

Appendix A10. Breakthrough Ce/Co Plots from the Full-Depth Column Tests

Breakthrough can be defined as a ratio of the effluent concentration (C_e) to the influent concentration (C_o) that is considered unacceptable. No chemical capacity remains when $C_e/C_o \geq 1$; however, breakthrough can be defined at earlier times (such as by using the permit limit as C_e and calculating the ratio at which the permit limit could be expected to be exceeded). The following graphs for long-term column breakthrough tests show the C_e/C_o ratios as a function of water loading on the columns. The first graph contains the data from all the media on a single graph; the second graph shows the behavior for each medium or media mixture.

The six tables at the end of this appendix compare the capacities of the various potential biofilter media components (site sand, rhyolite sand, site zeolite, SMZ, GAC, and PM) as calculated from the various testing protocols.

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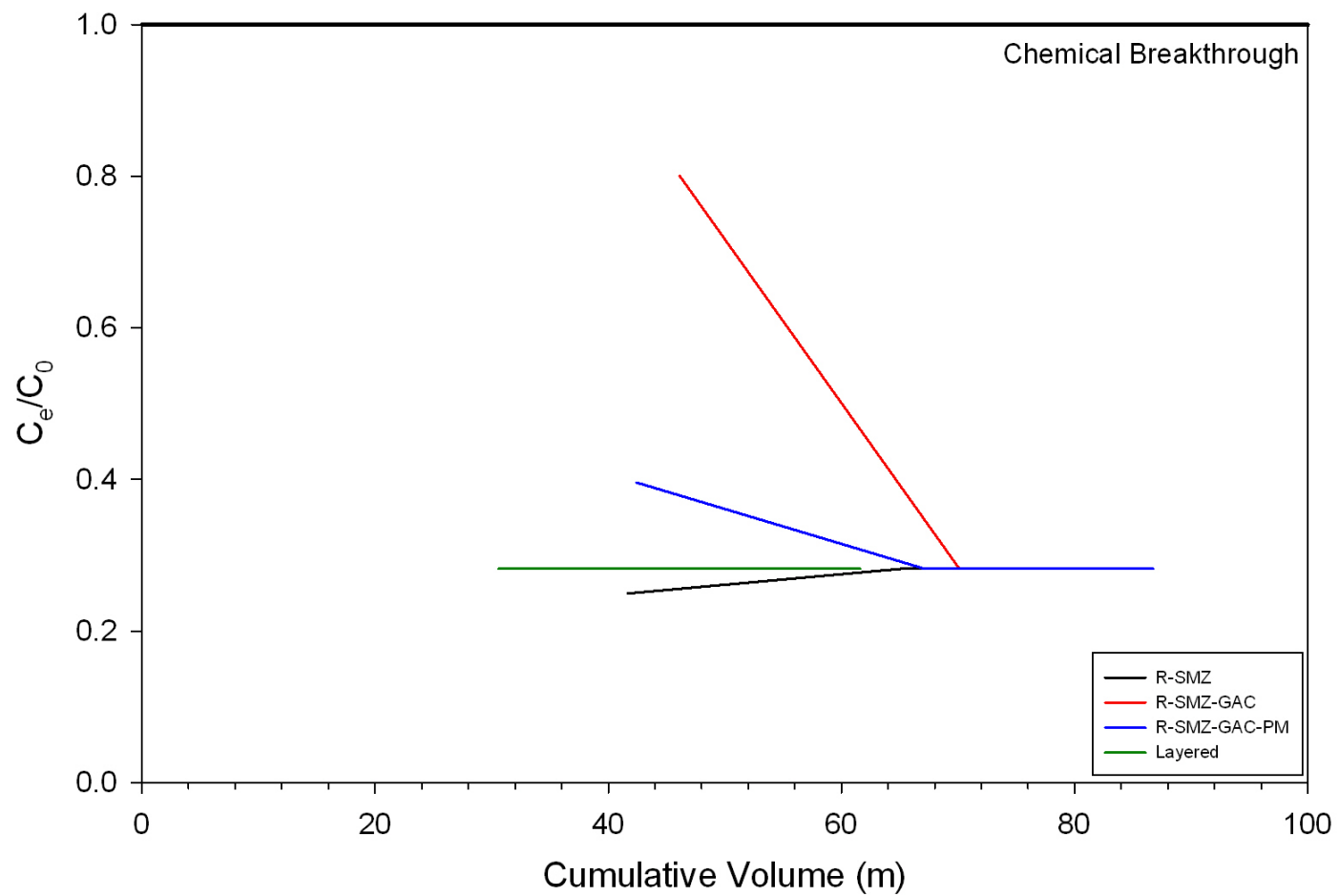
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Alpha Radium



