy winds, rain= 0.45 in (includes rain from 8/8/01 afternoon storm).

8/20/01 - Collected samples for analysis. Sumps full of algae. Cleaned screens.

8/23/01 - Measured oxygen content of the rock piles using YSI. Possible errors when the temperature reaches 35 C in the measuring chamber.

8/29/01 - Cleaned sumps on the prediction bins. Measured water volume and removed water while cleaning.

8/30/01 - Bin 1 pump was not working and resulted in lost flow. The lower sump switch was stuck in the off position, and water exited the sump via the outflow pipe.

9/12/01 - Collected samples for analysis and disposed of remaining sample.
Cleaned algae from screens.

Attachment A2.1. Page 7 of 8. Field notes on waste characterization bins.

9/24/01 - 0.93" rain on 9/22/01, heavy frost over night. Adjusted valve on bin #2 as there was very little water in the sample jar (AM). Cleaned algae from the valves and tubing around the valves that connect to the collection jars (PM). This algae may have been restricting flow to the sample collection jars.

9/25/01 - Oxygen measurements of the prediction bins ranged from 20 to 21%. Temps averaged 13.1 C for the top of the piles and 14.8 C for the bottom of the piles.

9/28/01 - Cleaned sumps with bleach solution, rinsed and pumped out remaining water. Will need to add 3L to the next meter reading for compensation of the water below the sump switch. Sumps switches on bins 1 and 2 were sticking in the on position. The problem with bin 1 cleared up after the sump was cleaned. The sump in bin 2 was tilted causing the switch to remain in the on position.

10/9/01 - No flow in sumps. Lost power at 10:30, power on at 11:30.

10/10/01 - All bins are flowing.

10/11/01 - Slow drip in all sumps. Collected samples for analysis. Flow rate for input water was a slow drip. The connection to flow meter was loose and leaked into the plastic bin (approximately 4" of water).

10/17/01 - Oxygen measurements of the prediction bins ranged from 21.6 to 23.8%. Temps averaged 11.7 C for the top of the piles and 8.9 C for the bottom of the piles. Prediction bins dripping in late AM, leftover from earlier rain or frost thawing.

10/19/01 - Placed heat lamps near sumps to prevent the pumps from freezing in cold weather.

10/23/01 - Rain evening of 10/22. Cleaned all screens on flow meters. Crud from inside tubing and small insects clogged the screens. Bin 3 had white fibrous material (hair-like) clogging the screen. Bins all flowing with fast drip to a trickle.

10/30/01 - Collected water samples for analysis.

11/8/01 - Rain PM of 11/7. Sponged water out of sumps.

11/26/01 - Rain over weekend (Sat.), snow today with more predicted overnight. Temps to drop by end of week. Heat lamps were out in Bin's 3 and 4, replaced bulbs. All sumps had slow, steady flow into them.

11/28/01 - Tripped sump switches so that all water emptied out of them. Switched sample jars on all bins and collected water for analysis. Bin's 2 through 4 still flowing, Bin #1 stopped flowing. All sumps had some green and brown, Bin #1 had fuzzy green algae (most likely from heat lamp).

Attachment A2.1. Page 8 of 8. Field notes on waste characterization bins.

12/7/01 - Slow flow

12/11/01 - Slow flow

12/13/01 - All bins flowing except Bin #1. Temperature of the rock piles range from 0.9 to1.8C for the top of the piles and 2.0 - 4.3C for the bottom of the piles. All rock piles have settled over time due to erosion activity.

12/17/01 - Slow flow in all bins.

12/19/01 - No flow in all bins.

12/20/01 - Changed collection jars in all bins.

Attachment A2.2. Page 1 of 3. Estimation of unmeasured flow from greenstone prediction bins in 2000.

The sampling instrumentation for the field bins includes an electronic flow meter and flow totalizer. When this instrumentation was installed there were problems with the electrical wiring to the meters. As a result all meters and totalizers were damaged and were sent back to the distributor for repair. Due to these problems flow was not recorded for bin 1 from July 21st to November 1st, for bin 2 from September 18th to November 1st, for bin 3 from September 5th to November 1st, and for bin 4 from August 14th to November 9th, 2000.

Flow estimates for these periods, as well as periods in the future when flow recording problems are encountered, will be based on the yield coefficient for each bin and precipitation during the period of unmeasured flow. The yield coefficient is the output from the bin over a given period of time divided by the input from rainfall during that same period. The following calculation is for the input volume to the bins.

20 ft. x 20 ft. x (ft/12 in) x P = 33.3 P ft^3 or 940 P Liters, where P is precipitation in inches.

After the meters were installed there were one to three week periods in 2000 for which yield coefficients could be calculated. The yield coefficients for these periods ranged from 0.50 to 0.63 (table I). These yields are in good agreement with a range of 0.44 to 0.58 reported for an earlier field study conducted by the MN DNR (Eger et al., 1985). Since these yield coefficients represent fairly short periods, 2001 data was used to estimate lost flow.

2001 yield coefficients for two periods were calculated (tables II and III). Yield coefficients for the approximate period of lost flow in 2000 (August to November) and for the entire field season (April to December) are presented in tables II and III, respectively. The yield coefficients for the August to November period were in fairly good agreement with the 2000 results with the exception of Bin 2 which was slightly higher. The yield coefficients for the entire field season (0.73 – 0.85) with the exception of bin 2 were much higher than either the 2000 or 2001 August to November results as well as data collected from an earlier field study conducted by the MN DNR.

At this time it is not clear why the yield coefficients for the entire field season seem higher than would be expected. Since the data from August to November for the 2001 field season is in fairly good agreement with the 2000 data as well as the earlier field study it was determined that those yield coefficients would be the most accurate to use when determining the 2000 lost flow (tables IV - VII).

 Estimation of unmeasured flow from greenstone prediction bins in 2000.

Table I. 2000 yield coefficients for greenstone prediction bins (Bins 1-3: 1-20 November; Bin 4: 13-20 November).

BIN	RAIN (in.)	INPUT (L)	OUTPUT (L)	YIELD COEFFICIENT
1	2.13	2002	1114	0.56
2	2.13	2002	1174	0.59
3	2.13	2002	1260	0.63
4	0.15	141	71	0.50

Table II. Yield coefficients for the period 2 August through 28 November, 2001.

BIN	RAIN (in.)	INPUT (L)	OUTPUT (L)	YIELD COEFFICIENT
1	11.55	10857	6864	0.63
2	11.55	10857	8781	0.81
3	11.55	10857	5622	0.52
4	11.55	10857	6641	0.61

Table III. Yield coefficients for the entire 2001 field season (1 January – 22 December).

BIN	RAIN (in.)	INPUT (L)	OUTPUT (L)	YIELD COEFFICIENT
1	25.61	24,073	20383	0.85
2	25.61	24,073	20029	0.83
3	25.61	24,073	17486	0.73
4	25.61	24,073	19606	0.81

Table IV. 2000 lost flow estimations based on yield coefficients from table II for bin 1.

SAMPLE DATE	RAIN (in.)	INPUT FLOW (L)	BIN 1 LOST FLOW (L)
8/14	2.03	1908	1202
8/29	1.22	1147	722
9/12	3.28	3083	1942
10/17	2.07	1946	1226
11/07	1.39	1306	823
Total	9.99	9390	5915

Attachment A2.2. Page 3 of 3. Estimation of unmeasured flow from greenstone prediction bins in 2000.

Table V. 2000 lost flow estimations based on yield coefficients from table II for bin 2.

SAMPLE DATE	RAIN (in.)	INPUT FLOW (L)	BIN 2 LOST FLOW (L)
10/17	2.07	1946	1576
11/07	1.39	1306	1058
Total	3.46	3252	2634

Table VI. 2000 lost flow estimations based on yield coefficients from table II for bin 3.

SAMPLE DATE	RAIN (in.)	INPUT FLOW (L)	BIN 3 LOST FLOW (L)
9/12	1.45	1363	709
10/17	2.07	1946	1012
11/07	1.39	1306	679
Total	4.91	4615	2400

Table VII. 2000 lost flow estimations based on yield coefficients from table II for bin 4.

SAMPLE DATE	RAIN (in.)	INPUT FLOW (L)	BIN 4 LOST FLOW (L)
8/14	2.03	1908	1164
8/29	1.22	1147	700
9/12	3.28	3083	1881
10/17	2.07	1946	1187
11/07	3.33	3130	1909
11/20	0.19	179	109
Total	12.12	11,393	6950

REFERENCES

Eger, P., Lapakko, K. 1985. Heavy metals study: Progress report on the field leaching and reclamation program: 1977-1983. Minnesota Department of Natural Resources, Division of Minerals. St. Paul, MN. 53p.

Attachment A2.3. Page 1 of 2. Dissolved oxygen and temperature field notes.

8/2/00	Used GC 502 meter, calibrated to 20.9 %. Set up pump and purged volume of tubing. Practiced oxygen measurements on Bins 1 & 4. Oxygen measurements ranged from 19.6% to 20.9%. Rock pile temperatures ranged from 18.1 to 23.9°C.
8/15/00	Calibrate GC 502 oxygen meter to 20.9% with probe in air. Once probe was placed in the measuring chamber, oxygen fell to 17.3%. Measured percent oxygen for Bins 1, 3, and 4. Oxygen measurements ranged from 8.5% to 17.3%. At the end of the recording time, removed probe out of measuring chamber and oxygen reading was 17.5%. Rock pile temperatures ranged from 18.1 to 23.9°C
8/18/00	Early AM, first comparison of YSI and GC 502 oxygen meters. Calibrated YSI according to conditions at site (air temp of 22C, and elevation of 1600' = saturation of 8.28 mg/L). GC 502 calibration was set to 20.9 % with probe in air. Performed a preliminary comparison on Bins 1 and 4. Oxygen readings were in the 10 to 17 % range. Late AM to early PM, performed a more rigorous comparison of the oxygen meters. Connected both YSI and CG 502 oxygen probes in tandem and read meters simultaneously at 1, 3, 5, and 10 minute intervals. Some difficulties keeping the YSI probe from leaking air into its measuring chamber. This was corrected by placing a layer of silicon around the rubber stopper that held the probe into the measuring chamber. The majority of the readings from the two meters differed by 1 to 2 %. The YSI meter typically produced the higher percent oxygen reading. On one sampling port (Bin 4, upper, 10'), the YSI meter read as much as 4.9% higher than the GC 502 meter. Oxygen readings were in the 16.9 to 22.8 % range. Rock pile temperatures ranged from 17.1 to 19.8°C
9/26/00	Measurement of oxygen in Bins 1,3, and 4 using the GC 502 meter. Meter was calibrated at 21.0% with the probe in the air. Oxygen readings were collected at 1, 3, and 5 minute intervals, and measurements ranged from 8.8 to 17.3%. Rock temperatures ranged from 11.5 to 12.2 C for the tops of the piles, and 11.3 to 14.6°C for the bottoms of the piles (partly cloudy conditions).
3/27/01	Measurement of oxygen in Bins 1 through 4 using the GC 502 meter. Meter was calibrated at 21.1% with the probe in the air. Oxygen readings were collected at 1, 3, and 5 minute intervals, and measurements ranged from 6.7 to 19.3%. Rock temperatures ranged from –2.2 to –1.60 C for the tops of the piles, and –0.5 to –0.1°C for the bottoms of the piles (sunny changing to partly cloudy).

Attachment A2.3. Page 2 of 2. Dissolved oxygen and temperature field notes.

6/21/01	Measurement of oxygen in Bins 1 through 4 using the YSI meter. Oxygen readings were collected at 1, 3, and 5 minute intervals, and measurements ranged from 16.7 to 22.0%. Rock temperatures ranged from 14.4 to 15.5 °C for the tops of the piles, and 11.8 to 13.1°C for the bottoms of the piles (partly cloudy conditions).
7/11/01	Measurement of oxygen in Bins 1 through 4 using the YSI meter. Oxygen readings were collected at 1, 3, and 5 minute intervals, and measurements ranged from 18.8 to 23.5%. Rock temperatures ranged from 17.6 to 20.0°C for the tops of the piles, and 14.6 to 15.6°C for the bottoms of the piles (partly cloudy, air temp 70's). It appears that the YSI reads high oxygen (%) at high temperatures.
7/24/01	Measurement of oxygen in Bins 1 through 4 using the YSI meter. Oxygen readings were collected at 1, 3, and 5 minute intervals, and measurements ranged from 20.5 to 21.9%. Rock temperatures ranged from 21.4 to 23.2°C for the tops of the piles, and 17.4 to 18.4°C for the bottoms of the piles (mostly cloudy, windy). It appears that the YSI reads high oxygen (%) at high temperatures.
8/2/01	Measurement of oxygen and temperature of rock piles using YSI meter. Calibration of meter in lab with probe in chamber. Oxygen readings were collected at 1, 3, and 5 minute intervals, and measurements ranged from 15.3 to 19.4%. Rock temperatures ranged from 19.0 to 20.6°C for the tops of the piles, and 17.1 to 17.9°C for the bottoms of the piles.
8/23/01	Measurement of oxygen and temperature of rock piles using YSI meter. Calibration of meter in lab with probe in chamber. . Oxygen readings at 5 minute intervals ranged from 13.9 to 22.2%. rock temperatures ranged from 18.6 to 20.0°C for the tops of the piles, and 16.7 to 18.0°C for the bottoms of the piles. YSI meter readings erratic during Bin 2 bottom 10' measurement. Let probe sit during lunch and it bounced back to normal. Both lower sampling ports of Bin 3, and one of Bin 4 appeared to have obstructed tubing.
9/25/01	Measurement of oxygen and temperature of rock piles using YSI meter. Calibration of meter in lab with probe in chamber. Oxygen readings at 5 minute intervals ranged from 20.2 to 20.9%. rock temperatures ranged from 12.8 to 12.9°C for the tops of the piles, and 13.8 to 15.1°C for the bottoms of the piles. The lower sampling ports (5') of Bin 3 and 4 appeared to have obstructed tubing.
10/17/01	Measurement of oxygen and temperature of rock piles using YSI meter. Calibration of meter in lab with probe in chamber. Oxygen readings at 5 minute intervals ranged from 15.6 to 25.5%. rock temperatures ranged from 8.5 to 9.2°C for the tops of the piles, and 11.5 to 11.8°C for the bottoms of the piles. The lower sampling ports (5') of Bin 3 and 4 appeared to have obstructed tubing.

Attachment A2.4. Page 1 of 3. Limestone addition field notes.

2000

10/24/00 - Filled limestone tanks.

10/27/00 - 1.29" rain on 10/26. No flow into the limestone tanks.

11/1/00 - 0.7"(or 0.07) rain. No flow.

11/6/00 - 0.15" rain, limestone tanks 1/5 full (1130), flow = slow drips

11/7/00 - 0.96" rain. Measured water volume with rain stick (in). First sample collected from tanks (-750 mL). Pumped water to sump. Unable to get all water out so remeasured water for leftover volume. Tanks still flowing slow drip (10 to 20 mL/drip).

11/8/00 - All tanks still dripping slowly. Measured volumes (924).

11/9/00 - All tanks had frozen pipes (1530). Measured volumes.

11/13/00 - Rain and snow over the weekend. All tanks had frozen pipes, however, must have been slight flow. Measured volumes (1245), pumped out water and sponged tanks dry.

11/14/00 - No flow, pipes frozen.

2001

3/22/01 - Noticed flow on 3/21. Measured volumes (1330), collected 500 mL samples for analysis, then pumped out water and sponged tanks dry. Water had a greenish-brown color.

3/23/01 - All tanks had some water (frozen), but not enough to cover bottom of sump. Weather turning cool again and inlet pipes frozen.

4/2/01 - Measured volume of water in sumps with rain stick. No water in sump 1 and 4 due to upheaval from ice. Some ice in most outflow pipes. Did not remove water from bins.

4/3/01 - All bins have heaved with melt during previous day and freeze overnight. Unable to reset bins due to ice in sand.

4/6/01 - Emptied bins (measured volume by pouring into 10L bucket). Attempted to reset bins, but still some ice under bins.

4/9/01 - 1.9" rain on 4/7. Collected water samples from all bins, but did not measure volumes due to upheaval of bins again.

Attachment A2.4. Page 2 of 3. Limestone addition field notes.

4/11/01 - Unable to take normal measurement for volume (sump upheaval), so took readings at the 4 corners of sump and averaged them. Pumped out all tanks.

4/13/01 - Measured volume of water with calibrated red buckets to nearest 0.5 L. Reset sumps #3 & #6.

4/17/01 - All tanks approximately 1 inch of water, tanks 1 and 4 dripping, all have ice.

4/20/01 - Measured water volume and dumped out water.

4/25/01 - Collected samples for analysis, and emptied sumps.

5/4/01 - Measured flow and emptied sumps.

5/10/01 - Collected samples for analysis and emptied sumps. All tanks appeared to be dripping except 4 and 5.

5/14/01 - Measured sumps for water volume. Outlet pipes from tanks have algae in them.

5/23/01 - Collected water samples for metal analysis, then pumped out remaining water. All sumps had yellow/brown water with floating algae, and tent caterpillars. Algae in tank pipes.

5/29/01 - Water in sumps is yellowish/brown. Tent caterpillars everywhere.

6/1/01 - Tent caterpillars on and in sump. Cleaned caterpillars out of sumps, but did not empty water.

6/9/01 - Measured water volume, then cleaned sumps and dumped out water (yellowish/green).

6/12/01 - Rain over the weekend. Measured water volume, but did not dump water. Water yellowish/green, and some caterpillars were present. Plants starting to grow in rocks in the tanks

6/14/01 - Rain storms previous evening. Measured water volume, but did not empty.

6/15/01 - Collected water samples for analysis. Measured water volume, but did not empty water. Algae present in most bins.

6/25/01 - Measured water volume and emptied sumps.

7/11/01 - Removed plants growing in tanks.

Attachment A2.4. Page 3 of 3. Limestone addition field notes.

8/1/01 - Thunderstorms previous evening, 0.96". Water stained in tanks: (1) light brown, (2) green, (3) green/brown with filamentous clump of green and orange, (4) light green with some algae clumps from inlet pipes, (5) green with few green clumps, (6) mostly clear with slight green tint. Also, usual spiders and some pin head sized insects (Collembola?).

8/2/01 - Collected water samples for analysis, and recorded water volume.

8/8/01 - Thunderstorms early AM with high winds. Tanks had low flow but not measurable.

8/20/01 - Collected water samples for analysis, and recorded water volume.

9/12/01 - Collected water samples for analysis, and recorded water volume. Emptied water from sumps.

9/24/01 - Heavy frost overnight, 0.93 inches of rain on 9/22.

9/28/01 - Took measurements of sumps and pumped water out. Water in all sumps slightly green, with tank 6 having the clearest water.

10/11/01 - Rain on Wednesday. Measured volume in tanks and pumped tanks dry. All tanks slowly dripping, 1 drop/3sec.

10/30/01 - Collected water samples for analysis, and pumped sumps dry.

11/26/01 - Rain over weekend (Saturday). Snow and wind today with more predicted overnight. Measured volumes from tanks, collected sample for analysis, bailed water out of sumps. Pipes from tanks to sumps frozen.

12/01 - Have thawing and freezing conditions. Some lost flow due to loose pipes from tank to sump. Very little water in sumps.

APPENDIX 3

DRAINAGE QUALITY FROM FIELD PREDICTION BINS AND LIMESTONE ADDITION TANKS

Prediction Bins

Limestone Addition Tanks

Attachment A3.1. Anomalous drainage quality data. The data have been verified to be as reported values (PPM), and appear to be anomalous. Anomalous data have been omitted from the cumulative mass release tables and figures.

Table	Reactor	Comment
Table A3.2	Prediction Bin 0.20% S	SO4 value 17.2 (4/9/01).
Table A3.3	Prediction Bin 0.39% S	SO4 value 5.14 (4/9/01).
Table A3.4	Prediction Bin 0.67% S	Ca value of 126 and Zn value of 126 (8/14/01)

Table A3.1. Page 1 of 2. Drainage quality data for the 0.02% sulfur greenstone prediction field bin (#1).

Concentrations are in mg/L, pH is in standard units, conductivity is in µS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alk	SO_4	Ca	Mg	Na	K	Co	Cu	Ni	Zn	Fe
08/14/00	1202	1450	8.06	35	42.0	122	29.6	114	19.2	<0.002	0.006	<0.002	<0.002	0.079
08/29/00	722	1525	8.04	60	46.4	140	34.3	116	16.5					0.056
08/31/00		950	7.45	35										
09/12/00	1942	5500	7.96	50	102	576	78.7	396	36.8					0.278
10/11/00		7500	7.95	65										
10/17/00	1226	4500	7.39	50	102	468	57.9	375	34.4	0.003	0.017	0.004	<0.002	0.271
10/27/00		3700	7.41											
11/07/00	1587	1275	7.57	50	58.3	121	17.8	197	24.1	<0.002	0.009	<0.002	0.006	0.052
11/20/00	350	2100	7.78	35	42.0	184	22.8	205	21.5					0.070
04/10/01	2702	525	7.50	45	22.7	34.6	3.87	63.8	7.8	<0.002	0.005	<0.002	<0.002	<0.002
04/25/01	3219	600	7.84	60	22.2	43.3	6.30	57.6	7.4					<0.002
05/10/01	1650	850	8.33	40	35.4	67.1	9.00	117	11.6					<0.002
05/23/01	1965	450	8.50		22.6	22.4	3.30	62.1	8.4	<0.002	0.004	<0.002	<0.002	<0.002
06/15/01	3009	450	8.79	70	18.1	17.5	1.99	56.2	7.8					<0.002
08/02/01	1675	390	8.37	100	21.7	22.4	2.54	50.3	9.6	<0.002	0.007	<0.002	<0.002	<0.002
08/20/01	931	525	8.09	100	29.8	30.6	3.92	59.0	9.7					0.026
09/12/01	238	500	7.96	100	32.8	33.9	4.31	57.8	10.6					0.021
10/11/01	2195	375	7.58	75	33.2	33.6	4.73	47.9	8.5	<0.002	0.002	<0.002	0.003	0.014
10/30/01	824	375	7.72	65	31.0	30.8	3.91	48.9	7.5					0.018
11/28/01	981	375	7.95	75	27.6	25.0	3.62	35.2	8.3					0.010

Table A3.1. Page 2 of 2. Drainage quality data for the 0.02% sulfur greenstone prediction field bin (#1).

Concentrations are in mg/L.

Date	Volume (L)	Mn	Al	Si	N	NH_3N	NO_3^{2}	TP
08/14/00	1202	<0.002	<0.002	5.45	<0.020	0.458	142	0.014
08/29/00	722	<0.002	<0.002	5.84	1.3	0.290	146	0.020
08/31/00								
09/12/00	1942	0.007	<0.002	4.30	3.4	1.93	528	0.020
10/11/00								
10/17/00	1226	0.033	<0.002	4.56	2.8	2.32	472	0.031
10/27/00								
11/07/00	1587	0.015	<0.002	4.32	1.1	0.220	184	0.029
11/20/00	350	0.017	<0.002	4.15				
04/09/01	2702	<0.002	0.010	1.78	0.94	0.561	39.8	0.041
04/25/01	3219	0.002	0.003					
05/10/01	1650	<0.002	0.004		0.52	0.050	68.7	0.024
05/23/01	1965	<0.002	0.002		0.48	0.024	30.9	<0.010
06/15/01	3009	<0.002	0.007					
08/02/01	1675	<0.002	0.006	5.35	0.43	0.030	24.6	0.020
08/20/01	931	<0.002	0.004		0.57	0.029	35.2	0.019
09/12/01	238	<0.002	0.007					
10/11/01	2195	<0.002	0.004	9.03	0.50	0.023	28.9	0.016
10/30/01	824	<0.002	0.003					
11/28/01	981	<0.002	<0.002		<0.20	<0.020	17.0	0.014

Table A3.2. Page 1 of 2. Drainage quality data for the 0.20% sulfur greenstone prediction field bin (#2).

Concentrations are in mg/L, pH is in standard units, conductivity is in μS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alk	SO_4	Ca	Mg	Na	K	Co	Cu	Ni	Zn	Fe
10/17/00	1576	2125	7.68	60	119	274	51.0	61.8	13.1	0.006	0.005	<0.002	<0.002	0.136
10/27/00		2900	7.52											
11/07/00	1739	3225	7.52	65	263	467	56.9	164	19.0	0.008	0.008	0.002	<0.002	0.160
11/20/00	493	4850	7.70	65	292	649	78.1	177	23.5					0.316
04/09/01	1992	5000	7.42	70	**17.2**	655	85.5	183	25.3	0.013	0.020	0.014	<0.002	0.009
04/25/01	2982	1325	7.83	60	112	157	17.2	60.1	12.6					<0.002
05/10/01	1114	1350	8.40	65	121	165	17.2	76.7	16.7					<0.002
05/23/01	1680	825	8.05		70.1	86.3	8.47	52.3	13.2	0.002	0.006	<0.002	<0.002	<0.002
06/15/01	2674	850	8.22	60	100	105	8.38	52.1	14.1					<0.002
08/02/01	1612	975	7.87	105	115	129	11.2	44.1	15.2	0.002	0.010	0.006	<0.002	<0.002
08/20/01	1961	1000	7.72	105	124	128	11.6	46.4	14.4					0.142
09/12/01	814	825	7.93	90	112	105	9.63	37.0	14.3					0.089
10/11/01	2677	600	7.35	75	95.2	92.5	9.33	28.9	9.40	<0.002	0.004	<0.002	<0.002	0.064
10/30/01	851	550	7.78	75	106	87.0	7.95	25.7	9.21					0.071
11/28/01	839	675	7.85	78	99.4	85.0	8.37	23.7	8.15					0.064

Values that appear anomalous are in bold.

Table A3.2. Page 2 of 2. Drainage quality data for the 0.20% sulfur greenstone prediction field bin (#2).

Concentrations are in mg/L.

Date	Volume (L)	Mn	Al	Si	N	NH_3N	NO_3^2	TP
10/17/00	1576	<0.002	<0.002	4.23	2.6	0.516	190	0.059
10/27/00								
11/07/00	1739	0.005	<0.002	5.08	3.4	1.10	284	0.067
11/20/00	493	0.011	<0.002	4.29				
04/09/01	1992	0.066	<0.002	5.00	4.7	2.88	486	0.112
04/25/01	2982	0.002	<0.002					
05/10/01	1114	<0.002	<0.002		2.7	0.935	88.7	0.041
05/23/01	1680	<0.002	<0.002		2.0	0.574	48.2	0.019
06/15/01	2674	0.004	<0.002					
08/02/01	1612	0.006	<0.002	7.86	1.2	0.047	69.2	0.013
08/20/01	1961	<0.002	0.002		1.9	0.115	42.3	0.023
09/12/01	814	<0.002	<0.002					
10/11/01	2677	<0.002	<0.002	9.60	1.8	<0.020	37.1	0.015
10/30/01	851	<0.002	<0.002					
11/28/01	839	<0.002	<0.002		1.6	<0.020	28.5	<0.010

Table A3.3. Page 1 of 2. Drainage quality data for the 0.39% sulfur greenstone field prediction bin (#3).

Concentrations are in mg/L, pH is in standard units, conductivity is in μS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alk	SO_4	Ca	Mg	Na	K	Co	Cu	Ni	Zn	Fe
10/17/00	1721	2225	7.61	60	77.4	242	54.8	89.1	17.4	0.012	0.006	<0.002	<0.002	0.114
10/27/00		3250	7.47											
11/07/00	1403	4300	7.36	45	191	474	76.9	233	32.4	0.021	0.011	0.003	0.004	0.212
11/20/00	536	5000	7.56	45	220	574	84.0	283	34.7					0.317
04/09/01	2696	1850	7.31	50	**5.14**	197	26.2	86.2	16.9	0.008	0.008	0.005	<0.002	<0.002
04/25/01	3143	950	7.80	45	47.0	102	12.8	62.3	14.2					<0.002
05/10/01	1050	1050	7.79	55	55.4	120	14.2	89.8	17.9					<0.002
05/23/01	1555	800	7.82		45.8	75.4	8.41	59.9	14.7	0.003	0.006	<0.002	<0.002	<0.002
06/15/01	2565	750	7.86	50	68.1	85.9	8.69	44.0	14.7					<0.002
08/02/01	1177	625	7.81	100	105	76.2	7.95	29.6	14.0	0.002	0.008	<0.002	<0.002	<0.002
08/20/01	778	700	7.98	100	113	83.0	9.38	31.5	14.2					0.078
09/12/01	219	600	7.88	80	115	82.3	9.18	27.2	13.4					0.069
10/11/01	1746	550	7.50	70	138	86.0	10.8	22.6	11.6	<0.002	0.003	<0.002	<0.002	0.057
10/30/01	879	600	7.74	70	175	99.6	11.4	21.6	11.3					0.080
11/28/01	804	725	7.86	65	172	94.2	11.5	19.0	10.1					0.076

Values that appear anomalous are in bold.

Table A3.3. Page 2 of 2. Drainage quality data for the 0.39% sulfur greenstone prediction field bin (#3).

Concentrations are in mg/L.

Date	Volume (L)	Mn	Al	Si	N	NH_3N	NO_3^{2}	TP
10/17/00	1721	<0.002	<0.002	4.60	3.7	2.98	204	0.031
10/27/00								
11/07/00	1403	0.008	<0.002	4.88	7.0	5.92	447	0.036
11/20/00	536	0.012	<0.002	5.05				
04/10/01	2696	0.012	0.003	2.18	2.5	3.66	199.9	0.044
04/25/01	3143	<0.002	<0.002					
05/10/01	1050	<0.002	0.002		3.2	2.00	85.3	0.022
05/23/01	1555	<0.002	<0.002		1.9	1.01	57.9	<0.010
06/15/01	2565	0.002	0.007					
08/02/01	1177	<0.002	<0.002	5.78	0.87	0.037	40.7	<0.010
08/20/01	778	<0.002	<0.002		1.5	0.029	37.3	0.017
09/12/01	219	<0.002	0.007					
10/11/01	1746	<0.002	0.012	8.08	0.93	0.024	27.0	<0.010
10/30/01	879	<0.002	<0.002					
11/28/01	804	<0.002	<0.002		1.3	<0.020	24.9	0.014

Table A3.4. Page 1 of 2. Drainage quality data for the 0.67% sulfur greenstone prediction field bin (#4).

Concentrations are in mg/L, pH is in standard units, conductivity is in µS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alk	SO_4	Ca	Mg	Na	K	Co	Cu	Ni	Zn	Fe
08/14/00	1164	550	8.74	185	79.5	48.0	39.2	12.3	2.42	<0.002	**0.126**	0.027	**0.126**	0.018
08/29/00		600	8.54	205										
09/12/00	2581	3200	7.51	45	197	408	57.4	145	28.1					0.165
10/11/00		3750	7.84	80										
10/17/00	1187	6750	7.30	60	386	834	108	265	33.5	0.007	0.015	0.006	<0.002	0.368
10/27/00		5000	7.36											
11/07/00	1989	2700	7.37	48	332	357	31.3	136	29.9	0.003	0.008	0.003	0.004	0.132
11/20/00	664	2750	7.65	48	363	386	31.7	138	27.5					0.172
04/12/01	2889	1075	7.59	55	179	147	12.0	44.6	12.0	<0.002	0.004	<0.002	<0.002	<0.002
04/25/01	2637	825	7.78	40	142	110	9.04	49.6	8.80					<0.002
05/10/01	1213	775	7.85	55	142	98.6	8.99	40.3	12.1					<0.002
05/23/01	1974	600	7.99		112	70.7	5.64	32.3	12.1	<0.002	0.004	<0.002	<0.002	<0.002
06/15/01	3290	500	8.06	60	107	67.8	4.66	22.4	11.9					<0.002
08/02/01	1483	500	7.82	95	123	67.7	5.03	15.7	12.7	<0.002	0.006	0.003	<0.002	<0.002
08/20/01	904	600	8.36	85	173	83.2	6.65	16.4	13.3					0.076
09/12/01	250	600	7.83	75	191	91.5	7.32	15.0	13.5					0.072
10/11/01	2042	550	8.17	63	210	100	8.78	13.4	11.2	<0.002	<0.002	<0.002	<0.002	0.073
10/30/01	1016	675	7.66	60	276	128	10.3	12.5	11.5					0.108
11/28/01	927	825	7.77	55	282	130	10.9	12.3	10.6					0.099

Values that appear anomalous are in bold.

Table A3.4. Page 2 of 2. Drainage quality data for the 0.67% sulfur greenstone prediction field bin (#4).

Concentrations are in mg/L.

Date	Volume (L)	Mn	Al	Si	N	NH_3N	NO_3^{2}	TP
08/14/00	1164	0.008	<0.002	5.96	<0.02	0.054	0.80	0.014
09/12/00	2581	0.004	<0.002	5.98	3.9	1.59	214	0.014
10/17/00	1187	0.030	<0.002	5.30	3.1	0.491	466	0.031
11/07/00	1989	0.021	0.013	4.18	2.5	0.103	183	0.029
11/20/00	664	0.019	<0.002	4.22				
04/11/01	2889	0.014	<0.002	2.24	1.2	0.355	53.1	0.036
04/25/01	2637	<0.002	<0.002					
05/10/01	1213	<0.002	<0.002		0.58	0.047	30.8	0.018
05/23/01	1974	<0.002	<0.002		0.65	0.027	24.4	<0.010
06/15/01	3290	<0.002	0.004					
08/02/01	1483	<0.002	<0.002		0.64	0.033	11.4	<0.010
08/20/01	904	<0.002	0.003		0.40	0.024	10.9	0.018
09/12/01	250	<0.002	<0.002					
10/11/01	2042	<0.002	<0.002	8.52	0.53	0.052	9.32	0.014
10/30/01	1016	<0.002	0.003					
11/28/01	927	<0.002	0.003		0.25	<0.020	9.72	0.013

Figure A3.1. Drainage quality vs. time for the 0.02% S prediction field bin (#1).

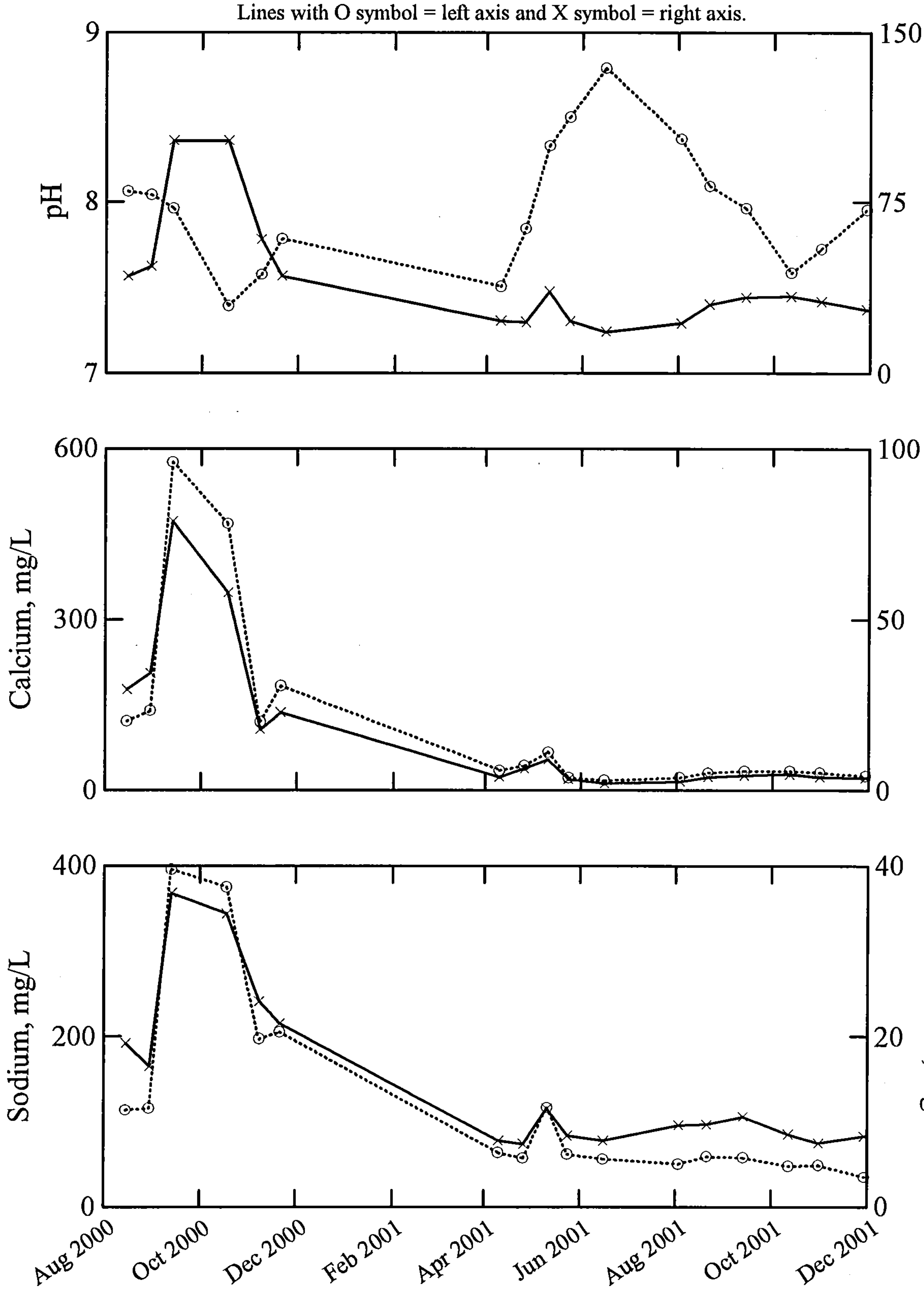


Figure A3.2. Drainage quality vs. time for the 0.20% S prediction field bin (#2).