ALPHA RADIUM

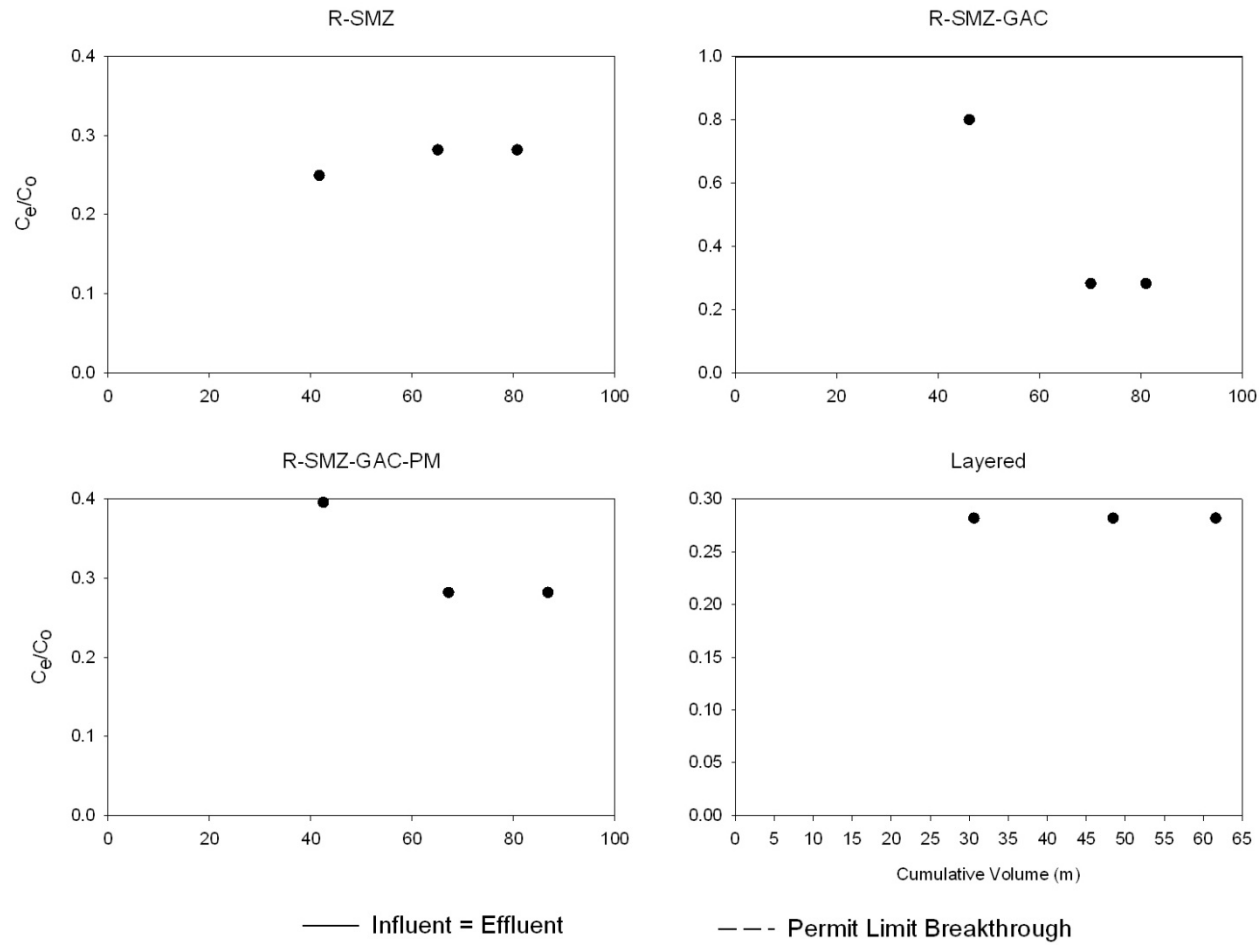
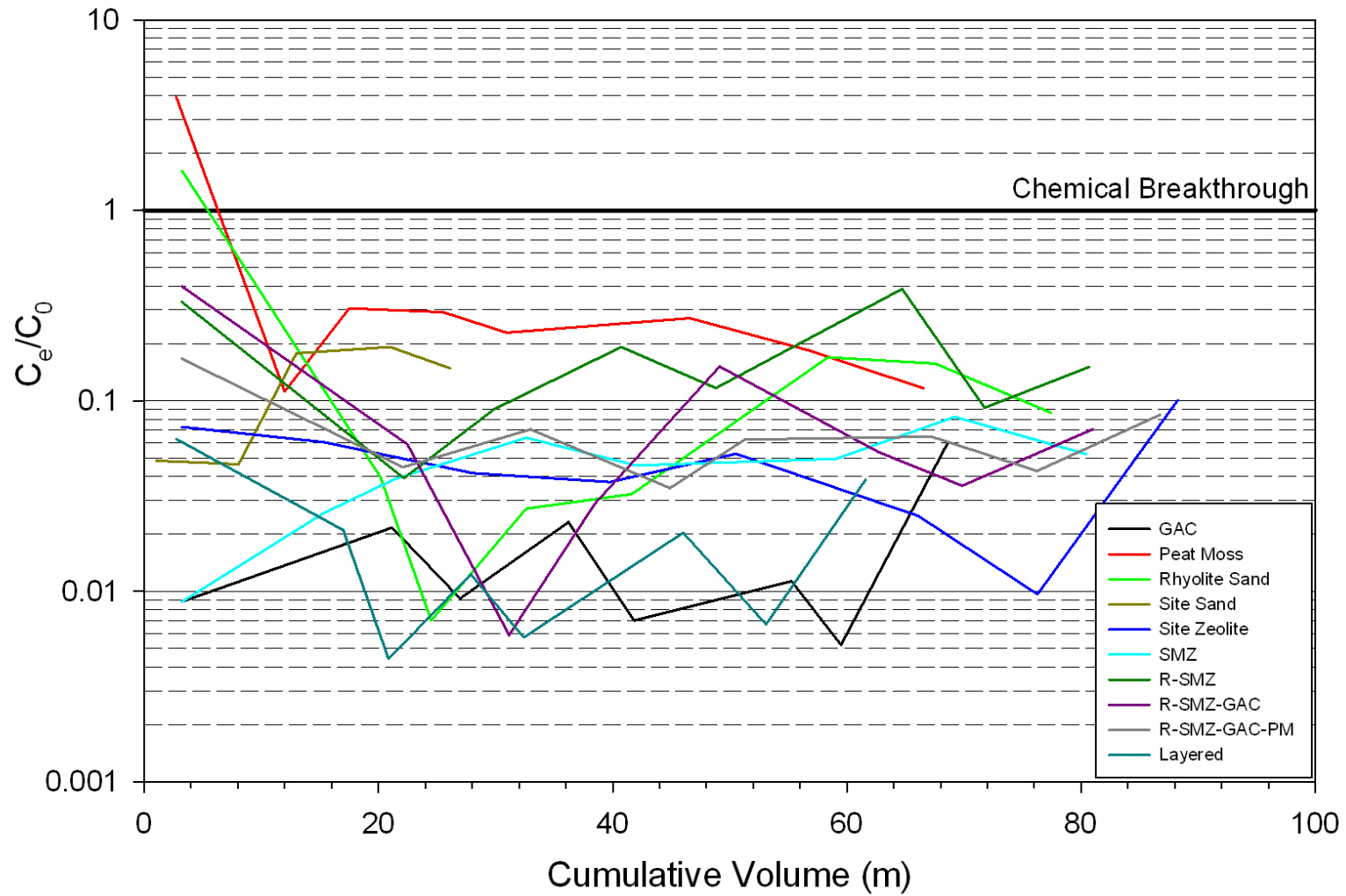