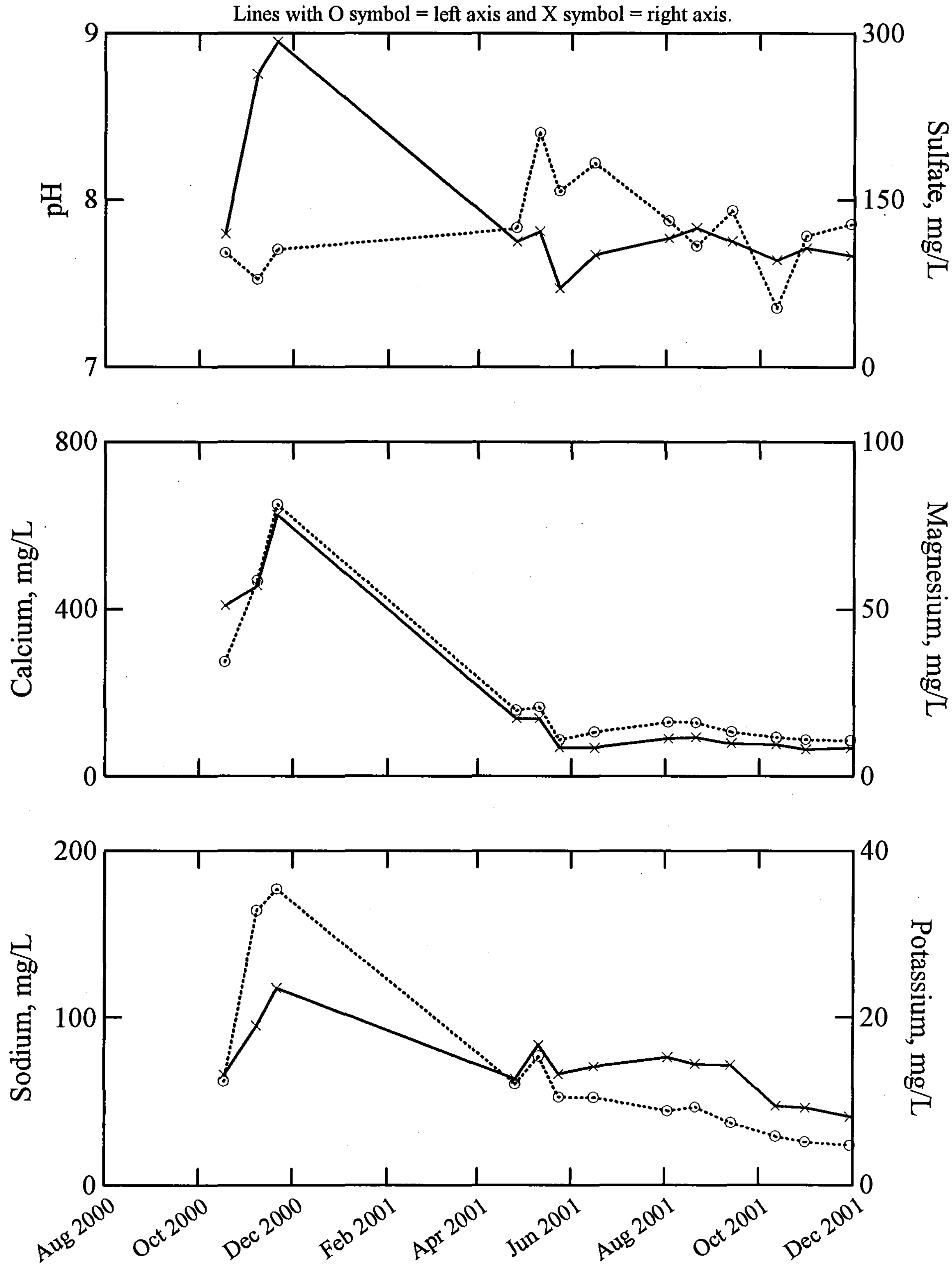


Figure A3.3. Drainage quality vs. time for the 0.39% S prediction field bin (#3).

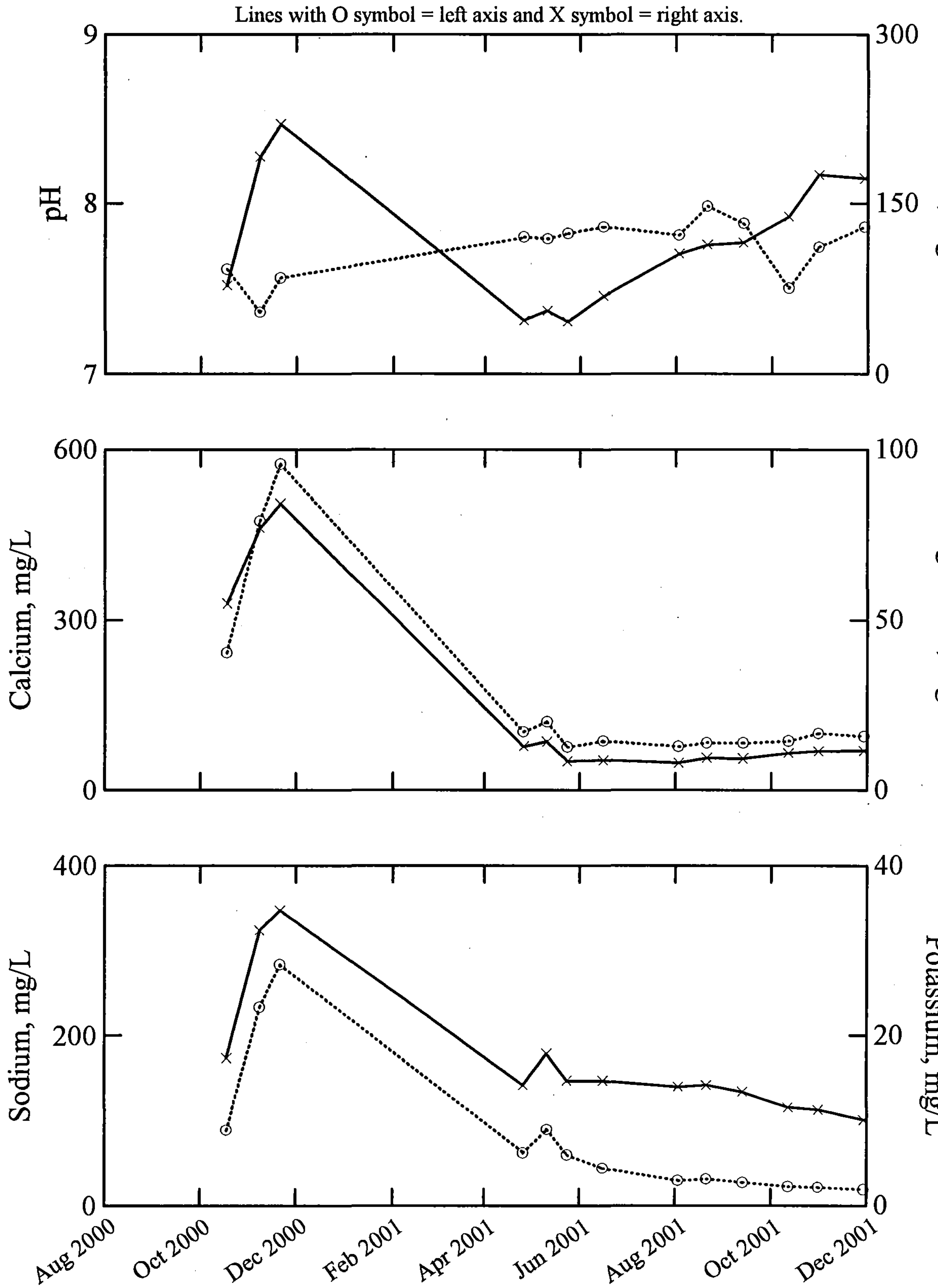


Figure A3.4. Drainage quality vs. time for the 0.67% S prediction field bin (#4).

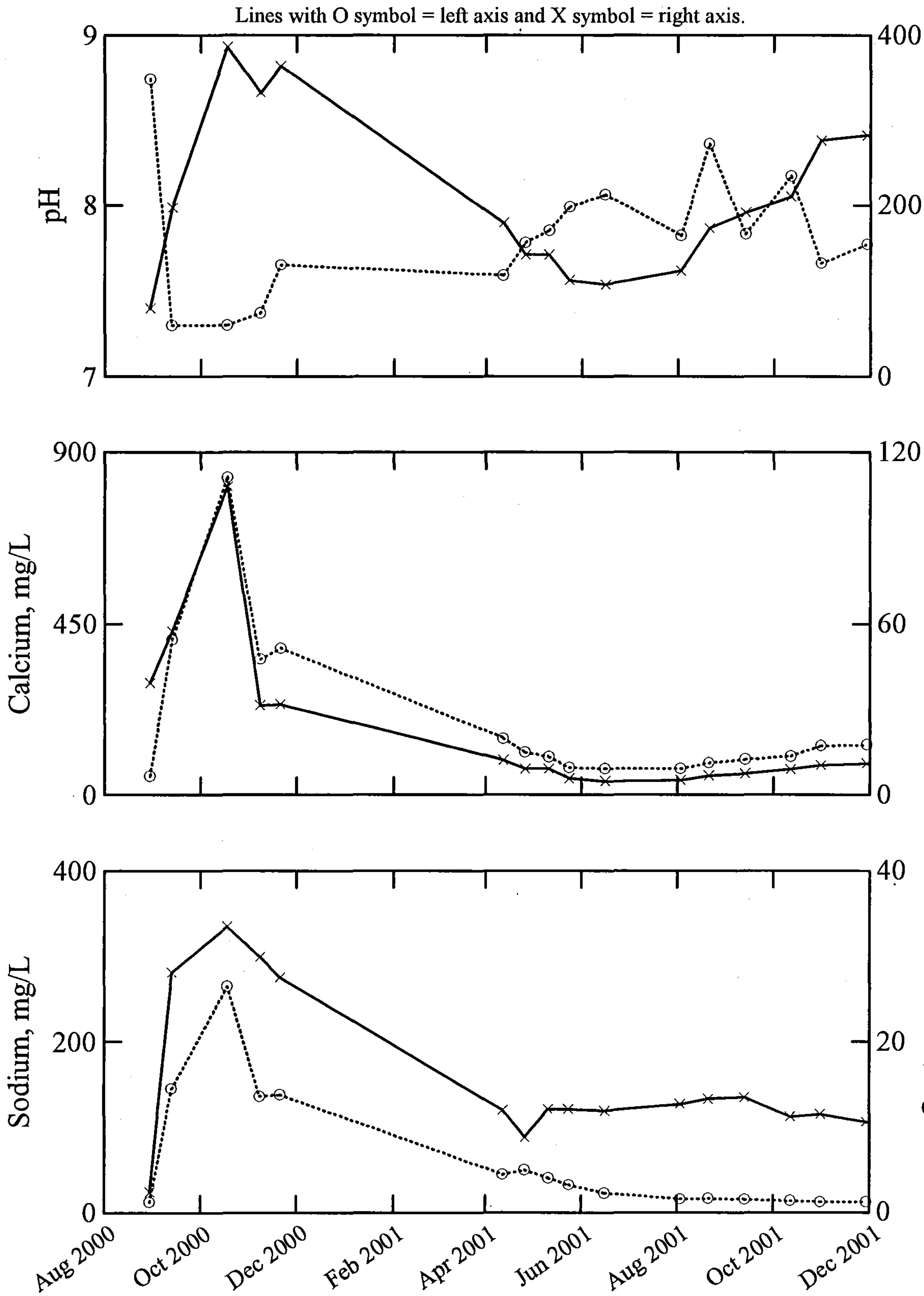


Table A3.5. Drainage quality data from the limestone addition control field tank (#1).

Concentrations are in mg/L, pH is in standard units, conductivity is in μS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alkalinity	SO_4	Ca	Mg	N	NH_3N	NO_3^2	TP
11/07/00	35	7500	7.42	50	683	926	104	6.8	1.68	515	0.082
03/22/01	60	2950	7.51		253	413	46.4				
04/09/01	34	1450	7.47	60	260	206	21.6				
04/25/01	121	900	7.82	70	108	138	13.4				
05/10/01	25	1325	8.04	95	210	190	20.0	4.8	0.988	77.8	0.044
05/23/01	58	875	7.80		180	138	13.0				
06/15/01	92	800	8.68	70	258	120	10.9				
08/02/01	40	800	8.44	100	256	136	11.4	1.9	0.055	16.8	0.026
08/20/01	28	950	8.13	55	355	149	12.3				
09/12/01	9	1250	8.31	55	522	233	20.3				
09/28/01	24	850	8.12	35	398	175	15.6				
10/11/01	49	825	7.21	25	398	163	15.0				
10/30/01	31	925	7.73	25	433	178	16.5	0.93	0.030	20.3	0.016
11/26/01	64	950	7.58	25	428	175	16.7				

Table A3.6. Drainage quality data from the limestone addition control field tank (#6).

Concentrations are in mg/L, pH is in standard units, conductivity is in µS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alkalinity	SO_4	Ca	Mg	N	NH_3N	NO_3^2	TP
11/07/00	32	5600	7.61	55	374	689	82.1	3.5	1.30	407	0.082
03/22/01	34	3300	7.50		311	418	49.1				
04/09/01	38	1950	7.62	55	262	260	29.0				
04/25/01	110	625	7.92	75	90.9	81.3	8.85				
05/10/01	15	800	8.07	80	172	109	10.8	3.4	0.657	33.5	0.039
05/23/01	58	750	7.73		188	110	10.9				
06/15/01	76	700	8.14	90	218	107	9.82				
08/02/01	32	700	8.23	70	219	119	10.9	1.1	0.044	13.7	0.010
08/20/01	26	950	8.44	55	381	164	14.6				
09/12/01	8	1250	8.17	50	564	236	21.9				
09/28/01	23	900	8.01	60	405	160	15.6				
10/11/01	50	725	7.32	23	353	138	13.6				
10/30/01	25	700	7.68	23	345	131	13.6	0.66	0.027	13.3	0.011
11/26/01	60	900	7.49	23	384	151	15.8				

Table A3.7. Drainage quality data from the limestone addition 1:1 ratio field tank (#2).

Concentrations are in mg/L, pH is in standard units, conductivity is in µS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alkalinity	SO_4	Ca	Mg	N	NH_3N	NO_3^2	TP
11/07/00	36	5000	7.46	50	496	708	84.5	4.8	1.49	391	0.082
03/22/01	30	3700	7.55		519	486	54.0				
04/09/01	35	1100	7.75	45	184	163	17.9				
04/25/01	114	800	7.94	85	85	95.6	10.6				
05/10/01	21	900	8.25	105	118	122	13.4	3.5	0.713	42.0	0.038
05/23/01	56	725	7.96		163	108	10.9				
06/15/01	83	700	8.14	90	180	99.3	9.91				
08/02/01	46	725	8.44	100	230	118	12.0	1.3	0.046	14.9	0.015
08/20/01	26	975	8.50	75	333	144	14.9				
09/12/01	5	1100	8.35	85	434	201	21.0				
09/28/01	22	850	8.15	65	376	161	17.7				
10/11/01	51	675	7.48	43	275	125	14.0				
10/30/01	28	600	8.06	43	222	114	12.6	0.83	0.023	14.1	0.011
11/26/01	41	850	7.73	43	305	132	16.0				

Table A3.8. Drainage quality data from the limestone addition 1:1 ratio field tank (#5).

Concentrations are in mg/L, pH is in standard units, conductivity is in μS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alkalinity	SO_4	Ca	Mg	N	NH_3N	NO_3^{2}	TP
11/07/00	34	5800	7.55	60	694	1090	144	8.1	3.69	697	0.093
03/22/01	25	2750	7.58		294	360	40.7				
04/09/01	23	2050	7.78	70	306	268	30.7				
04/25/01	109	700	8.03	95	85.2	94.4	10.2				
05/10/01	18	1075	8.31	105	151	153	16.6	3.8	0.695	48.5	0.036
05/23/01	58	800	7.92		231	122	12.2				
06/15/01	87	800	8.29	90	238	122	11.3				
08/02/01	48	925	8.33	100	310	169	15.8	1.6	0.047	19.4	0.013
08/20/01	26	1150	8.45	75	434	213	18.7				
09/12/01	6	1450	8.38	75	720	290	28.2				
09/28/01	22	1100	8.25	55	519	217	20.9				
10/11/01	50	825	7.65	40	406	169	16.2				
10/30/01	32	825	8.19	40	381	154	15.7	0.94	0.032	15.4	<0.010
11/26/01	50	950	7.79	40	394	163	16.7				

Table A3.9. Drainage quality data from the greenstone limestone addition 3:1 ratio field tank (#3).

Concentrations are in mg/L, pH is in standard units, conductivity is in µS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alkalinity	SO_4	Ca	Mg	N	NH_3N	NO_3^2	TP
11/07/00	39	5700	7.59	65	733	925	112.0	5.3	1.31	546	0.085
03/22/01	64	3450	7.49		366	436	54.4				
04/09/01	34	1625	7.82	85	165	210	25.7				
04/25/01	113	725	7.98	105	103	97.3	11.4				
05/10/01	13	850	8.36	135	168	120	14.3	3.5	0.476	32.3	0.037
05/23/01	58	750	7.96		192	110	12.4				
06/15/01	86	750	8.54	113	224	119	12.3				
08/02/01	46	850	8.31	115	304	139	16.0	1.4	0.053	12.0	0.015
08/20/01	26	1125	8.50	100	456	207	22.7				
09/12/01	6	1450	8.43	110	704	296	34.0				
09/28/01	23	1050	8.28	85	475	200	24.6				
10/11/01	49	825	7.60	53	395	167	20.5				
10/30/01	30	850	8.05	55	397	162	21.4	0.97	<0.020	18.0	0.012
11/26/01	51	950	7.82	58	394	166	21.5				

Table A3.10. Drainage quality data from the limestone addition 3:1 ratio field tank (#4).

Concentrations are in mg/L, pH is in standard units, conductivity is in μS/cm, and net alkalinity is in mg/L as $CaCO_3$.

Date	Volume (L)	Conductivity	pH	Net Alkalinity	SO_4	Ca	Mg	N	NH_3N	NO_3^2	TP
11/07/00	36	5750	7.61	60	673	785	99.1	4.1	1.28	480	0.075
03/22/01	48	3100	7.52		386	396	48.5				
04/09/01	34	1500	7.77	70	191	206	24.9				
04/25/01	111	750	7.99	85	85.6	99.6	11.9				
05/10/01	15	1000	8.22	105	169	140	16.7	3.4	0.821	47.6	0.034
05/23/01	63	750	7.91		162	106	12.5				
06/15/01	83	700	8.42	90	189	105	11.1				
08/02/01	34	650	8.24	90	222	113	12.6	1.1	0.093	12.1	0.017
08/20/01	28	950	8.34	85	363	160	17.9				
09/12/01	8	1225	8.41	95	545	230	26.6				
09/28/01	23	850	8.32	90	387	157	19.7				
10/11/01	48	700	7.64	50	327	132	16.6				
10/30/01	31	800	8.04	50	364	143	18.6	1.2	0.031	18.2	0.014
11/26/01	44	925	7.88	50	374	150	19.5				

Table A3.11. Initial scan results of additional parameters for the limestone addition field tanks (11/07/00).

Concentrations are in mg/L

Treatment	Tank #	Volume (L)	Na	K	Si	Mn	Al	Fe	Co	Cu	Ni	Zn
Control	1	35	257	38	4.14	0.034	<0.002	0.393	0.007	0.018	0.006	0.004
1:1 ratio	2	36	242	34.9	3.88	0.066	<0.002	0.269	0.005	0.018	0.005	0.018
3:1 ratio	3	39	329	46.3	3.08	0.069	0.055	0.444	0.007	0.018	0.005	0.002
3:1 ratio	4	36	278	38.7	3.73	0.028	<0.002	0.319	0.006	0.016	0.004	0.004
1:1 ratio	5	34	396	54.6	4.62	0.065	<0.002	0.491	0.008	0.022	0.006	0.007
Control	6	32	249	32.8	3.97	0.048	<0.002	0.289	0.005	0.014	0.004	0.003

Figure A3.5. Drainage quality vs. time for the limestone addition control tank (#1).

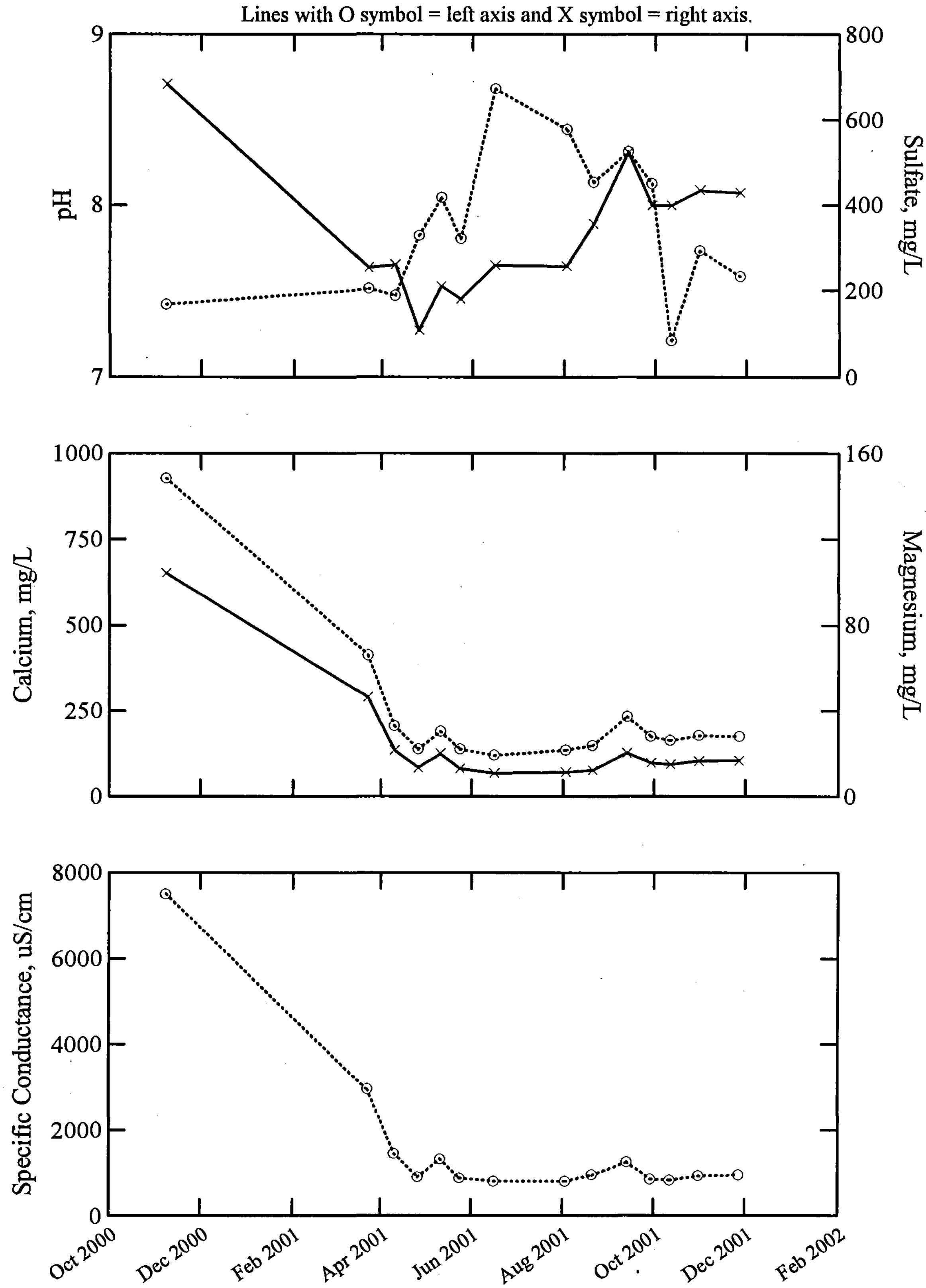


Figure A3.6. Drainage quality vs. time for the limestone addition control tank (#6).

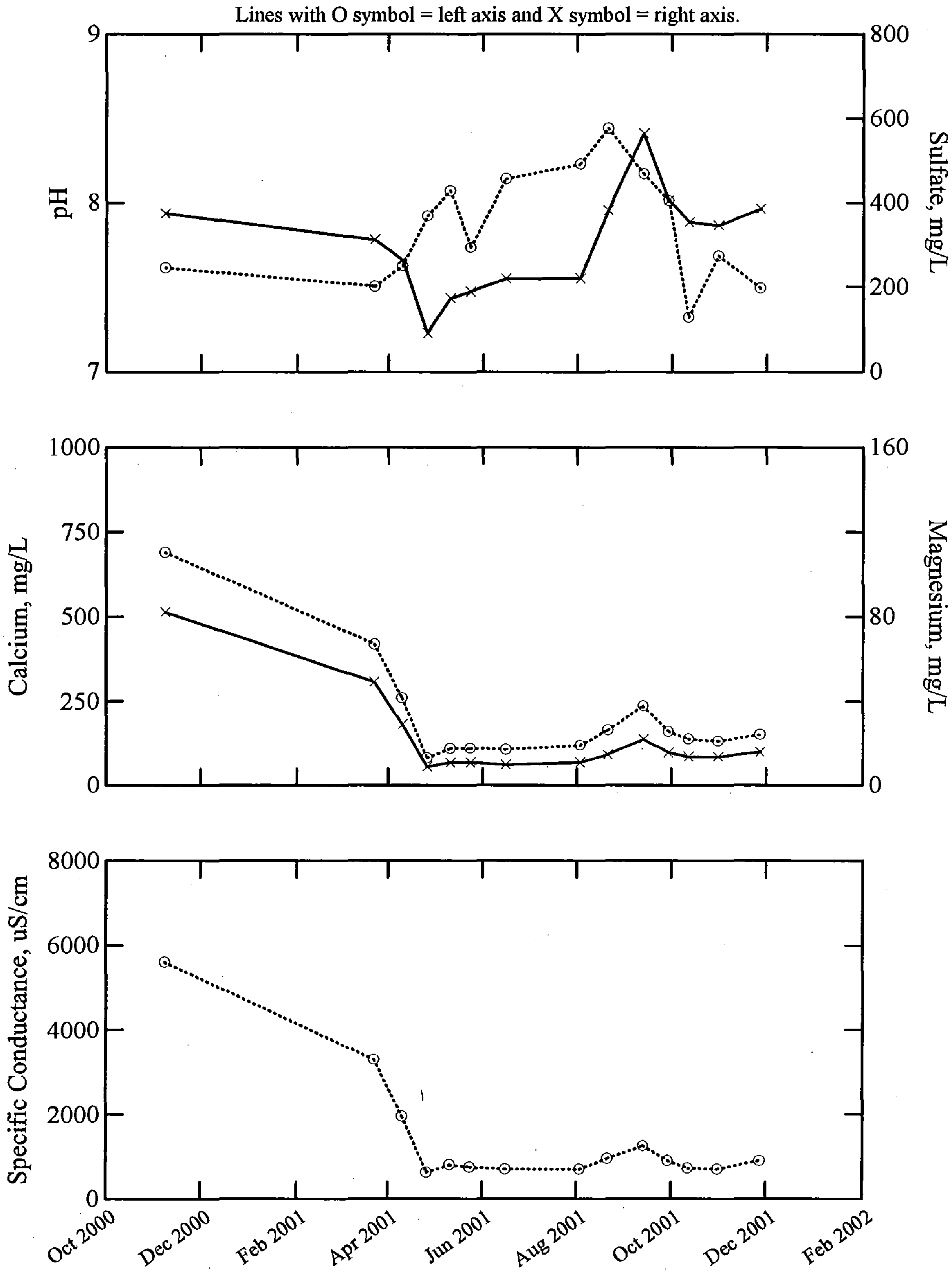


Figure A3.7. Drainage quality vs. time for the limestone addition 1:1 ratio tank (#2).

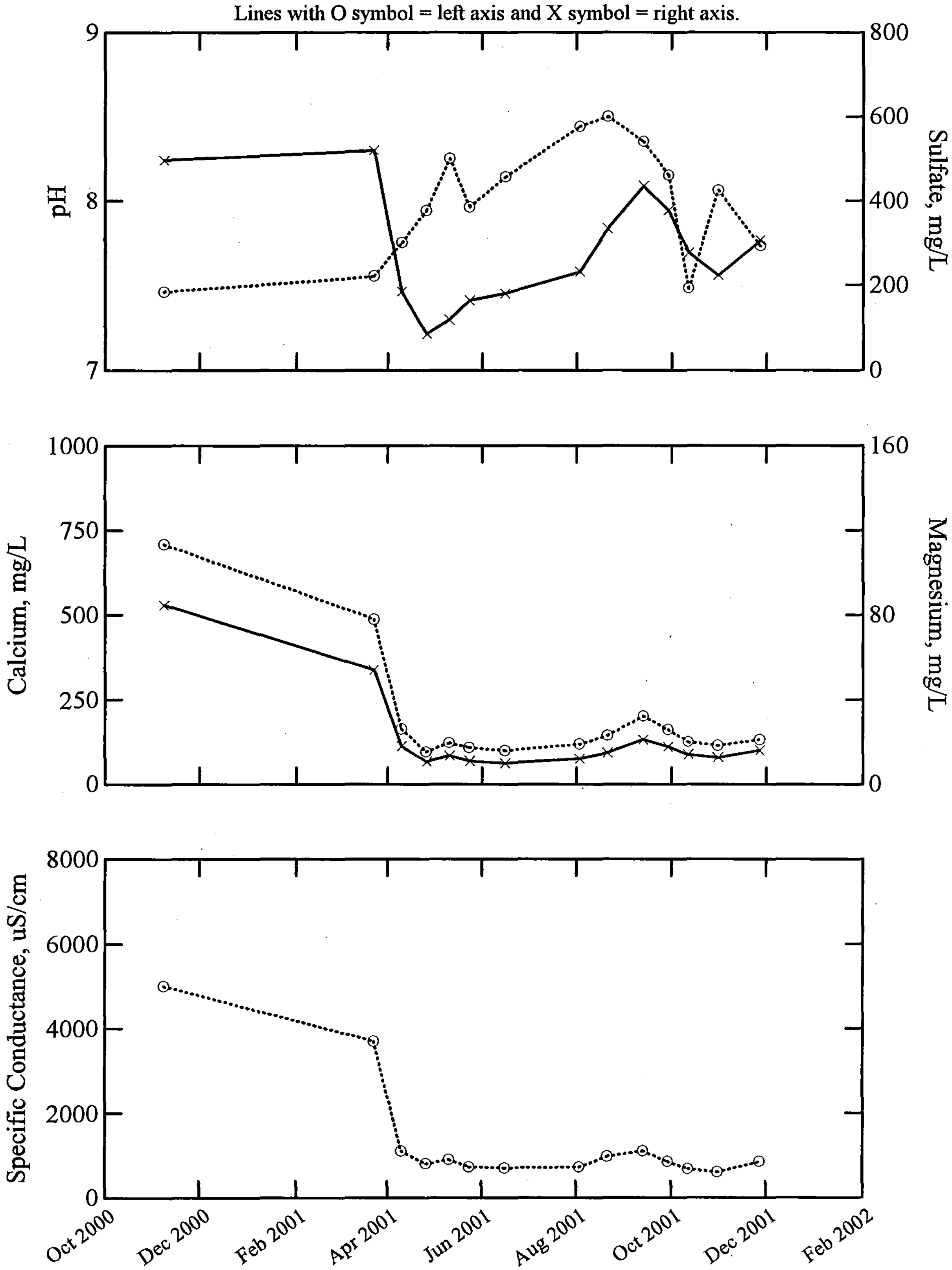


Figure A3.8. Drainage quality vs. time for the limestone addition 1:1 ratio tank (#5).

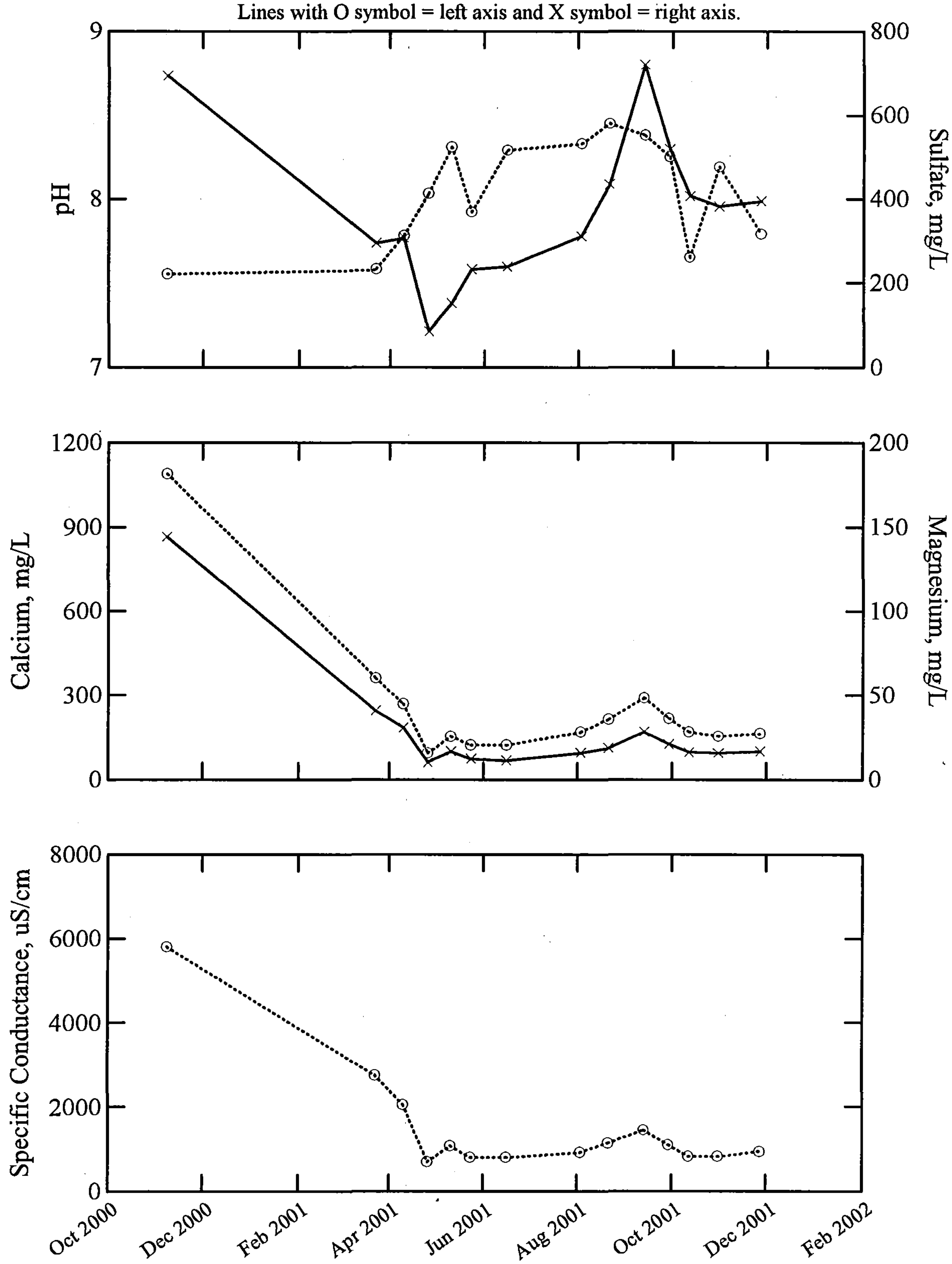


Figure A3.9. Drainage quality vs. time for the limestone addition 3:1 ratio tank (#3).

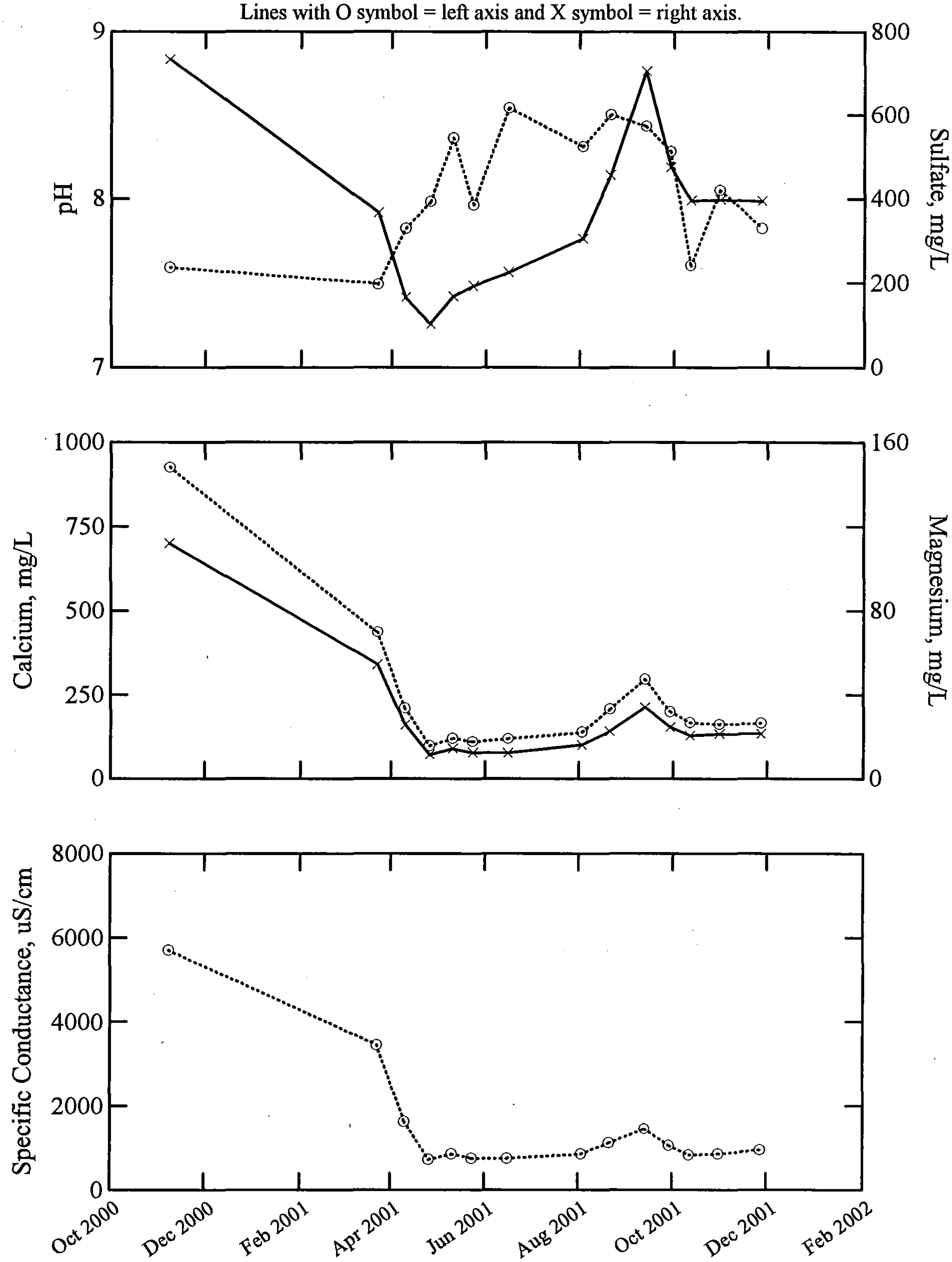
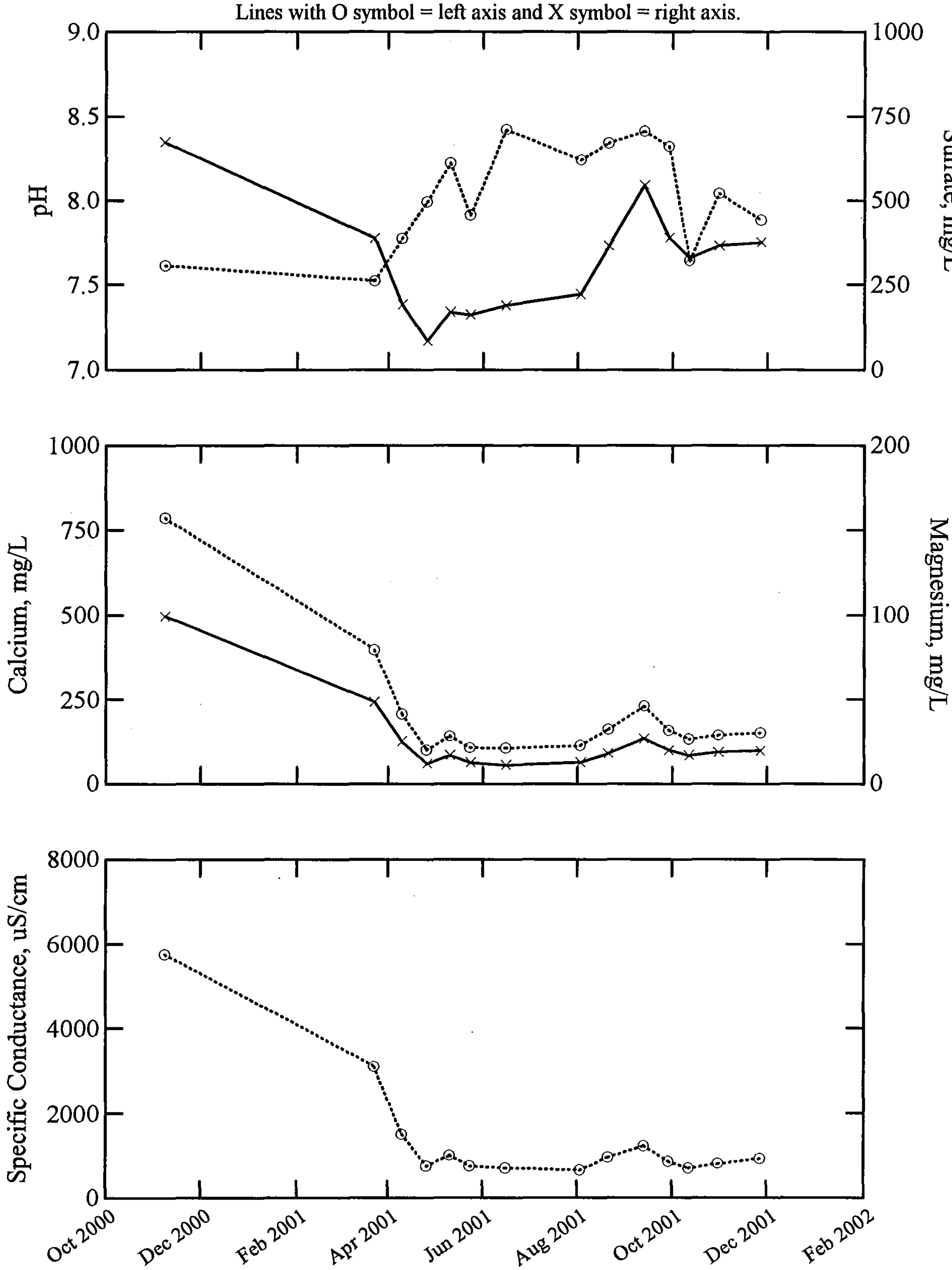


Figure A3.10. Drainage quality vs. time for the limestone addition 3:1 ratio tank (#4).