Figure A10-1. Alpha Radium Normalized Breakthrough Plots

Aluminum, Total



ALUMINUM, TOTAL

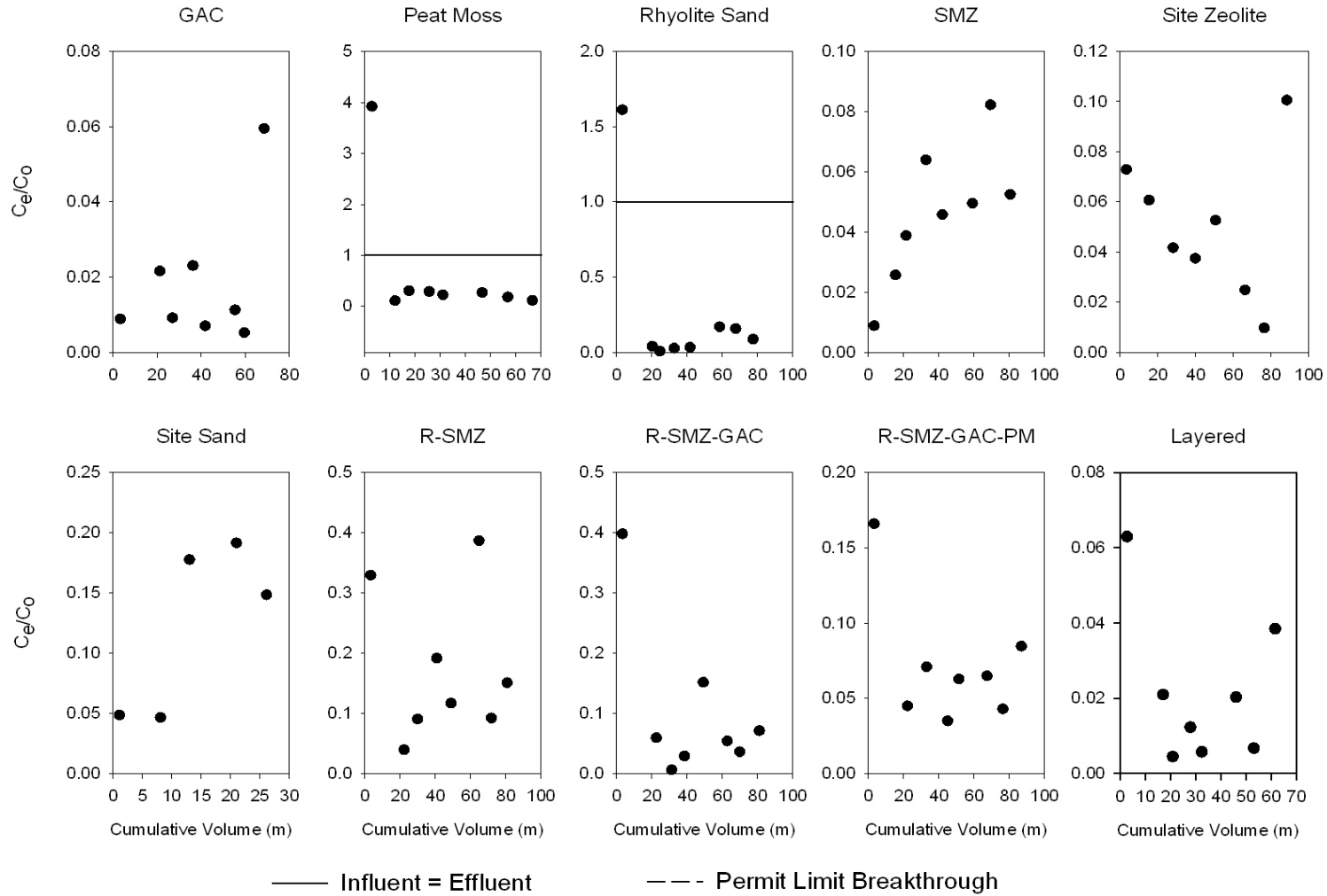
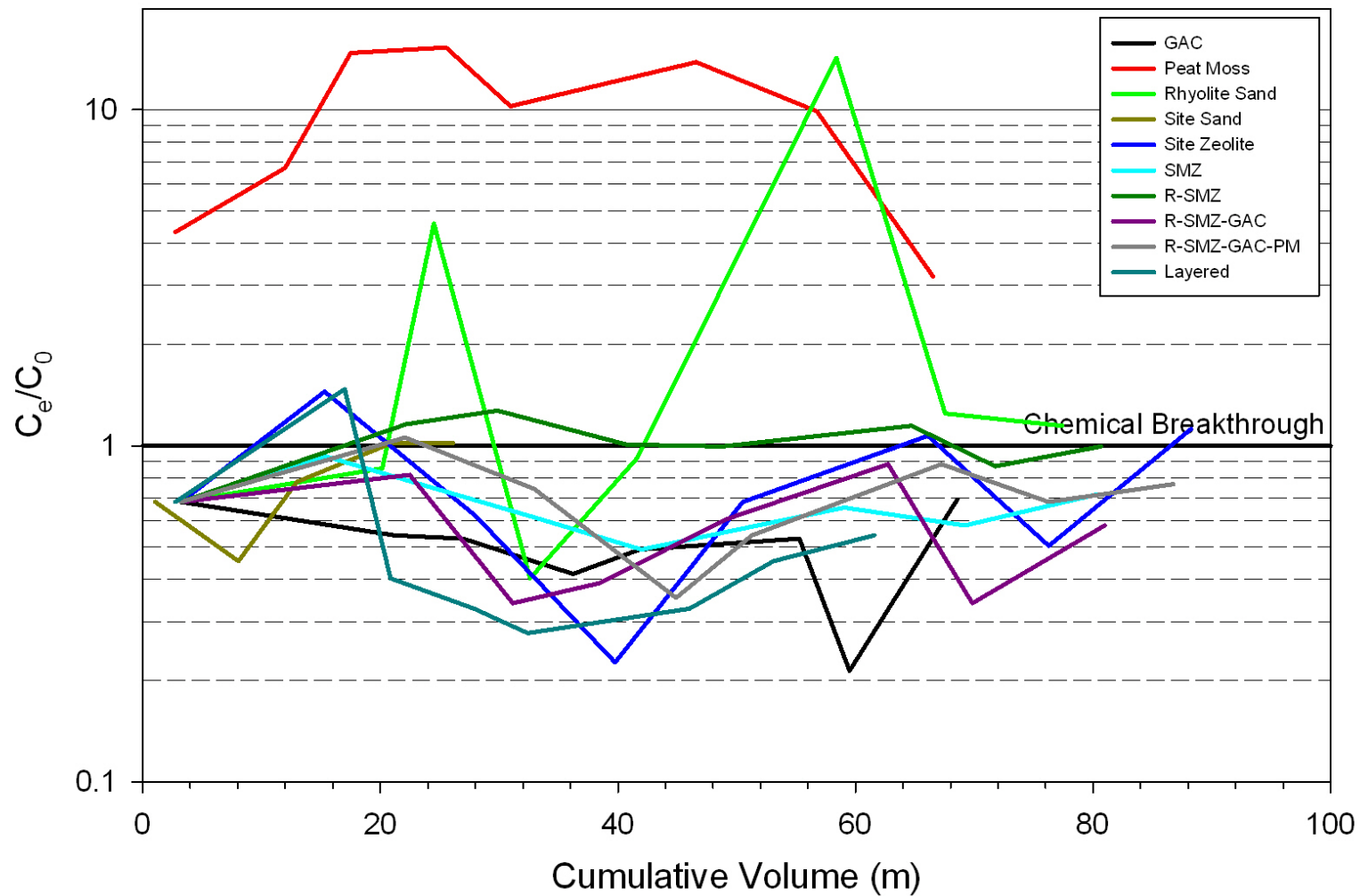