APPENDIX 4

CUMULATIVE SULFATE, CALCIUM, AND MAGNESIUM MASS RELEASE FROM FIELD PREDICTION BINS AND LIMESTONE ADDITION TANKS

Prediction Bins

Limestone Addition Tanks

Table A4.1. Cumulative sulfate, calcium and magnesium mass release from the 0.02% sulfur field prediction bin (#1).

Mass release recorded in moles, concentration in mg/L.

			Sulfate			Calcium			Magnesium	
Date	Volume (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
08/14/00	1202	42.0	0.526	0.526	122	3.66	3.66	29.6	1.46	1.46
08/29/00	722	46.4	0.349	0.874	140	2.52	6.18	34.3	1.02	2.48
09/12/00	1942	102	2.06	2.94	576	27.9	34.1	78.7	6.29	8.77
10/17/00	1226	102	1.30	4.24	468	14.3	48.4	57.9	2.92	11.7
11/07/00	1587	58.3	0.963	5.20	121	4.79	53.2	17.8	1.16	12.9
11/20/00	350	42.0	0.153	5.35	184	1.61	54.8	22.8	0.328	13.2
04/10/01	2702	22.7	0.639	5.99	34.6	2.33	57.1	3.87	0.430	13.6
04/25/01	3219	22.2	0.744	6.74	43.3	3.48	60.6	6.30	0.835	14.4
05/10/01	1650	35.4	0.608	7.34	67.1	2.76	63.3	9.00	0.611	15.1
05/23/01	1965	22.6	0.462	7.81	22.4	1.10	64.4	3.30	0.267	15.3
06/15/01	3009	18.1	0.567	8.37	17.5	1.31	65.8	1.99	0.246	15.6
08/02/01	1675	21.7	0.378	8.75	22.4	0.936	66.7	2.54	0.175	15.7
08/20/01	931	29.8	0.289	9.04	30.6	0.710	67.4	3.92	0.150	15.9
09/12/01	238	32.8	0.081	9.12	33.9	0.201	67.6	4.31	0.042	15.9
10/11/01	2195	33.2	0.759	9.88	33.6	1.84	69.4	4.73	0.427	16.4
10/30/01	824	31.0	0.266	10.15	30.8	0.633	70.1	3.91	0.133	16.5
11/28/01	981	27.6	0.282	10.43	25.0	0.612	70.7	3.62	0.146	16.6

Table A4.2. Cumulative sulfate, calcium and magnesium mass release from the 0.20% sulfur field prediction bin (#2).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Volume (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
10/17/00	1576	119	1.95	1.95	274	10.8	10.8	51.0	3.31	3.31
11/07/00	1739	263	4.76	6.71	467	20.3	31.0	56.9	4.07	7.38
11/20/00	493	292	1.50	8.21	649	7.98	39.0	78.1	1.58	8.96
4/9/2001*	1992	202	4.19	12.4	655	32.5	71.5	85.5	7.01	16.0
04/25/01	2982	112	3.48	15.9	157	11.7	83.2	17.2	2.11	18.1
05/10/01	1114	121	1.40	17.3	165	4.58	87.8	17.2	0.789	18.9
05/23/01	1680	70.1	1.23	18.5	86.3	3.62	91.4	8.47	0.586	19.5
06/15/01	2674	100	2.78	21.3	105	7.00	98.4	8.38	0.922	20.4
08/02/01	1612	115	1.93	23.2	129	5.19	104	11.2	0.743	21.1
08/20/01	1961	124	2.53	25.8	128	6.26	110	11.6	0.936	22.1
09/12/01	814	112	0.949	26.7	105	2.13	112	9.63	0.323	22.4
10/11/01	2677	95.2	2.65	29.4	92.5	6.18	118	9.33	1.03	23.4
10/30/01	851	106	0.939	30.3	87.0	1.85	120	7.95	0.278	23.7
11/28/01	839	99.4	0.868	31.2	85.0	1.78	122	8.37	0.289	24.0

Note: Starred (*) weeks concentrations for SO_4 were estimated by linear interpolation between the previous and subsequent.

Table A4.3. Cumulative sulfate, calcium and magnesium mass release from the 0.39% sulfur prediction field bin (#3).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Volume (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
10/17/00	1721	77.4	1.39	1.39	242	10.4	10.4	54.8	3.88	3.88
11/07/00	1403	191	2.79	4.18	474	16.6	27.0	76.9	4.44	8.32
11/20/00	536	220	1.23	5.40	574	7.67	34.6	84.0	1.85	10.2
4/10/2001*	2696	134	3.75	9.15	197	13.2	47.9	26.2	2.91	13.1
04/25/01	3143	47.0	1.54	10.7	102	7.99	55.9	12.8	1.66	14.7
05/10/01	1050	55.4	0.606	11.3	120	3.14	59.0	14.2	0.614	15.3
05/23/01	1555	45.8	0.741	12.0	75.4	2.92	61.9	8.41	0.538	15.9
06/15/01	2565	68.1	1.82	13.9	85.9	5.49	67.4	8.69	0.917	16.8
08/02/01	1177	105	1.29	15.1	76.2	2.24	69.7	7.95	0.385	17.2
08/20/01	778	113	0.915	16.1	83.0	1.61	71.3	9.38	0.300	17.5
09/12/01	219	115	0.262	16.3	82.3	0.449	71.7	9.18	0.083	17.6
10/11/01	1746	138	2.51	18.8	86.0	3.74	75.5	10.8	0.776	18.3
10/30/01	879	175	1.60	20.4	99.6	2.18	77.7	11.4	0.412	18.8
11/28/01	804	172	1.44	21.9	94.2	1.89	79.6	11.5	0.380	19.1

Note: Starred (*) weeks concentrations for SO_4 were estimated by linear interpolation between the previous and subsequent.

Table A4.4. Cumulative sulfate, calcium and magnesium mass release from the 0.67% sulfur field prediction bin (#4).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Volume (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
08/14/00	1164	79.5	0.963	0.963	48	1.39	1.39	39.2	1.88	1.88
09/12/00	2581	197	5.29	6.26	408	26.3	27.7	57.4	6.10	7.97
10/17/00	1187	386	4.77	11.0	834	24.7	52.3	108	5.28	13.2
11/07/00	1989	332	6.87	17.9	357	17.7	70.0	31.3	2.56	15.8
11/20/00	664	363	2.51	20.4	386	6.4	76.4	31.7	0.866	16.7
04/12/00	2889	179	5.38	25.8	147	10.6	87.0	12.0	1.43	18.1
04/25/01	2637	142	3.90	29.7	110	7.23	94.3	9.04	0.981	19.1
05/10/01	1213	142	1.79	31.5	98.6	2.98	97.2	8.99	0.449	19.5
05/23/01	1974	112	2.30	33.8	70.7	3.48	101	5.64	0.458	20.0
06/15/01	3290	107	3.66	37.5	67.8	5.56	106	4.66	0.631	20.6
08/02/01	1483	123	1.90	39.3	67.7	2.50	109	5.03	0.307	20.9
08/20/01	904	173	1.63	41.0	83.2	1.88	111	6.65	0.247	21.2
09/12/01	250	191	0.497	41.5	91.5	0.570	111	7.32	0.075	21.3
10/11/01	2042	210	4.46	45.9	100	5.09	116	8.78	0.738	22.0
10/30/01	1016	276	2.92	48.9	128	3.24	120	10.3	0.431	22.4
11/28/01	927	282	2.72	51.6	130	3.01	123	10.9	0.416	22.8

Figure A4.1. Cumulative sulfate, calcium, and magnesium mass release for 0.02% sulfur field prediction bin (#1).

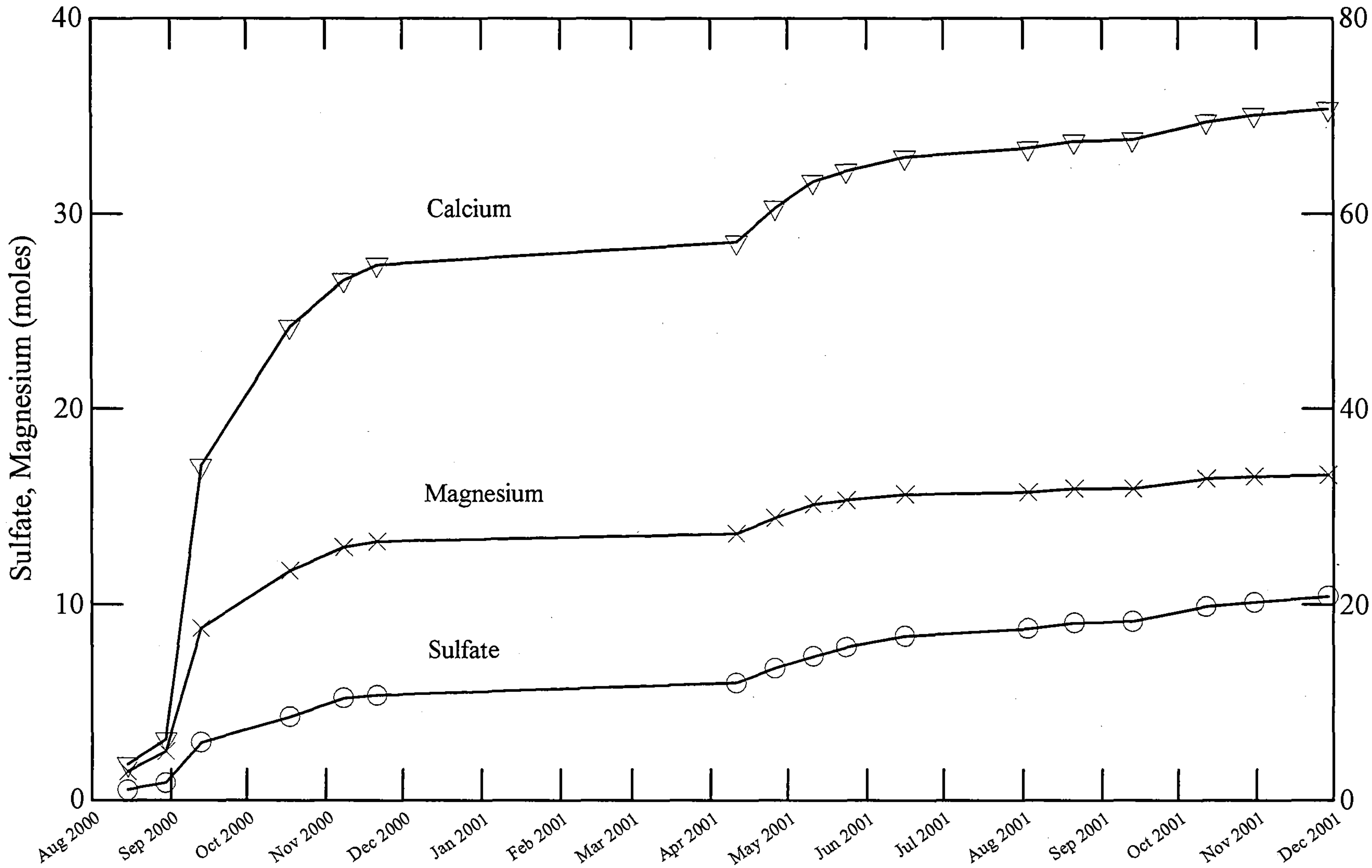


Figure A4.2. Cumulative sulfate, calcium, and magnesium mass release for 0.20% sulfur field prediction bin (#2).

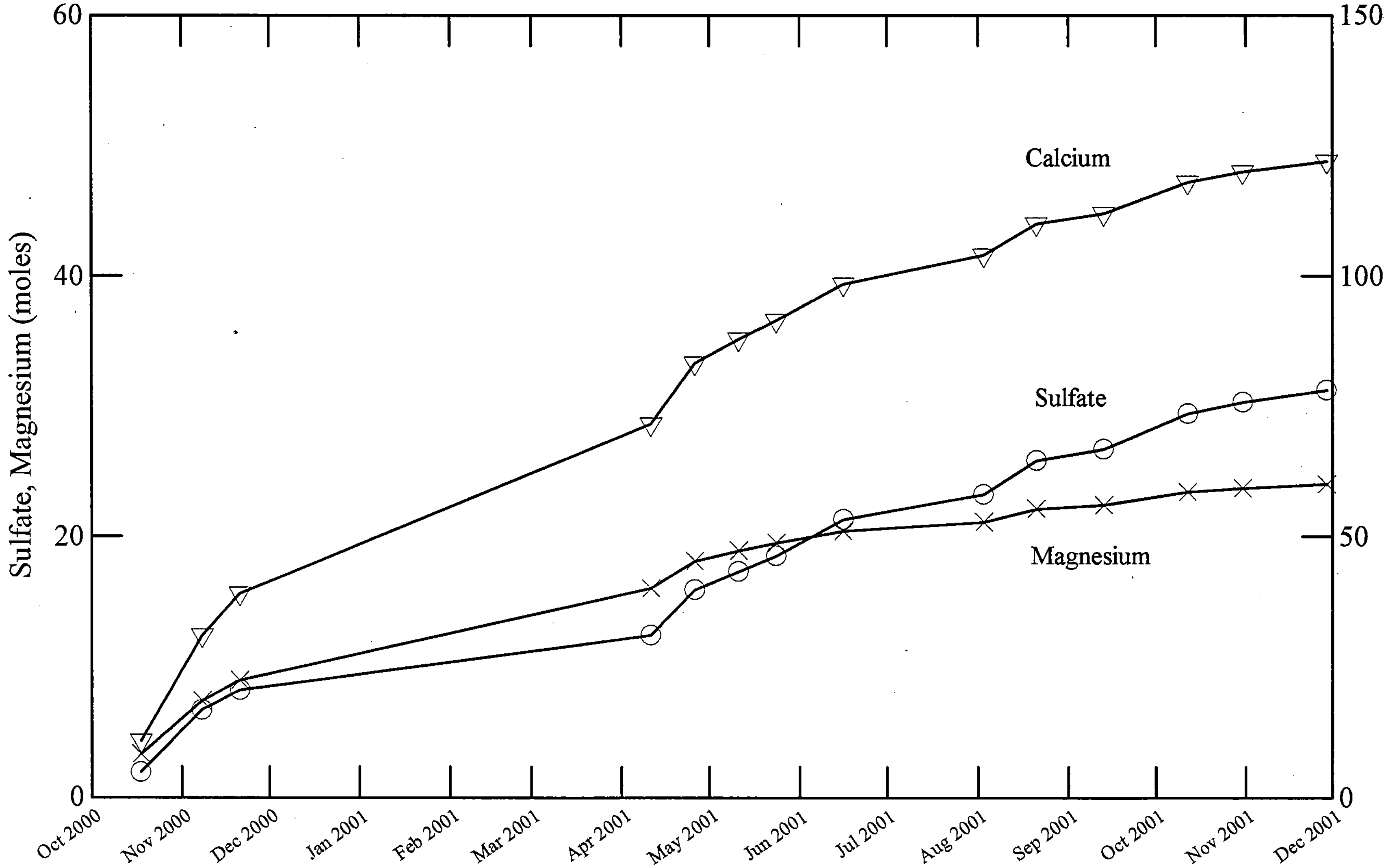


Figure A4.3. Cumulative sulfate, calcium, and magnesium mass release for 0.39% sulfur field prediction bin (#3).

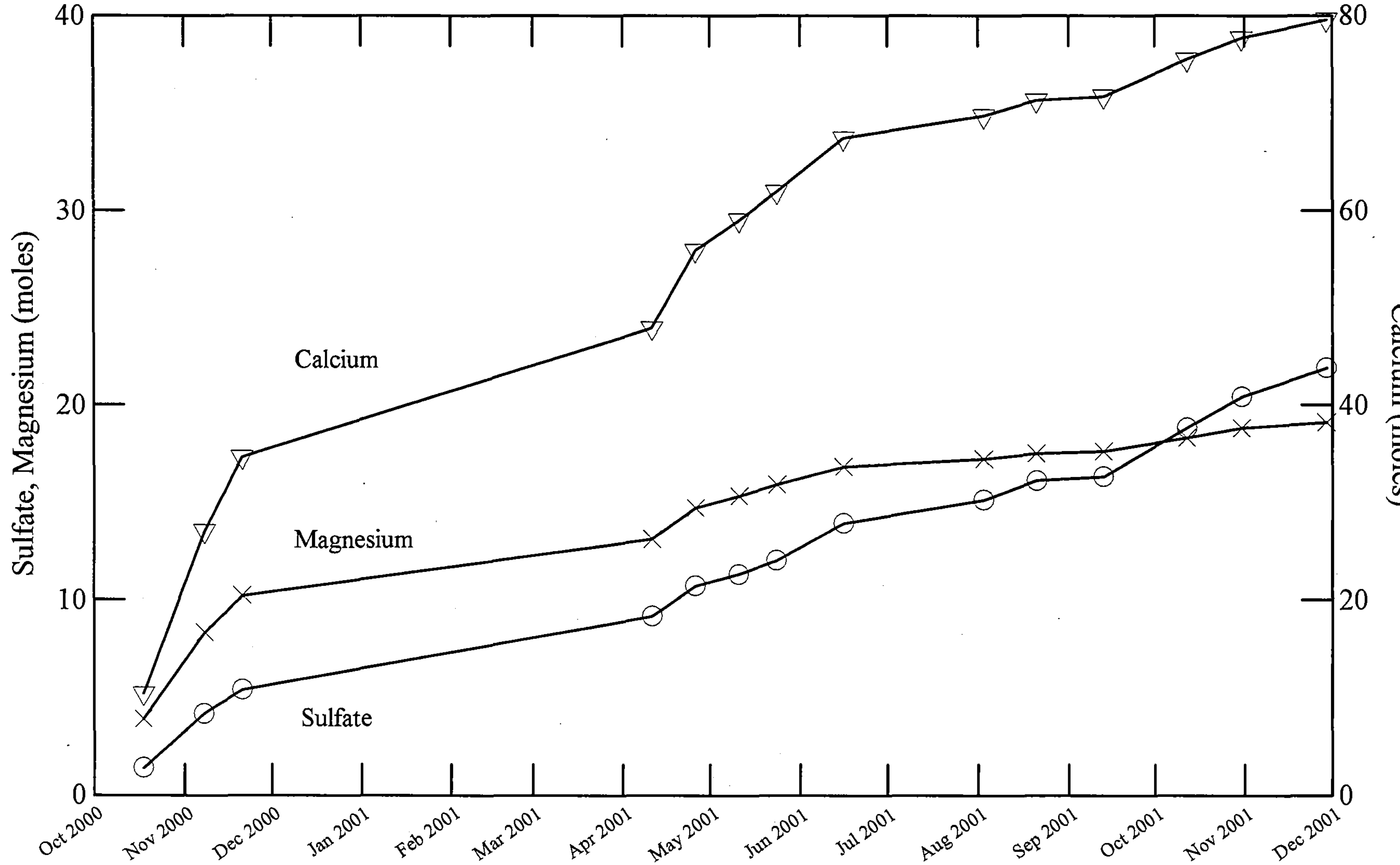


Figure A4.4. Cumulative sulfate, calcium, and magnesium mass release for 0.67% sulfur field prediction bin (#4).