Figure A10-2. Aluminum (Total) Normalized Breakthrough Plots

Aluminum, Filtered



ALUMINUM, FILTERED

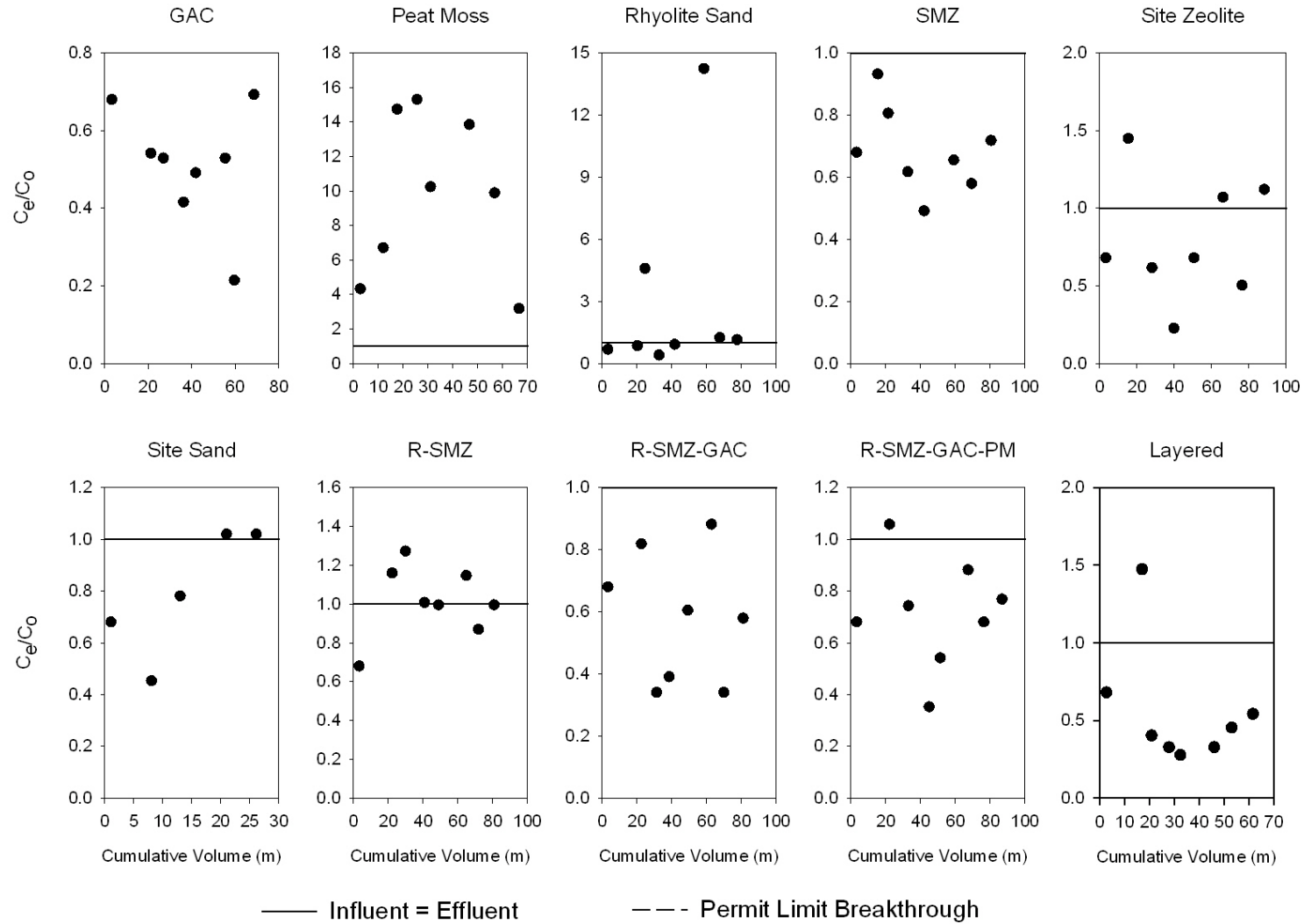
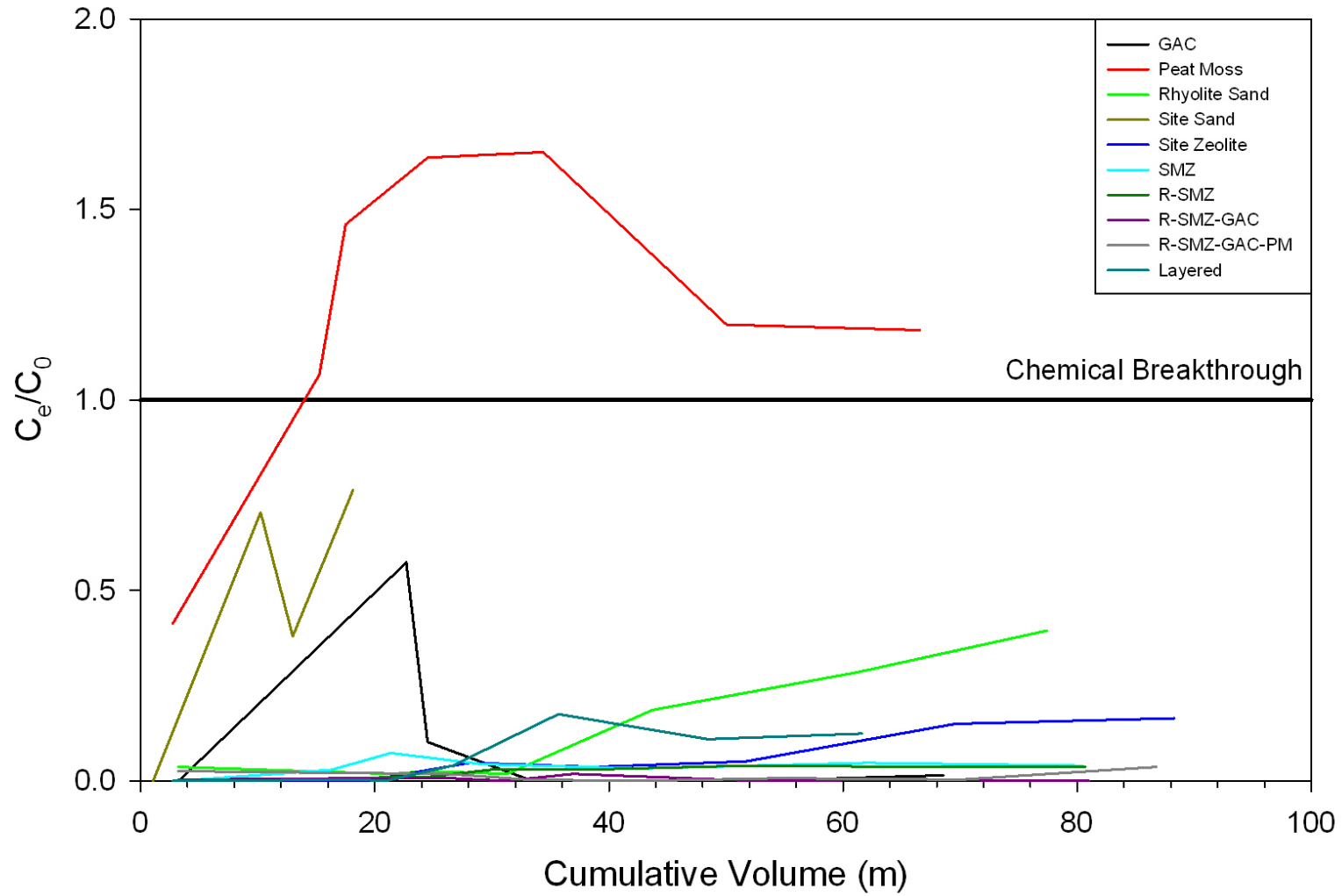