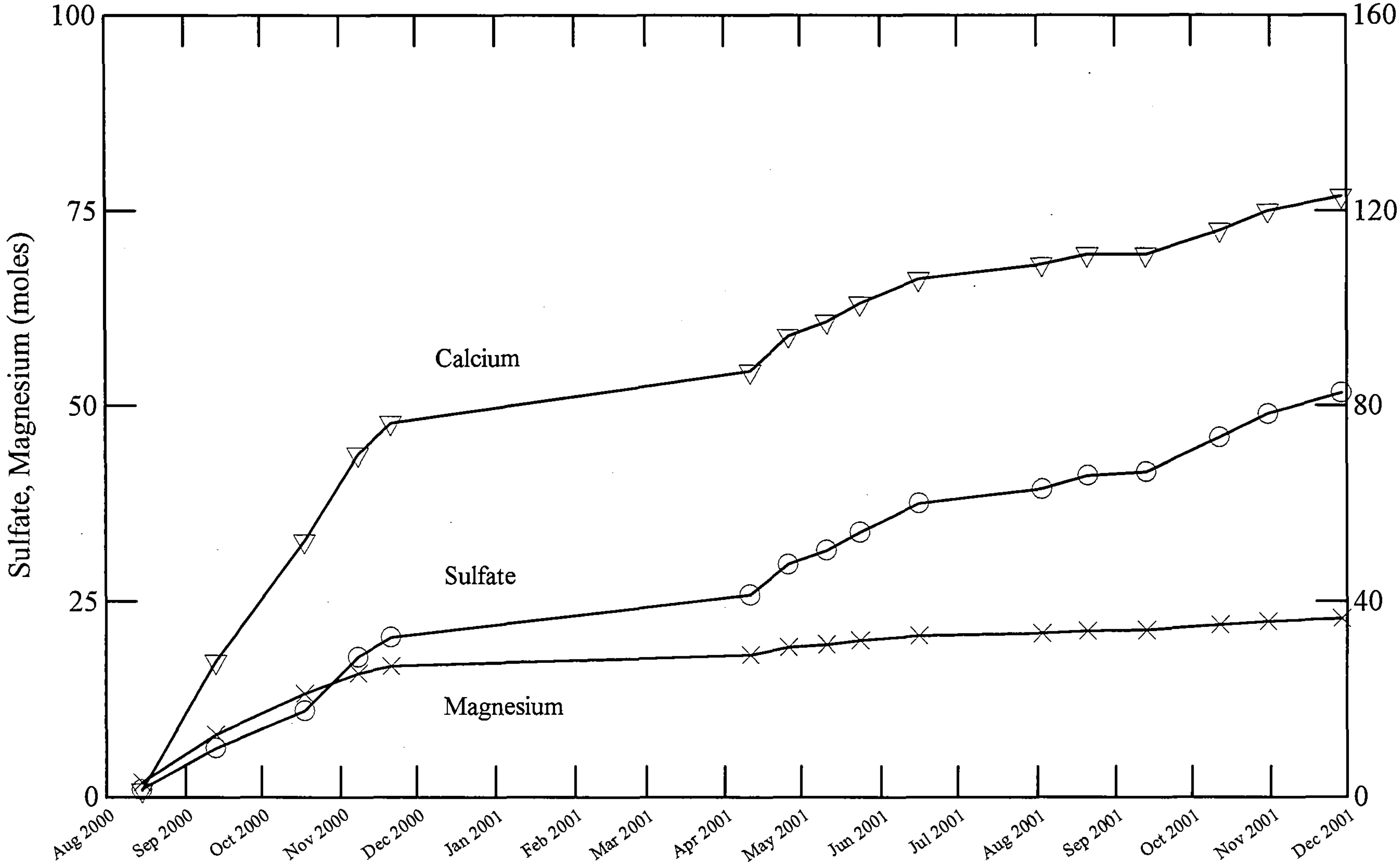


Table A4.5. Cumulative sulfate, calcium and magnesium mass release from the limestone addition control field tank (#1).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Vol. (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
11/07/00	35	683	0.249	0.249	926	0.808	0.808	104	0.150	0.150
03/22/01	60	253	0.159	0.408	413	0.621	1.43	46.4	0.115	0.265
04/09/01	34	260	0.091	0.498	206	0.172	1.60	21.6	0.030	0.295
04/25/01	121	108	0.136	0.634	138	0.417	2.02	13.4	0.067	0.361
05/10/01	25	210	0.055	0.690	190	0.120	2.14	20.0	0.021	0.382
05/23/01	58	180	0.109	0.799	138	0.201	2.34	13.0	0.031	0.413
06/15/01	92	258	0.247	1.05	120	0.275	2.61	10.9	0.041	0.455
08/02/01	40	256	0.108	1.15	136	0.137	2.75	11.4	0.019	0.474
08/20/01	28	355	0.103	1.26	149	0.103	2.85	12.3	0.014	0.488
09/12/01	9	522	0.047	1.30	233	0.050	2.90	20.3	0.007	0.495
09/28/01	24	398	0.099	1.40	175	0.104	3.01	15.6	0.015	0.510
10/11/01	49	398	0.203	1.61	163	0.199	3.21	15.0	0.030	0.541
10/30/01	31	433	0.140	1.75	178	0.138	3.35	16.5	0.021	0.562
11/26/01	64	428	0.287	2.03	175	0.281	3.63	16.7	0.044	0.606

Table A4.6. Cumulative sulfate, calcium and magnesium mass release from the limestone addition control field tank (#6).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Vol. (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
11/07/00	32	374	0.126	0.126	689	0.558	0.558	82.1	0.110	0.110
03/22/01	34	311	0.112	0.238	418	0.359	0.917	49.1	0.070	0.179
04/09/01	38	262	0.104	0.341	260	0.246	1.16	29.0	0.045	0.225
04/25/01	110	91	0.104	0.446	81	0.224	1.39	8.85	0.040	0.265
05/10/01	15	172	0.027	0.473	109	0.041	1.43	10.8	0.007	0.271
05/23/01	58	188	0.114	0.587	110	0.160	1.59	10.9	0.026	0.298
06/15/01	76	218	0.173	0.760	107	0.203	1.79	9.82	0.031	0.328
08/02/01	32	219	0.072	0.832	119	0.094	1.89	10.9	0.014	0.343
08/20/01	26	381	0.105	0.937	164	0.108	1.99	14.6	0.016	0.359
09/12/01	8	564	0.047	0.984	236	0.047	2.04	21.9	0.007	0.366
09/28/01	23	405	0.098	1.082	160	0.092	2.13	15.6	0.015	0.381
10/11/01	50	353	0.183	1.264	138	0.171	2.30	13.6	0.028	0.408
10/30/01	25	345	0.090	1.355	131	0.082	2.39	13.6	0.014	0.423
11/26/01	60	384	0.241	1.60	151	0.227	2.61	15.8	0.039	0.462

Table A4.7. Cumulative sulfate, calcium and magnesium mass release from the limestone addition 1:1 ratio field tank (#2).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Vol. (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
11/07/00	36	496	0.188	0.188	708	0.643	0.643	84.5	0.127	0.127
03/22/01	30	519	0.165	0.353	486	0.369	1.01	54.0	0.068	0.194
04/09/01	35	184	0.068	0.420	163	0.144	1.16	17.9	0.026	0.220
04/25/01	114	85.0	0.101	0.521	95.6	0.272	1.43	10.6	0.050	0.270
05/10/01	21	118	0.026	0.547	122	0.064	1.49	13.4	0.012	0.282
05/23/01	56	163	0.096	0.642	108	0.152	1.64	10.9	0.025	0.307
06/15/01	83	180	0.155	0.797	99.3	0.205	1.85	9.91	0.034	0.341
08/02/01	46	230	0.109	0.907	118	0.134	1.98	12.0	0.023	0.363
08/20/01	26	333	0.090	0.996	144	0.093	2.07	14.9	0.016	0.379
09/12/01	5	434	0.024	1.02	201	0.027	2.10	21.0	0.005	0.384
09/28/01	22	376	0.086	1.11	161	0.088	2.19	17.7	0.016	0.400
10/11/01	51	275	0.146	1.25	125	0.159	2.35	14.0	0.029	0.429
10/30/01	28	222	0.066	1.32	114	0.081	2.43	12.6	0.015	0.444
11/26/01	41	305	0.129	1.45	132	0.134	2.56	16.0	0.027	0.470

Table A4.8. Cumulative sulfate, calcium and magnesium mass release from the limestone addition 1:1 ratio field tank (#5).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Vol. (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
11/07/00	34	694	0.249	0.249	1090	0.936	0.936	144	0.204	0.204
03/22/01	25	294	0.077	0.326	360	0.226	1.16	40.7	0.042	0.246
04/09/01	23	306	0.072	0.398	268	0.151	1.31	30.7	0.029	0.275
04/25/01	109	85	0.097	0.495	94	0.257	1.57	10.2	0.046	0.321
05/10/01	18	151	0.028	0.523	153	0.069	1.64	16.6	0.012	0.333
05/23/01	58	231	0.139	0.662	122	0.175	1.81	12.2	0.029	0.362
06/15/01	87	238	0.215	0.877	122	0.264	2.08	11.3	0.040	0.402
08/02/01	48	310	0.154	1.03	169	0.201	2.28	15.8	0.031	0.433
08/20/01	26	434	0.117	1.15	213	0.137	2.42	18.7	0.020	0.453
09/12/01	6	720	0.045	1.19	290	0.043	2.46	28.2	0.007	0.460
09/28/01	22	519	0.118	1.31	217	0.118	2.58	20.9	0.019	0.479
10/11/01	50	406	0.213	1.52	169	0.212	2.79	16.2	0.034	0.512
10/30/01	32	381	0.127	1.65	154	0.123	2.91	15.7	0.021	0.533
11/26/01	50	394	0.206	1.86	163	0.204	3.12	16.7	0.034	0.568

Table A4.9. Cumulative sulfate, calcium and magnesium mass release from the limestone addition 3:1 ratio field tank (#3).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Vol. (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
11/07/00	39	733	0.296	0.296	925	0.894	0.894	112.0	0.179	0.179
03/22/01	64	366	0.242	0.538	436	0.691	1.58	54.4	0.142	0.321
04/09/01	34	165	0.058	0.596	210	0.178	1.76	25.7	0.036	0.357
04/25/01	113	103	0.121	0.718	97.3	0.275	2.04	11.4	0.053	0.410
05/10/01	13	168	0.023	0.741	120	0.040	2.08	14.3	0.008	0.418
05/23/01	58	192	0.116	0.857	110	0.160	2.24	12.4	0.030	0.448
06/15/01	86	224	0.201	1.06	119	0.256	2.49	12.3	0.044	0.491
08/02/01	46	304	0.147	1.20	139	0.161	2.65	16.0	0.031	0.522
08/20/01	26	456	0.126	1.33	207	0.137	2.79	22.7	0.025	0.546
09/12/01	6	704	0.044	1.37	296	0.044	2.83	34.0	0.008	0.555
09/28/01	23	475	0.115	1.49	200	0.116	2.95	24.6	0.023	0.578
10/11/01	49	395	0.202	1.69	167	0.204	3.15	20.5	0.041	0.620
10/30/01	30	397	0.126	1.82	162	0.123	3.28	21.4	0.027	0.646
11/26/01	51	394	0.209	2.03	166	0.211	3.49	21.5	0.045	0.691

Table A4.10. Cumulative sulfate, calcium and magnesium mass release from the limestone addition 3:1 ratio field tank (#4).

Mass release recorded in moles, concentration in mg/L.

		Sulfate			Calcium			Magnesium		
Date	Vol. (L)	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass	Conc.	Mass	Sum Mass
11/07/00	36	673	0.251	0.251	785	0.700	0.700	99.1	0.146	0.146
03/22/01	48	386	0.192	0.442	396	0.471	1.17	48.5	0.095	0.241
04/09/01	34	191	0.068	0.511	206	0.177	1.35	24.9	0.035	0.276
04/25/01	111	85.6	0.099	0.610	99.6	0.276	1.62	11.9	0.054	0.331
05/10/01	15	169	0.026	0.635	140	0.051	1.67	16.7	0.010	0.341
05/23/01	63	162	0.106	0.741	106	0.166	1.84	12.5	0.032	0.373
06/15/01	83	189	0.163	0.904	105	0.217	2.06	11.1	0.038	0.411
08/02/01	34	222	0.080	0.984	113	0.097	2.15	12.6	0.018	0.429
08/20/01	28	363	0.105	1.09	160	0.111	2.27	17.9	0.020	0.449
09/12/01	8	545	0.045	1.13	230	0.046	2.31	26.6	0.009	0.458
09/28/01	23	387	0.091	1.22	157	0.088	2.40	19.7	0.018	0.476
10/11/01	48	327	0.165	1.39	132	0.159	2.56	16.6	0.033	0.509
10/30/01	31	364	0.117	1.51	143	0.110	2.67	18.6	0.024	0.533
11/26/01	44	374	0.171	1.68	150	0.164	2.83	19.5	0.035	0.568

Figure A4.5. Cumulative sulfate, calcium, and magnesium mass release from the limestone addition control field tank (#1).

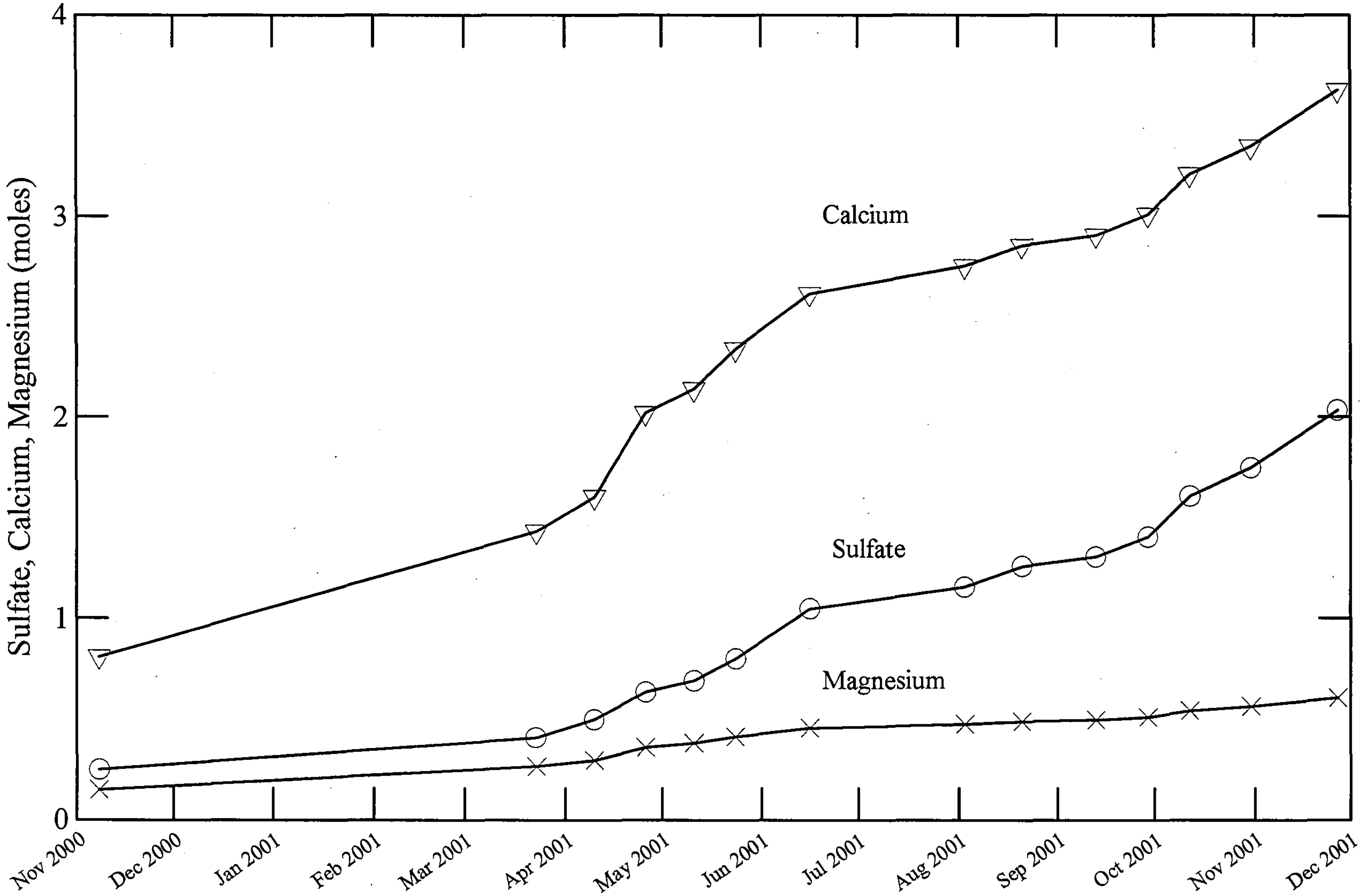


Figure A4.6. Cumulative sulfate, calcium, and magnesium mass release from the limestone addition control field tank (#6).