Figure A10-3. Aluminum (Filtered) Normalized Breakthrough Plots

Ammonia



AMMONIA

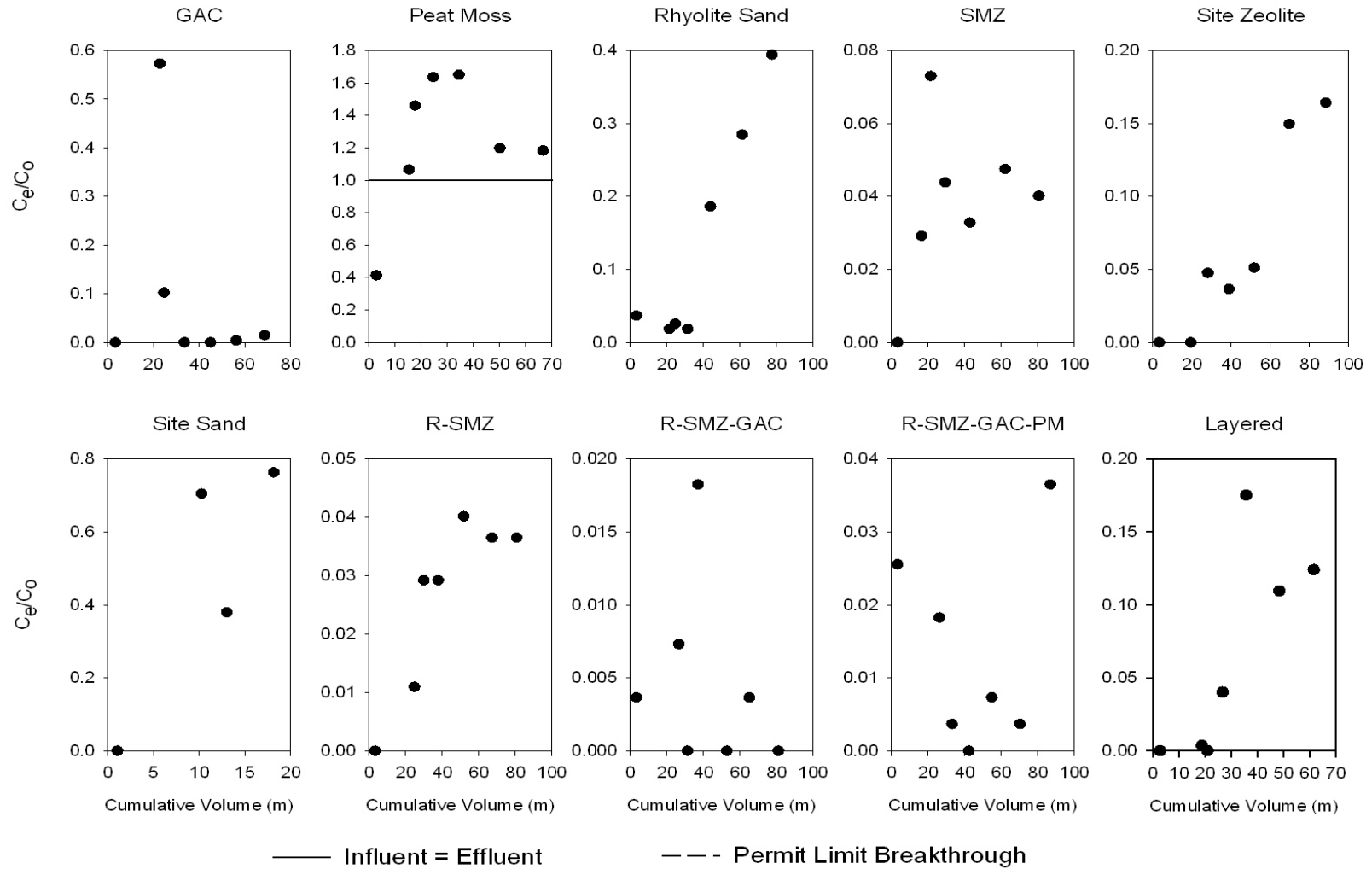