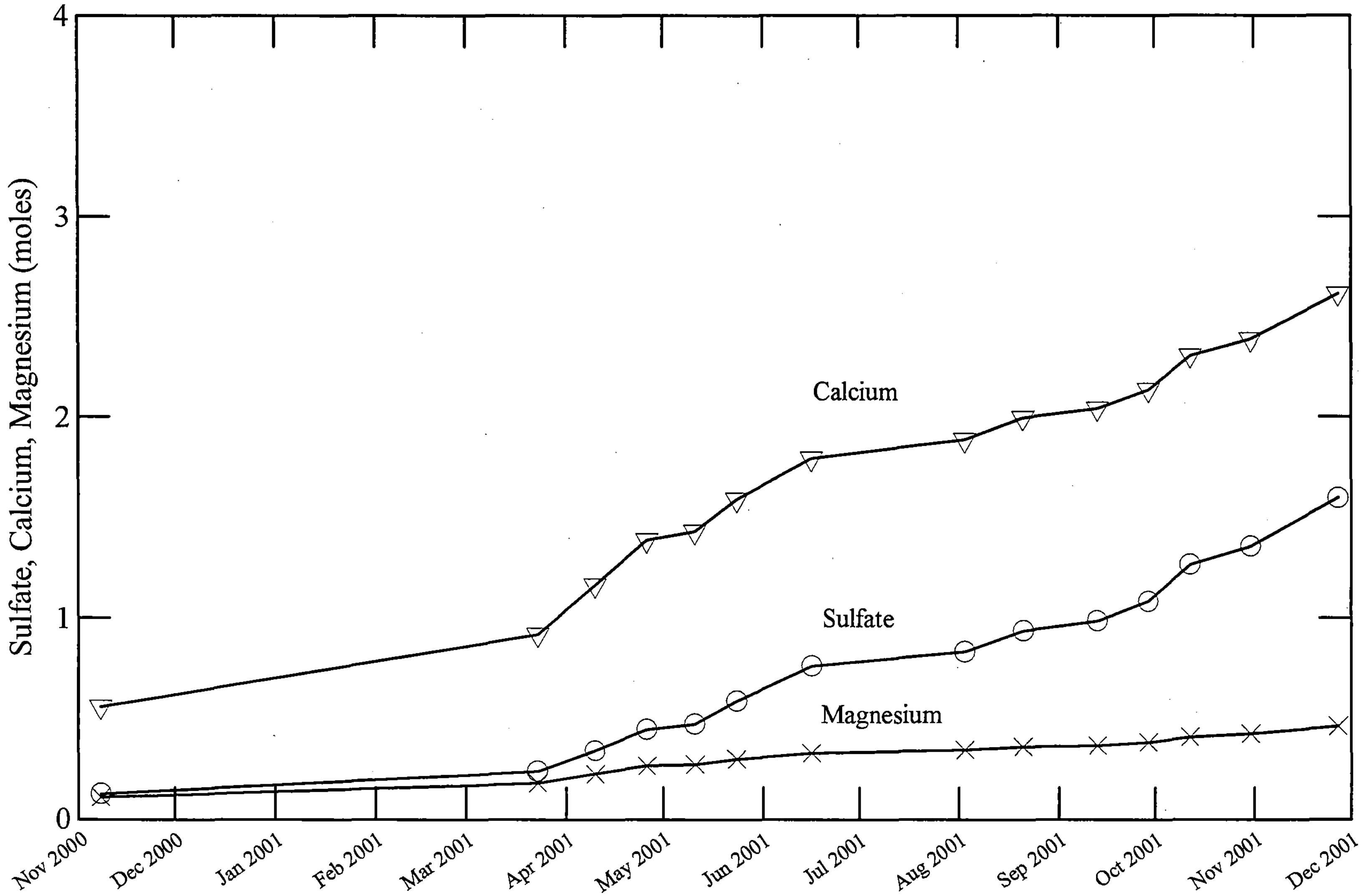


Figure A4.7. Cumulative sulfate, calcium, and magnesium mass release from the limestone addition 1:1 ratio field tank (#2).

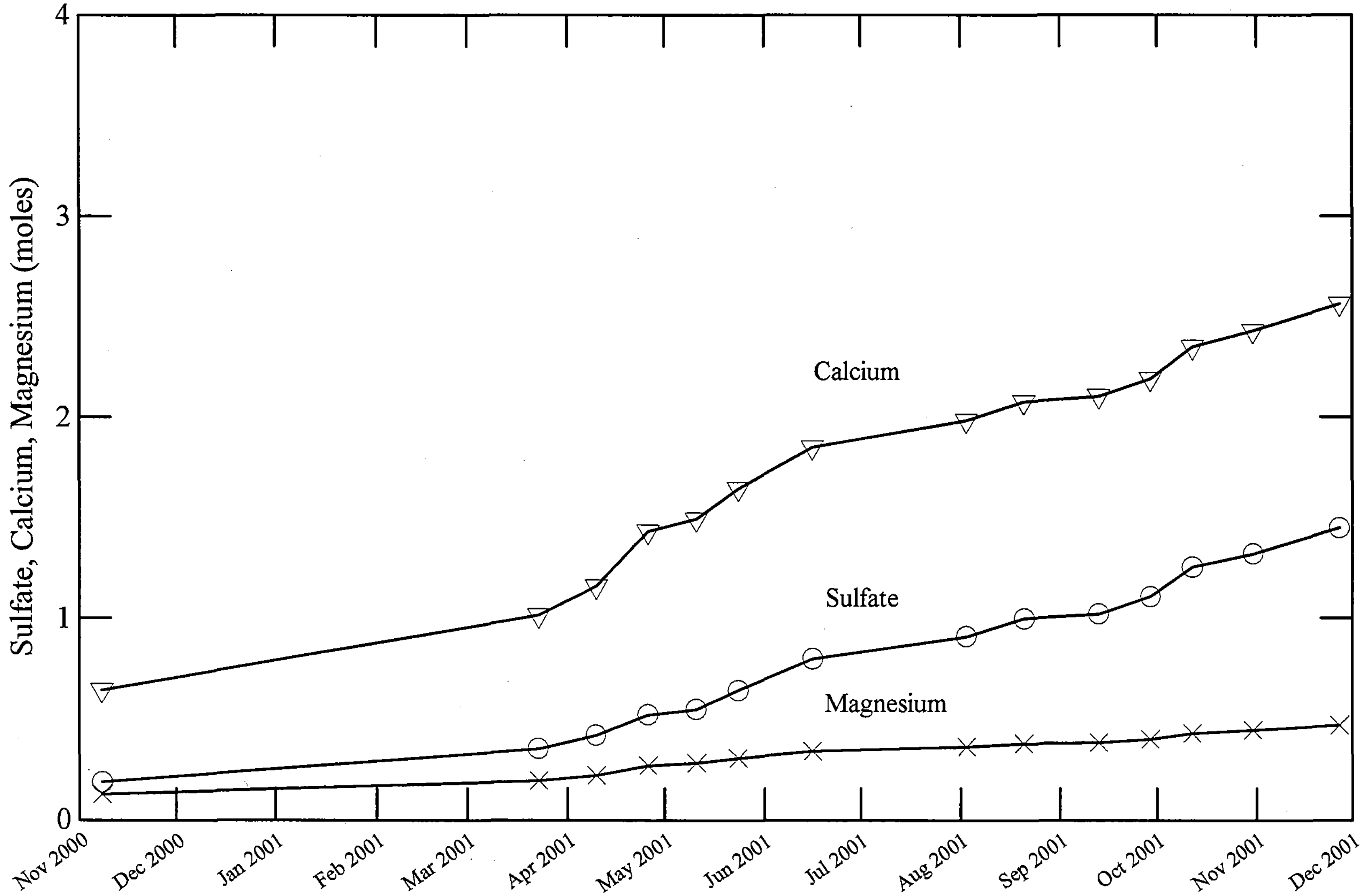


Figure A4.8. Cumulative sulfate, calcium, and magnesium mass release from the limestone addition 1:1 ratio field tank (#5).

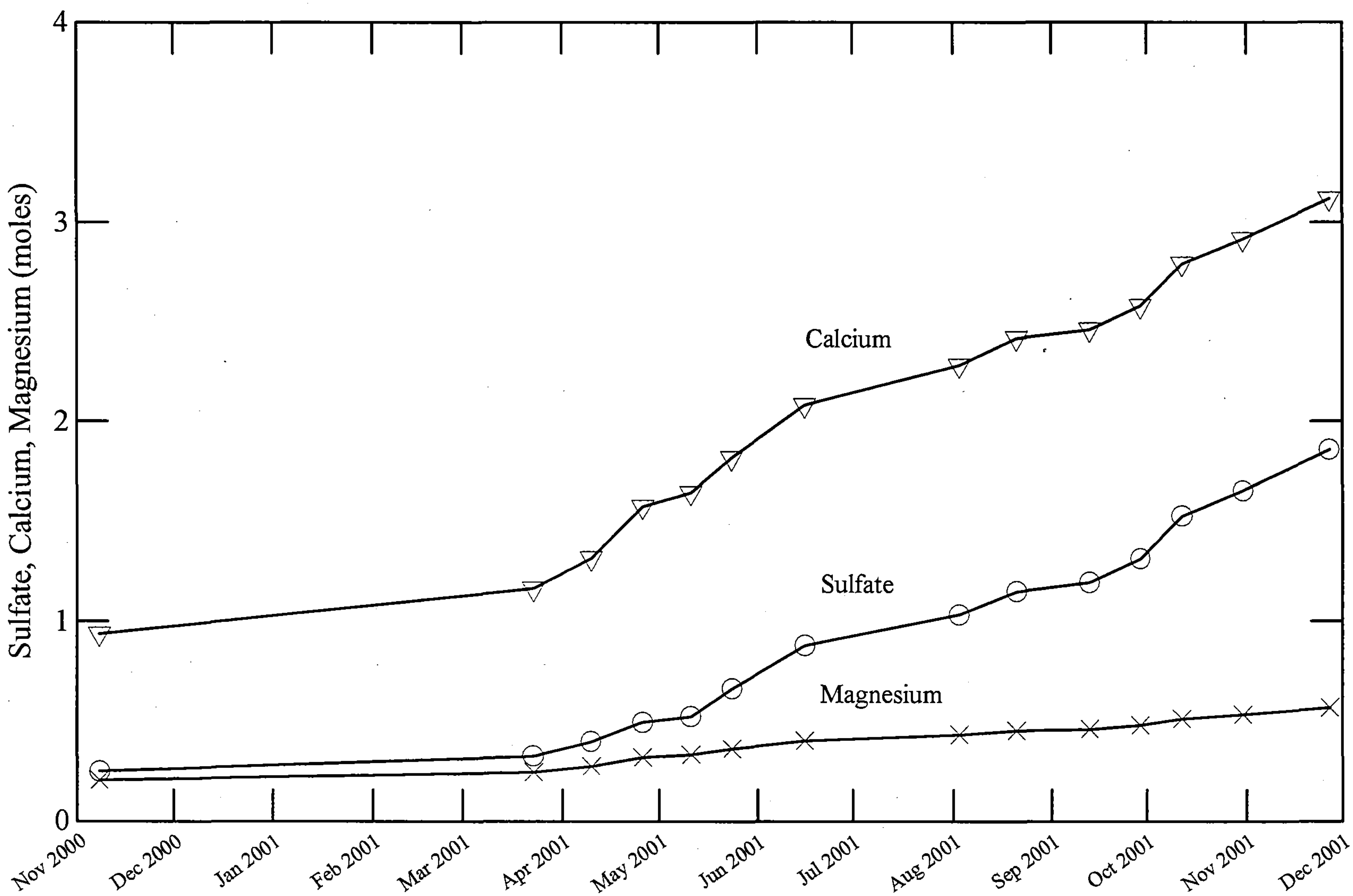


Figure A4.9. Cumulative sulfate, calcium, and magnesium mass release from the limestone addition 3:1 ratio field tank (#3).

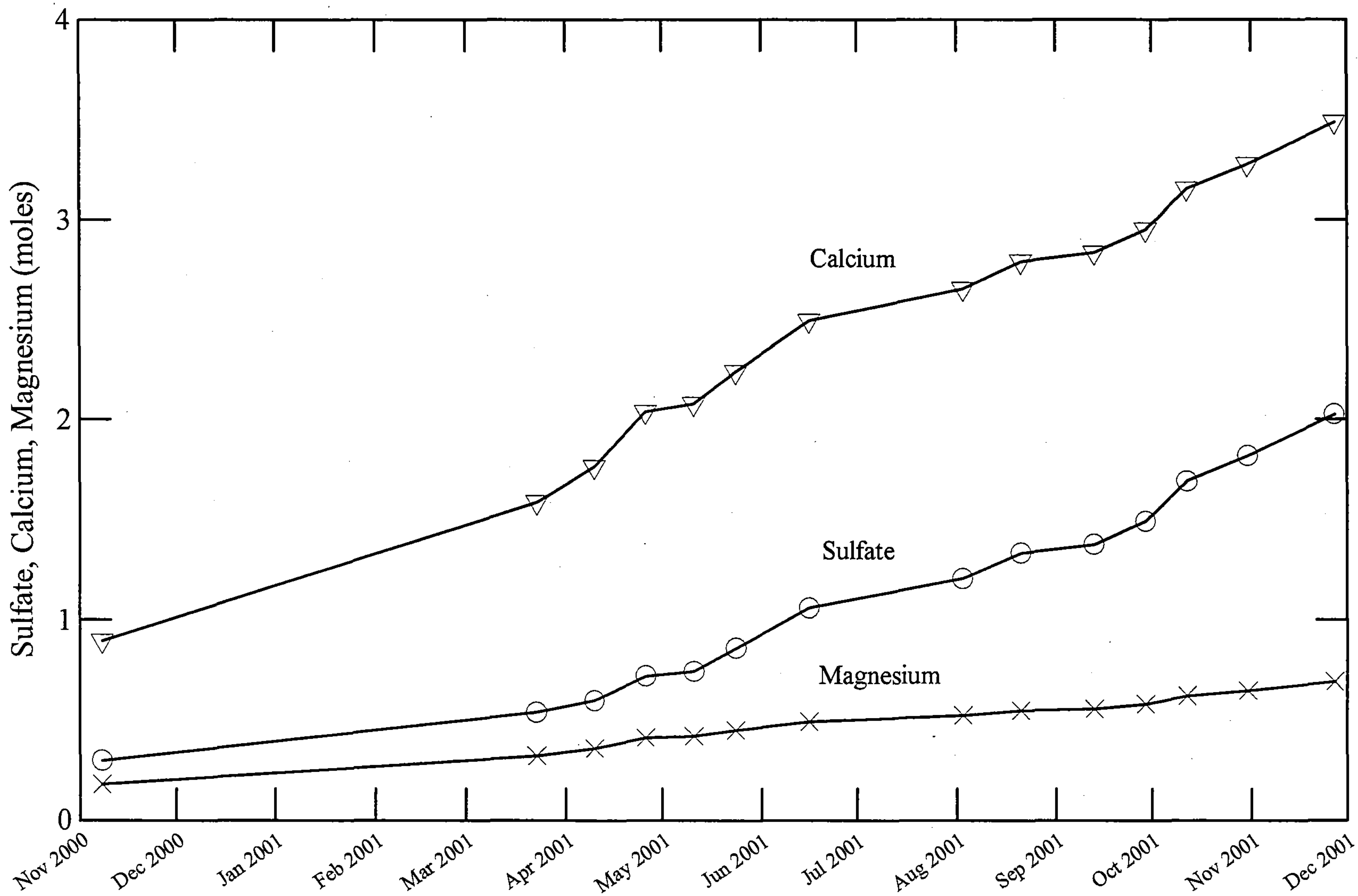
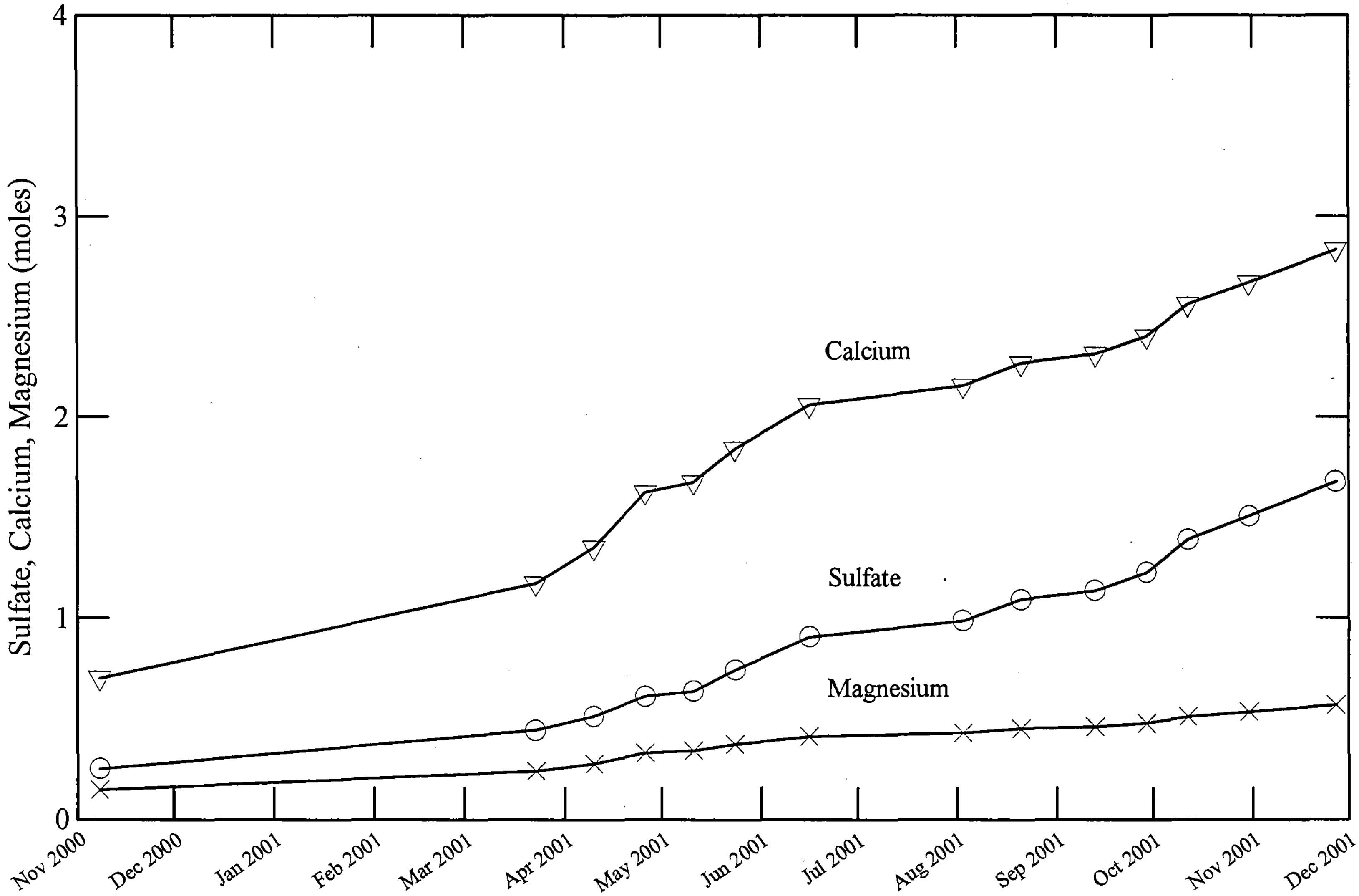


Figure A4.10. Cumulative sulfate, calcium, and magnesium mass release from the limestone addition 3:1 ratio field tank (#4).



APPENDIX 5

QUALITY ASSURANCE

Attachment A5.1	Minnesota Department of Agriculture Quality Assurance Program.
Attachment A5.2	Minnesota Department of Agriculture Quality Assurance Reporting Methods.
Attachment A5.3	Department of Natural Resources Laboratory Quality Assurance Program.

Attachment A5.1.

Minnesota Department of Agriculture
Quality Assurance Program

Quality Assurance Objectives

Precision, accuracy, completeness, data comparability and sample representativeness are necessary attributes to ensure that analytical data are reliable, scientifically sound, and defensible. Each analytical result or set of results generated for this project should be fully defensible in any legal action, whether administrative, civil or criminal.

1. Definitions
   1.1 Precision
   Whenever possible, a minimum of one duplicate sample should be run in order to determine precision. It is understood that in some cases there may be insufficient sample to run duplicates and therefore a determination of precision would not be possible.
   1.2 Accuracy
   Whenever possible, a minimum of one matrix spike should be run in order to determine accuracy. It is understood that in some cases there may be insufficient sample to run matrix spikes and therefore a determination of accuracy would not be possible.
   1.3 Completeness
   Should be 100% ideally. Realistically a minimum level of 90% is expected.
   1.4 Comparability
   Should be ensured by adherence to method protocols.
   1.5 Representativeness
   Should be ensured by adherence to standard laboratory sub-sampling protocols. The nature of the material being sampled must be taken into account when subsampling.

The precision and accuracy of each method is dependent on the sample matrix and analyte concentration. Therefore, for these types of analyses, the matrix and concentration determine the values of precision and accuracy (bias) which are acceptable.

2. Parameter List, Matrix Type, Required Action Limits, Method Detection Limits

   Parameters
   Metals, sulfates and nutrients.

   Matrices
   Aqueous and Solids

   Required Action Limit
   Required action limits will be determined by the MDNR personnel prior to the analysis of samples by MDA. Action limits will be communicated to the Laboratory by the Minerals Reclamation Laboratory QA Officer.