Figure A10-4. Ammonia Normalized Breakthrough Plots

ANTIMONY, TOTAL

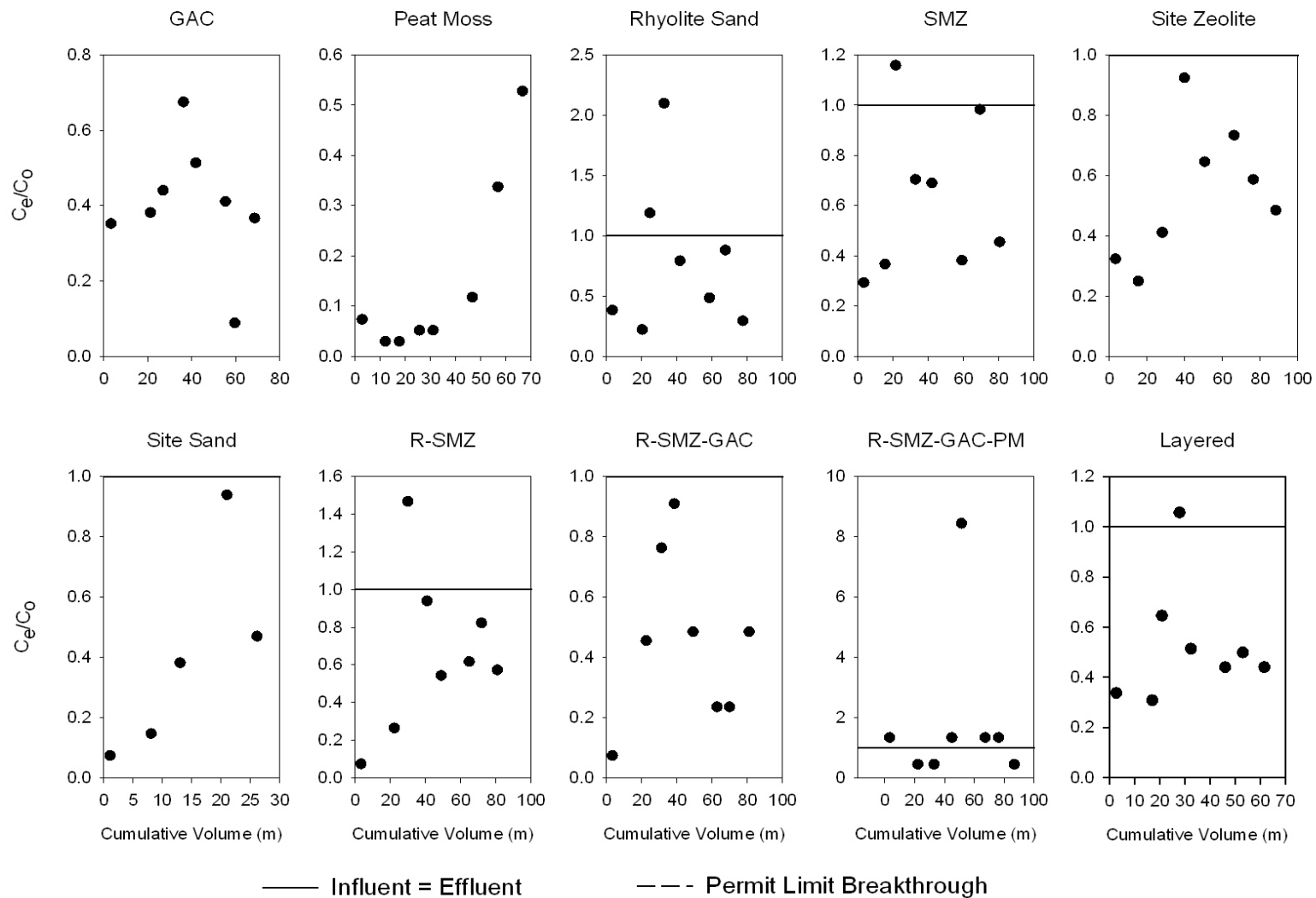
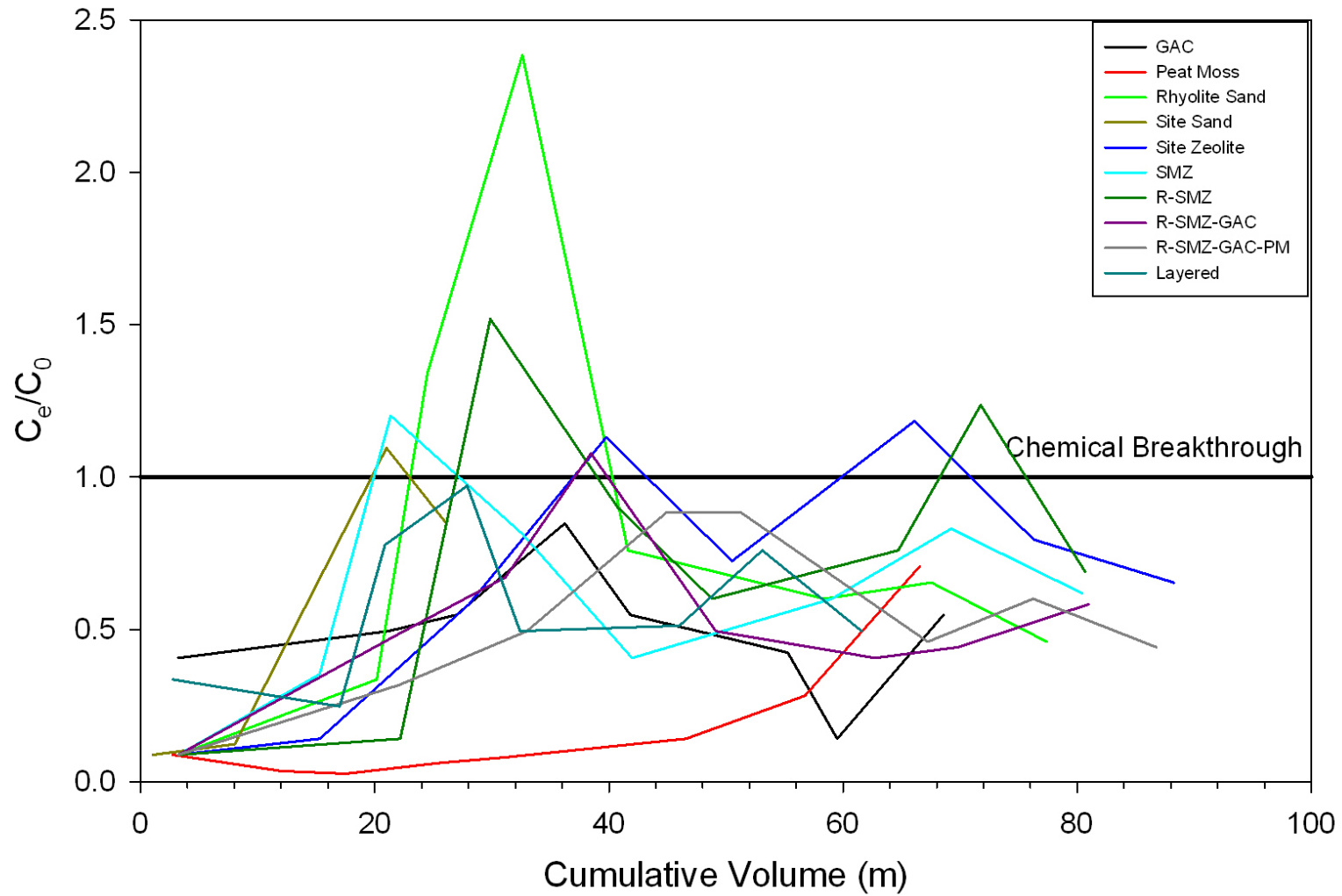