   Method Detection Limit
   Method detection limits are determined by the laboratory following guidelines defined in EPA CFR 40 Part 136, Appendix B. Reporting limits are based on the lab MDLs and requirements for the program.

3. Laboratory Methods
   The laboratory will follow methods based on EPA methodologies and Standard Methods for the Examination of Water and Wastewater.

4. Samples
   4.1 Required Turn-Around Time for Analysis
       "Regular" parameters: 30 days after MDA receipt.
       "Permit" parameters within the stated time listed in the MPCA permit.

5. Quality Control Samples
   5.1 Field Blanks: One blank for every 50 samples of each experiment.
   5.2 Laboratory QC requirements and minimum volume of sample needed:
       - Metals- 60 mL
       - Sulfates- 60 mL
   5.3 Blind Set Points: One submitted with every box of samples.

Field Sampling Requirements

1. Type of Samples to be Collected.
   Aqueous samples will be colleted.

2. Field Sampling Requirements: NA

3. NPDES samples will require chain of custody and proper preservation as required for permit samples. This is required in the QA plan approved by Minnesota Department of Health.

4. Preservation
   All metals samples will be preserved with ultra pure nitric acid. Samples requiring refrigeration (storage at 4°C ± 2°) will be shipped on ice or cool packs to the MDA laboratory.

Sample Custody Requirements

1. Transportation of Samples from Field to Laboratory
   Regulator samples will either be shipped by State contract courier or hand delivered by Minerals personnel to MDA within 2 working days.
   Permit samples will wither be shipped by State contract courier or hand delivered by Minerals personnel to MDA within 2 working days of shipment. The samples will be sent on ice.

2. Notification Procedure
   MDA will be notified by the MDNR Program Coordinator or MDNR QA Officer when *Permit* samples are being shipped. MDNR will also alert MDA when "non regular" samples are being shipped.

3. Sample Log-in Procedure
   Upon receipt of the sample(s), the sample custodian inspects the shipping container(s), the sample(s), the official seal(s), and documentation related to the sample(s) and other records. If accepted for analysis, the sample(s) are entered by the sample custodian into the sample logbook, database and assigned a unique laboratory number.

Samples are to be properly documented, preserved, packaged, maintained under custody and transferred to the laboratory in a defensible manner. The Laboratory Information Section Supervisor should notify the MDNR Program Coordinator, appropriate MDNR Field Project Leader or Reclamation Laboratory QA Officer when problems are encountered with the quality of incoming samples or when laboratory problems arise that could affect the reliability and/or defensibility of analytical results.

4. Analysis
   A supervisor assigns the sample(s) to an analyst. After assignment, the sample custodian retrieves the sample(s) and transfers it to the analyst who completes the appropriate lines on the custody form. If the sample(s) is assigned to a different analyst, the appropriate lines in the second column of the custody form are completed by the new analyst. Similarly, the third column or even additional sheets can be used to document additional sample transfers within the laboratory. The original seal(s) should be kept with the sample(s) and maintained in a legible condition. Upon completion of the analysis, any remaining sample is placed in the appropriate storage location.

Calibration Procedures and References

1. Field Equipment Calibration
   None

2. Laboratory Calibration
   Each instrument used routinely in the laboratory should be monitored, calibrated, and maintained. Specifications for instrument maintenance, calibration and monitoring are described in manufacturer's manuals, in analytical methods, and/or appropriate standard operating procedures. If an instrument malfunctions, or if improper sensitivity, resolution and/or reproducibility is detected, corrective action is necessary before analyses are attempted. Any corrective action taken will be documented in the appropriate instrument manual.

   Analytical standards used to prepare calibration or standard solutions are obtained from the National Institute for Standards and Technology (NIST), EPA, USDA, FDA or other reliable sources. Stock standard solution(s) are prepared as specified in the SOP. All inform on their preparation is recorded in the designated logbook(s).

Depending on the method, a three to five point calibration curve will be used.

Analytical Procedures

1. Analytical Procedures
   All analyses for permit samples will be done according to methods approved by the Minnesota Department of Health as written in the MDA methods manual. These methods are based on approval EPA methodologies and Standard Methods for the Examination of Water and Wastewater.

   Other analyses will be done using laboratory methods based on EPA, ASTM, AOAC, etc. methodologies.

Data Analysis, Validation and Reporting

This section describes the basic procedures for data analysis, validation and reporting for this project.

1. Data Analysis
   Data analysis is performed on a batch run basis for samples analyzed using FAA and GFAA. Out of range samples are diluted manually for FAA and automatically for GFAA. Colorimetric autoanalysis usually relies on batch data analysis where confirmatory samples are then redirected to another automated method (IC) or a manual method. Manual methodology requires a sample by sample data analysis procedure, with confirmation by an alternate method if indicated. Details of data analysis are contained individual methods.

2. Validation of Results
   Validation of data is described in detail in the laboratory standard operating procedures. In most cases, data validation consists of a review of the analytical method. calculations and quality control results. Initial review is done by the analyst, and final review by the Chemistry Supervisor or a designated Senior Analyst. Certain samples or cases may be validated by the Laboratory Quality

Assurance Officer if required or desirable. When a review indicates a need, the analysis is repeated using either the same method or an alternate method. Questionable data may result from the condition of the sample, inadequacy of the method, lack of validation, time constraints or other factors.

Any questionable data will be clearly identified and qualified. The Laboratory Quality Assurance Officer conducts periodic in-depth audits to assure compliance with the validation requirements.

3. Reporting
Analytical data is reported according to the format(s) provided in the standard operating procedures. In addition to the analytical results, the reference for the method and quality control results are reported. Quality control results may include spike recovery, results of duplicate analyses, analysis of reagent blanks, but are not limited to these. When the compound(s) of interest is not detected in the sample(s), it is reported as such with the method detection limit. Any pertinent observations about the samples or the analytical process are also reported.

All written reports will be sent to the MDNR Program Coordinator.

Internal Quality Control Checks

The internal quality control (QC) checks are a systematic in-house approach to ensure the production of high quality data. The objectives of these control checks are:

- To provide reliable and defensible analytical results,
- To provide a measure of the precisions and accuracy of the analytical methods,
- To monitor the accuracy and precision of the analyst,
- To identify problematic methods which can be flagged for further research,
- To detect training needs within the laboratory,
- To provide a permanent record of instrument performance which is used for validating data and projecting instrument repair or replacement needs, To monitor the effectiveness of the quality assurance program and laboratory performance and provide a basis for modifications of the quality

assurance program.

The quality control procedures for analytical methods used for misuse cases may include:

- Demonstration of analytical capability,
- Analysis of a quality control check sample, when available,
- Daily instrument check,
- Recoveries of or matrix spikes,
- Analysis of reagent blank,
- Duplicate analysis,
- Analysis of laboratory control standards,
- Blind performance evaluation samples,
- Analysis of instrument quality control standards,
- Confirmation of analyte.

Performance and System Audits

The Minnesota Department of Agriculture is committed to participate in the evaluation of the laboratory quality assurance program and to lend itself to any coordinated on-site systems audits by qualified representatives of MDNR. The department is also committed to using the results of such performance and systems audits to improve the reliability, defensibility, capability and efficiency of the laboratory and filed operations. A quality assurance/quality control manual will also be available to the MDNR-mineral for review.

LSD will maintain accreditation with the Minnesota Department of Health with respect to clean water requirements including participation in EPA WP and WS proficiency samples.

Systems and laboratory audits along with analytical data and record review, may be performed by qualified representatives of MDNR which reserves such audit rights. The audit is conducted upon joint consent of both agencies. The report of all findings and recommendations are made promptly to the MDA. The systems audit includes areas in the laboratory immediately impacting overall quality assurance.

The Laboratory Quality Assurance Officer performs in-house systems audits to identify strengths, weaknesses, potential problems and solutions to problems. The audits provide an evaluation of the adequacy of the overall measurement systems to provide data of sufficient quantity and quality to meet the comprehensive laboratory pesticide program's objectives. The in-house systems audits are the basis for quality assurance reports to management.

The in-house systems audit consist of observing the various aspects of the laboratory activities related to this project. Check lists which delineate the critical aspects of each procedure are used during the audit and serve to document all observations. At a minimum, the following topics will be evaluated during the internal audit:

1. GENERAL PROCEDURES
   A. Procedures for Sampling and Sample Documentation
   B. Documentation of Procedures
   C. Sample Receipt and Storage
   D. Sample Preparation
   E. Sample Tracking

2. ANALYTICAL PROCEDURES
   A. General Instrumentation Procedures
   B. Calibration Procedures
   C. Internal Quality Control
   D. Data Handling Procedures

Preventative Maintenance Procedure and Schedule

1. Field Maintenance
   None

2. Laboratory Instrument Maintenance
   The primary objective of a comprehensive maintenance program is to ensure the timely and effective completion of a measurement effort. Preventive maintenance is described in the laboratory or field standard operating procedures (SOPs) and appropriated instrument manual. It is designed to minimize the down time of crucial sampling and/or analytical equipment due to component failure. The focus of the program is in four primary areas:

- Establishment of maintenance responsibility.
- Establishment of maintenance schedules for major and/or critical instrumentation and apparatus.
- Establishment of an adequate inventory of critical spare parts and equipment.
- Documentation and filing of all service and maintenance records.

The Agronomy Laboratory supervisor is responsible for maintenance of laboratory instruments and equipment. The appropriate program managers are responsible for the maintenance of field equipment. With assistance from the Laboratory and Reclamation Laboratory Services Quality Assurance Officers, the Agronomy Laboratory establishes maintenance procedures and schedules for each piece of major equipment. Responsibility for individual items is delegated to technical personnel. The manufacture's recommendations and/or the protocols for instrument maintenance and calibration are followed. Each piece of major equipment is designated a repair and maintenance logbook where all maintenance activities are dated and documented by laboratory or filed personnel.

In the interest of maintaining instruments in top operating condition, it is management's policy to secure annual service contracts with instrument manufacturers whenever financially possible. The service contracts are especially desirable for laboratory instruments. Under the service contracts, certified service engineers perform preventive maintenance, calibration and repair for instruments. Laboratory personnel perform routine maintenance and repair between manufacturers' service to ensure correct performance of an instrument.

Analytical balances are serviced by certified service engineers at least once a year. In addition to performing repair and maintenance, the engineer calibrates and certifies each analytical balance. Laboratory personnel check the calibration of the balance with a class S weight at least four times a year. Digital pH meters are checked before each use with standards and calibrated according to the manufacturer's directions. Freezers and refrigerators are monitored to assure that proper temperatures are maintained and that failure has not occurred.

An adequate inventory of spare parts is maintained to minimize equipment down time. This inventory emphasizes those parts which:

- Are subject to frequent failure,
- Have limited useful lifetime,
- Cannot be obtained in a timely manner should failure occur.

Assessment of Data

An objective of the laboratory is to demonstrate that performance on all analyses is in statistical control. Routine procedures used to assess reliability and quality of data are specified in the laboratory standard operating procedures (SOPs).

For residue analysis, duplicates are used to establish precision, spike sample recoveries are used to establish accuracy and blanks are analyzed to assure non-interference from solvents, reagents and laboratory environment.

Precision refers to the reproducibility of replicate results about a mean which is not necessarily the true value. Duplicate analysis is the primary means of evaluating measurement data variability or precision. Two commonly used measures of variability which adjust for the magnitude of analyte concentration are coefficient of variation and relative percent difference.

The coefficient of variation is used most often when the size of the standard deviation changes with the magnitude of the mean. Coefficient of variation (CV), also called relative standard deviation (RSD), is defined:

$$CV \ or \ RSD = \left(\frac{s}{y}\right) * 100$$

where: y = mean of replicate analyses
s = sample standard deviation, defined as:

$$S = \sqrt{\sum_{i=1}^{N} \frac{(y_i - y)^2}{n - 1}}$$

where: y_i = measured valued of the ith replicate
y = mean of replicate analyses
n = number of replicates

Sample standard deviation (s) and coefficient of variation (CV) are used when there are at least three replicate measurements.

The second measure of variability which adjusts for the magnitude of the analyte is relative percent difference (RPD) or relative range (RR). This measure is used when duplicate measurements are made and is defined:

$$RR\ or\ RPD = \frac{|A - B|}{\left(\frac{A + B}{2}\right)} * 100$$

where: A = First observed values
B = Second observed values

Precision is monitored by plotting control charts for repetitive analysis. A warning limit of ±2s is established with a control limit of ±3s (see Section 3).

Accuracy is the nearness of a result to the true value and is often described as error, bias or percent recovery. Accuracy estimates are frequently based on the recovery of surrogate spikes and/or the recovery of know analytes. The percent recovery is calculated as:

$$\%R = \left(\frac{SSA - S}{SA}\right) * 100$$

where: SSA = measured concentration in spiked aliquot
S = measured concentration in unspiked aliquot
SA = actual concentration of spike added

Completeness is a measure of the amount of valid data obtained from a measurement system compared to the amount expected to be obtained under correct, normal conditions. For all measurements, completeness is defined:

$$\%C = \left(\frac{V}{n}\right) * 100$$

where: %C = percent completeness

V = number of measurements judged valid
n = number of measurements necessary to achieve a specified statistical level of confidence in decision making

To determine "n" a judgment must be made regarding the amount of data required to provide adequate evidence that a system is in control. Completeness is calculated for monitoring programs where similar analyses are performed on a regular basis. Loss of data due to such occurrences as breakage of containers, spilling of the sample, contamination, instrument failure or exceeding holding time before analysis must account for no more than 10 percent of all requested analysis. If excessive loss of data occurs, the reasons must be identified and evaluated and, if necessary, action must be taken to solve the problem(s).

Corrective Action

Corrective action is taken whenever data is determined as unacceptable.

Corrective action is taken in the order listed below.

- Review of sample collection procedures.
- Review of analytical raw data and calculations.
- Review of laboratory procedures - Was the analytical method followed?
- Review of analytical method - Is it applicable?
- Review of instrument operation, calibration and maintenance.
- Review of the calibration standard(s) used.
- Review of quality control measurement (spike, duplicate, surrogate, etc.).

As a result of the above review, further corrective action may be identified and pursued as necessary:

- Repeat the sampling and corresponding documentation.
- Issuing an amended analytical report.
- Repeat analysis (confirmation methods).
- Repair, recalibration or replacement of instrumentation.
- Additional training of staff.

Persistent problems require a thorough review of all field and analytical data (including quality control measurements and procedures), increased check sample and reference material analyses and additional field and/or analytical system evaluations by outside agencies or individuals.

QA Reports to Management

A quality assurance report is generated by the Minnesota Department of Agriculture and Laboratory Services Division and sent to MDA and MDNR management at least once a year.

The report may contain the following:

- Changes in Quality Assurance Project Plan,
- Summary of quality assurance/quality control programs, training and accomplishments,
- Results of technical systems and performance evaluation audits,
- Significant quality assurance/quality control problems, recommended solutions and results of corrective actions,
- Summary of data quality assessment for precision, accuracy, representativeness, completeness, comparability and method detection limit,
- Discussion of whether the quality assurance objectives were met and the resulting impact on technical and enforcement areas,
- Limitations on use of the measurement data and discussion of the effects of such limitations on the defensibility of the data.

The MDNR Reclamation Laboratory QA Officer and MDA QA Officer will review this plan once a year.

Guide to analytical Values for Flame and Zeeman GFAA

Matrix Water
Date December 1995
The following detection limits were determined by analyzing the corresponding analyses on Flame and Zeeman GFAA.
Seven standard solutions of the same concentration, alternating with seven blanks were used to get the corresponding absorbance.
From the absorbance reading each detection limit was calculated using the Method Detection Limits according to US EPA recommendation.

Analyze	Method	Method Description	Detection Limit ug/L	Method	Method Description	Detection Limit ug/L
Al	3111D	Flame/Nitrous oxide	500			
As				3113B	Furnace Zeeman	0.8
Ca	3111B	Flame/Acetylene	100			
Ca	3111D	Flame/Nitrous oxide	80			
Cd	3111B	Flame/Acetylene	100	3113B	Furnace Zeeman	0.4
Co	3111B	Flame/Acetylene	100	3113B	Furnace Zeeman	0.4
Cu	3111B	Flame/Acetylene	100	3113B	Furnace Zeeman	0.4
Fe	3111D	Flame/Acetylene	100			
Hg				2452	Auto Cold Vapor	0.5
K	3111B	Flame/Acetylene	50	3113B		
Mg	3111B	Flame/Acetylene	80	3113B		
Mn	3111B	Flame/Acetylene	100	3113B		
Na	3111B	Flame/Acetylene	50	3113B		
Ni	3111B	Flame/Acetylene	100	3113B	Furnace Zeeman	0.8
Pb	3111B			3113B	Furnace Zeeman	0.8
Sb				3113B	Furnace Zeeman	0.4
Zn	3111B	Flame/Acetylene	50	3113B		

Key:
- 3111B = Flame analyses using Air/acetylene gas
- 3111D = Flame analyses using Acetylene/Nitrous oxide gas
- 3113D = Zeeman Graphite Furnace analyses using argon gas

Source:

1) Standard Methods for the examination of water and wastewater 18th Ed. 1993.
   Greenberg, E. Arnold: Clesceri, S. Lenore and Easton, D. Andrew.
2) Analytical Methods for Graphite Tube Atomizers, Varian. 1988.
   Rothery, R. Varian Australia Pty. Ltd.
3) Analytical Methods Flame Atomic Absorption Spectrometry. 1989.
   Rothery, E. Varian Australia Pty. Ltd.
4) Methods for the determination of metals in environmental samples. 1992.
   U. S. Environmental Protection Agency.
   Smoley, C. K.

$$MDL = (t) * (s)$$

Where t = Student's t value for a 99% confidence level and a standard deviation estimate with n-1 degrees of freedom. (t - 3.14 for several replicates).
s = standard deviation of the replicate analyses.

Attachment A5.2. MN Department of Agriculture (MDA) quality assurance reporting methods.

The DNR sends MDA batches of samples that contain approximately fifty samples. MDA performs quality assurance/quality control (QA/QC) analyses on each batch following the procedures outlined in Attachment A6.1. QA/QC analysis is run on each parameter in a batch unless sample volume becomes limiting. When sample volume becomes limiting it is up to the discretion of MDA as to which parameters will be analyzed. If re-runs of set point standards that are out of range are needed and if there is an insufficient amount of sample remaining to perform the analysis, it is noted on the final report.

The test typically performed include percent recovery of spiked samples duplicate analyses, laboratory blanks, and analytical set point standards. The following three pages are examples of QA/QC reports for Flame AA analyses, ICP-MS analyses, and sulfate analyses. When reports are received by the DNR they are examined for accuracy and completeness by the DNR laboratory supervisor and then retained on file. Any discrepancies are reported to MDA so the proper corrective action can be performed.

Attachment A5.3.

Department of Natural Resources
Laboratory Quality Assurance Program

Laboratory Calibration

- pH and specific conductance (SC) analysis of laboratory distilled water.
- Reference checks of Eh meter and probe.
- Daily calibration of pH meters with standard buffer solutions.
- Calibration of conductivity meters with standard reference solutions.
- Precision comparison between pH meters.
- Calibration at any time meter or probe is suspect.
- Accuracy check with inter-laboratory set point standards for pH, SC and alkalinity.
- Dissolved oxygen meters are calibrated before each sampling.

Laboratory Instrument Maintenance

- pH probes are cleaned according to probe manual instructions (EDTA) plus additional cleaning when used for measuring pH of extraordinarily dirty or organic samples (HCL).
- SC meters are cleaned using a mild cleaning solution when needed.

Analytical set points and distilled water blanks

- One masked set point per 50 metals or sulfate samples sent to the Minnesota Dept. of Agriculture.
- One masked distilled water blank per 50 samples sent to the Minnesota Dept. of Agriculture to monitor for contamination from sample collection or laboratory washing procedures.