Figure A10-5. Antimony (Total) Normalized Breakthrough Plots

Antimony, Filtered



ANTIMONY, FILTERED

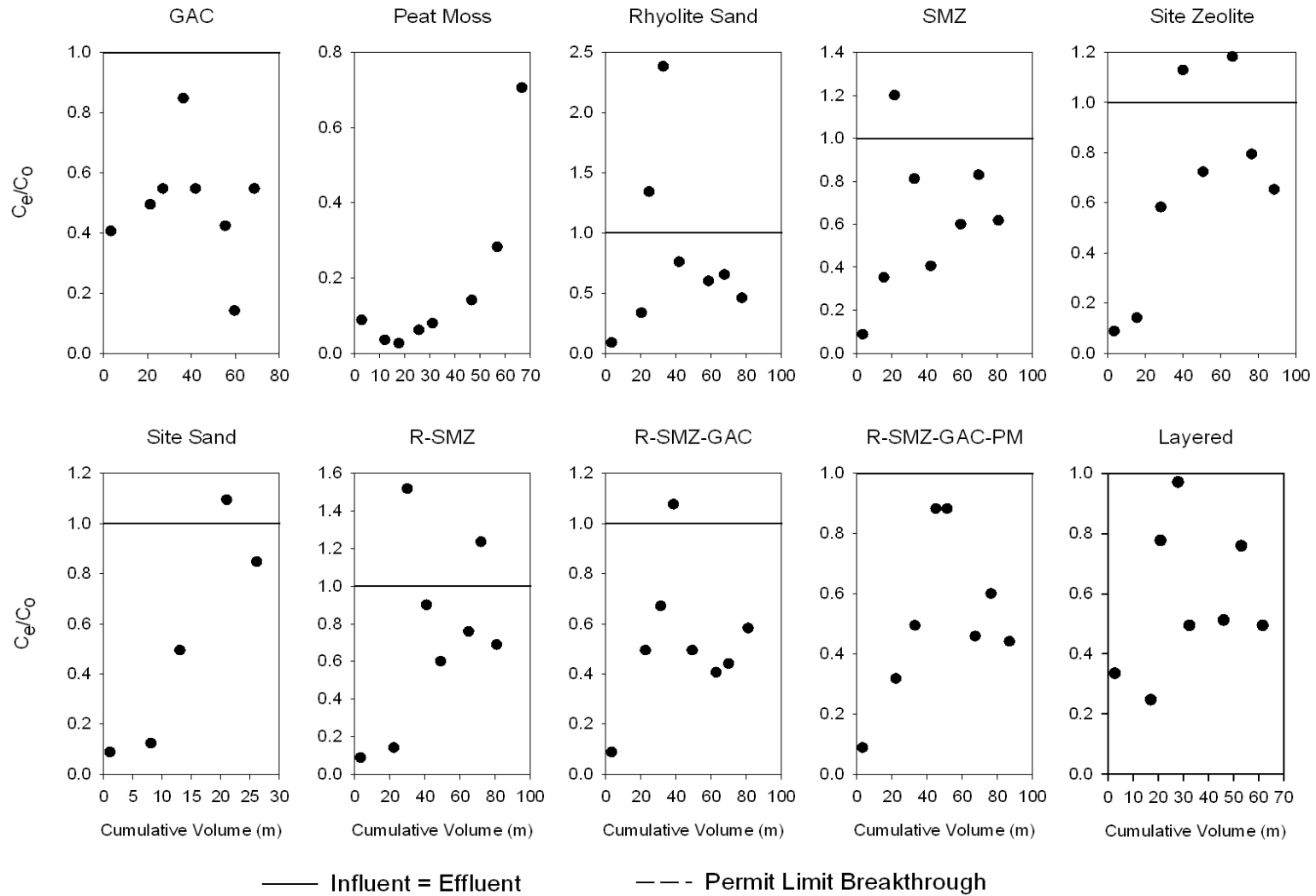


Figure A10-6. Antimony (Filtered) Normalized Breakthrough Plots

ARSENIC, TOTAL

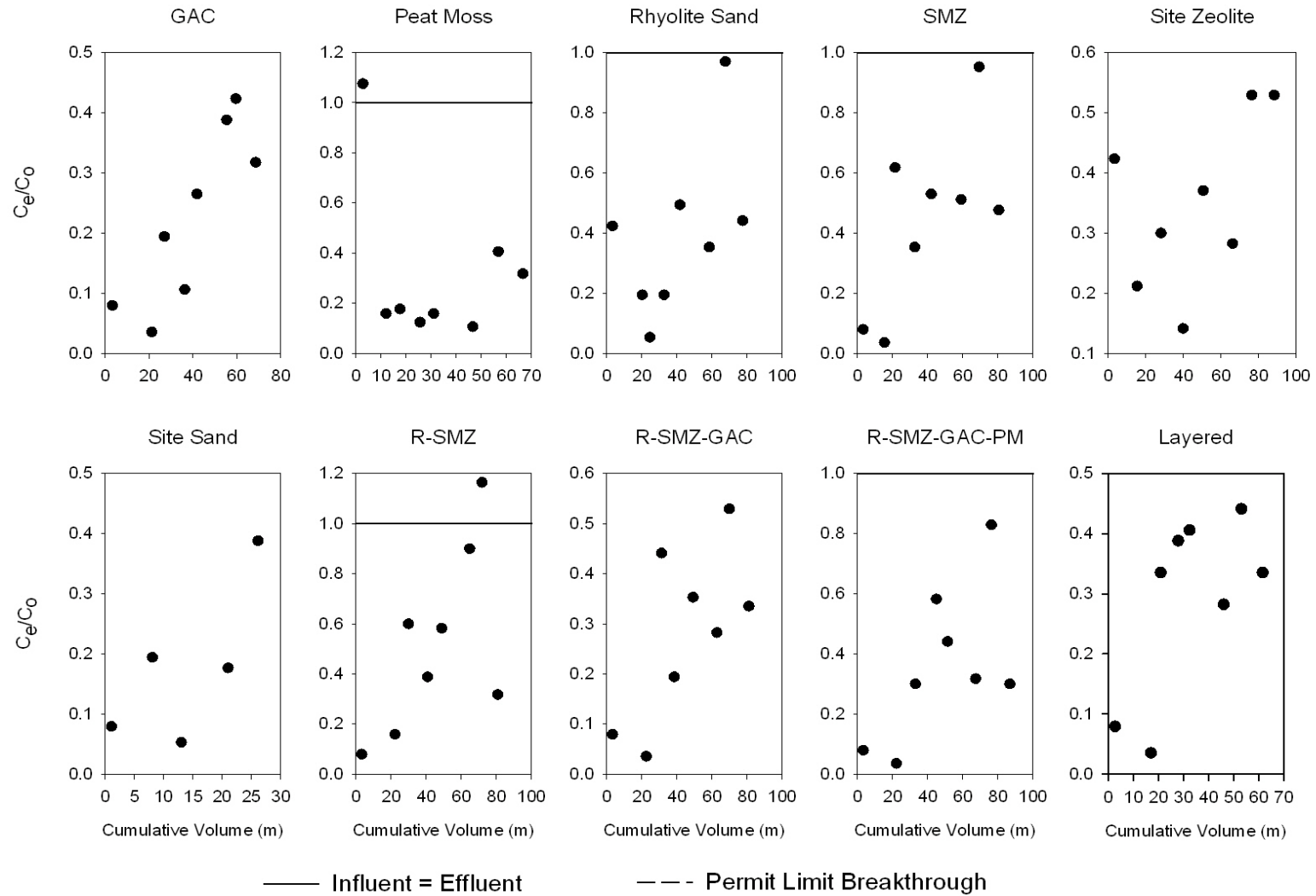
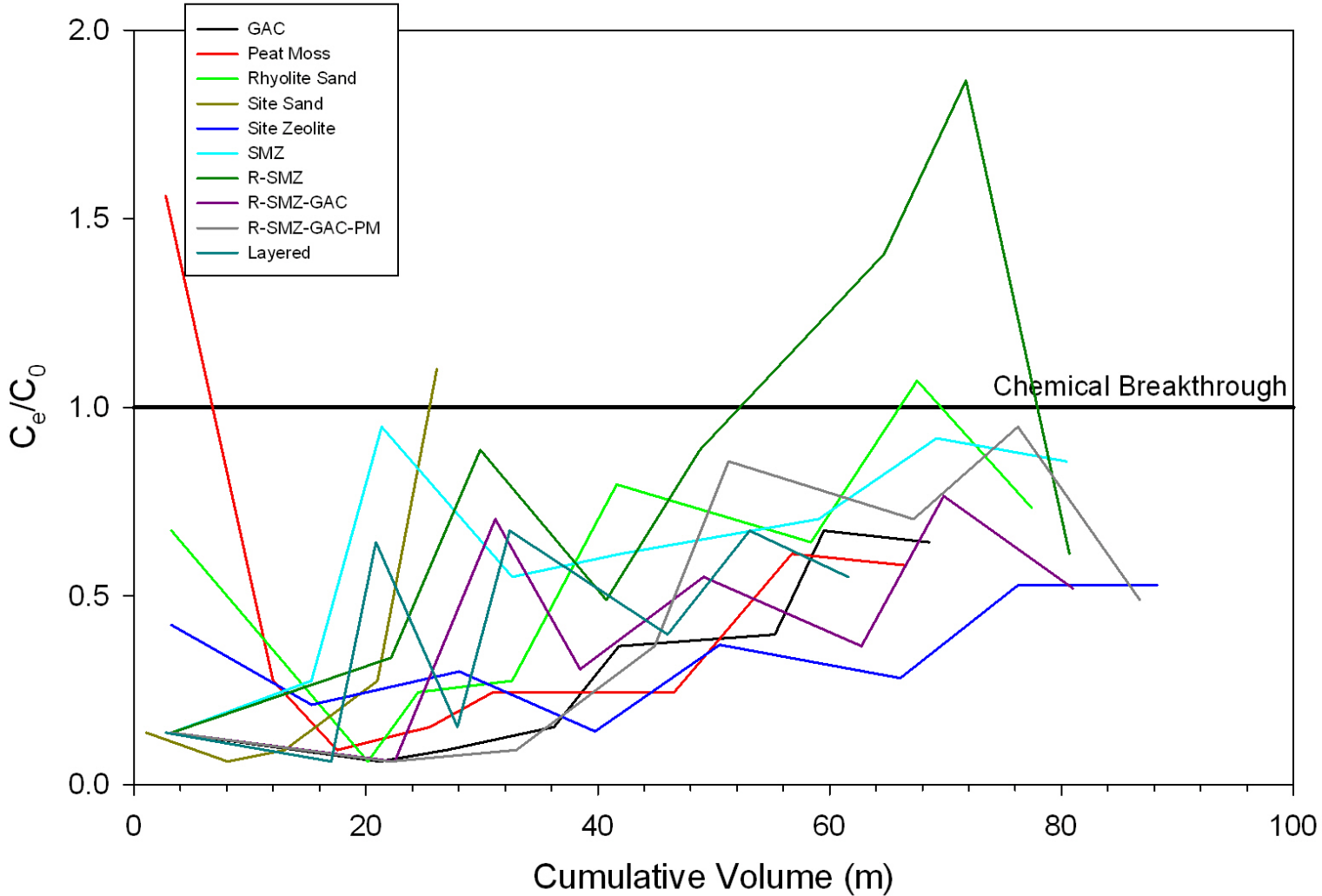


Figure A10-7. Arsenic (Total) Normalized Breakthrough Plots

Arsenic, Filtered



ARSENIC, FILTERED

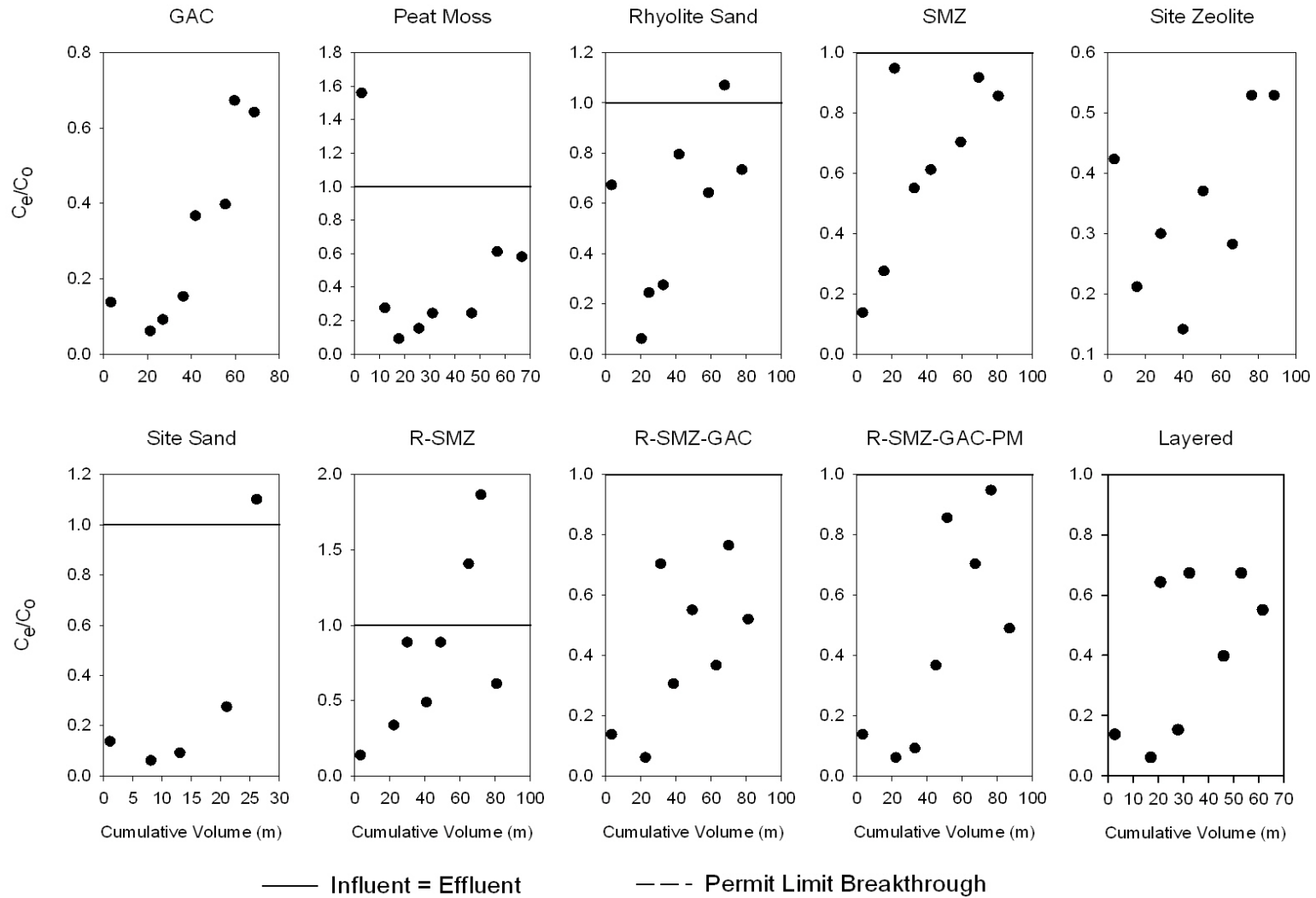


Figure A10-8. Arsenic (Filtered) Normalized Breakthrough Plots

BORON, TOTAL

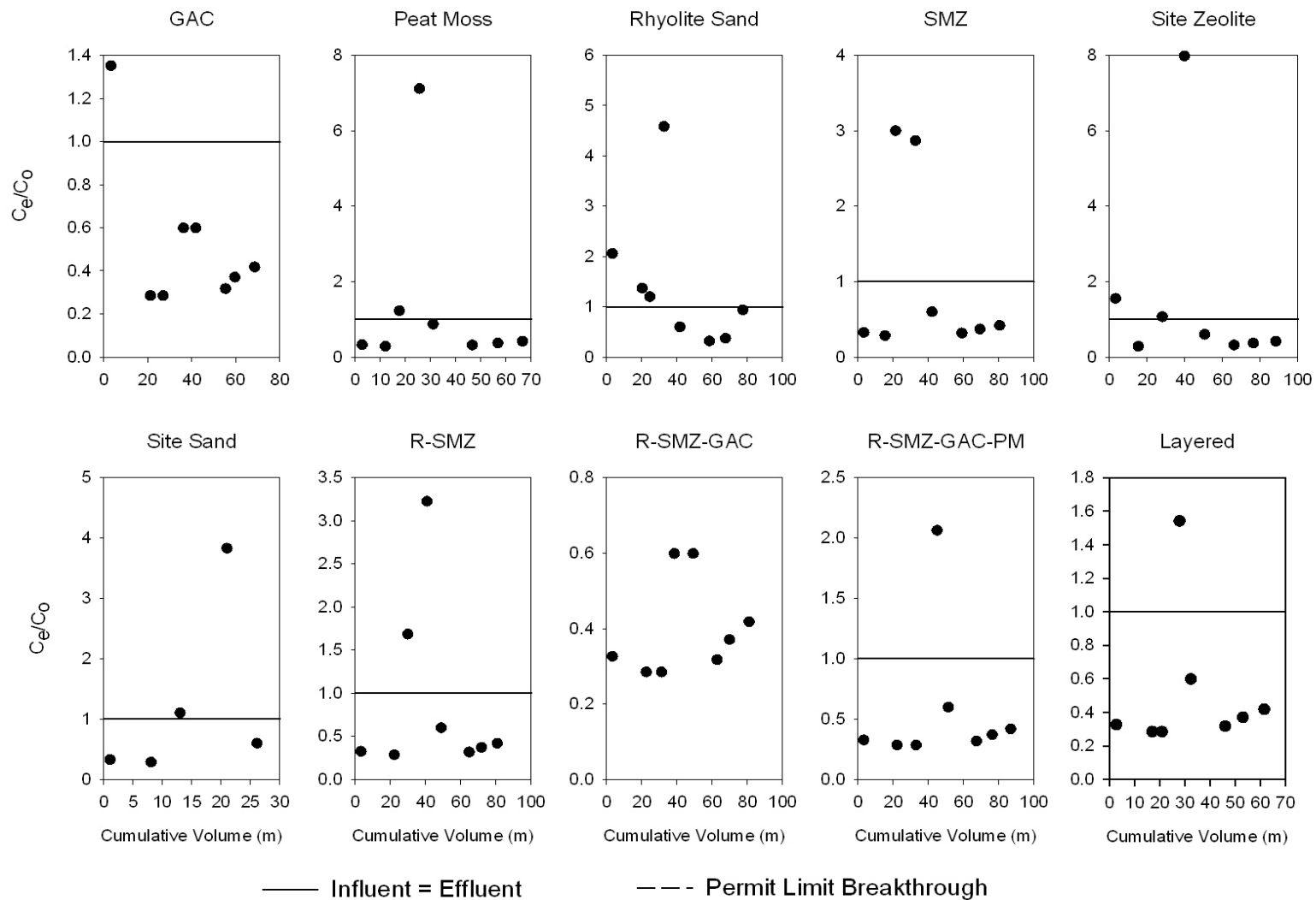


Figure A10-9. Boron (Total) Normalized Breakthrough Plots

BORON, FILTERED

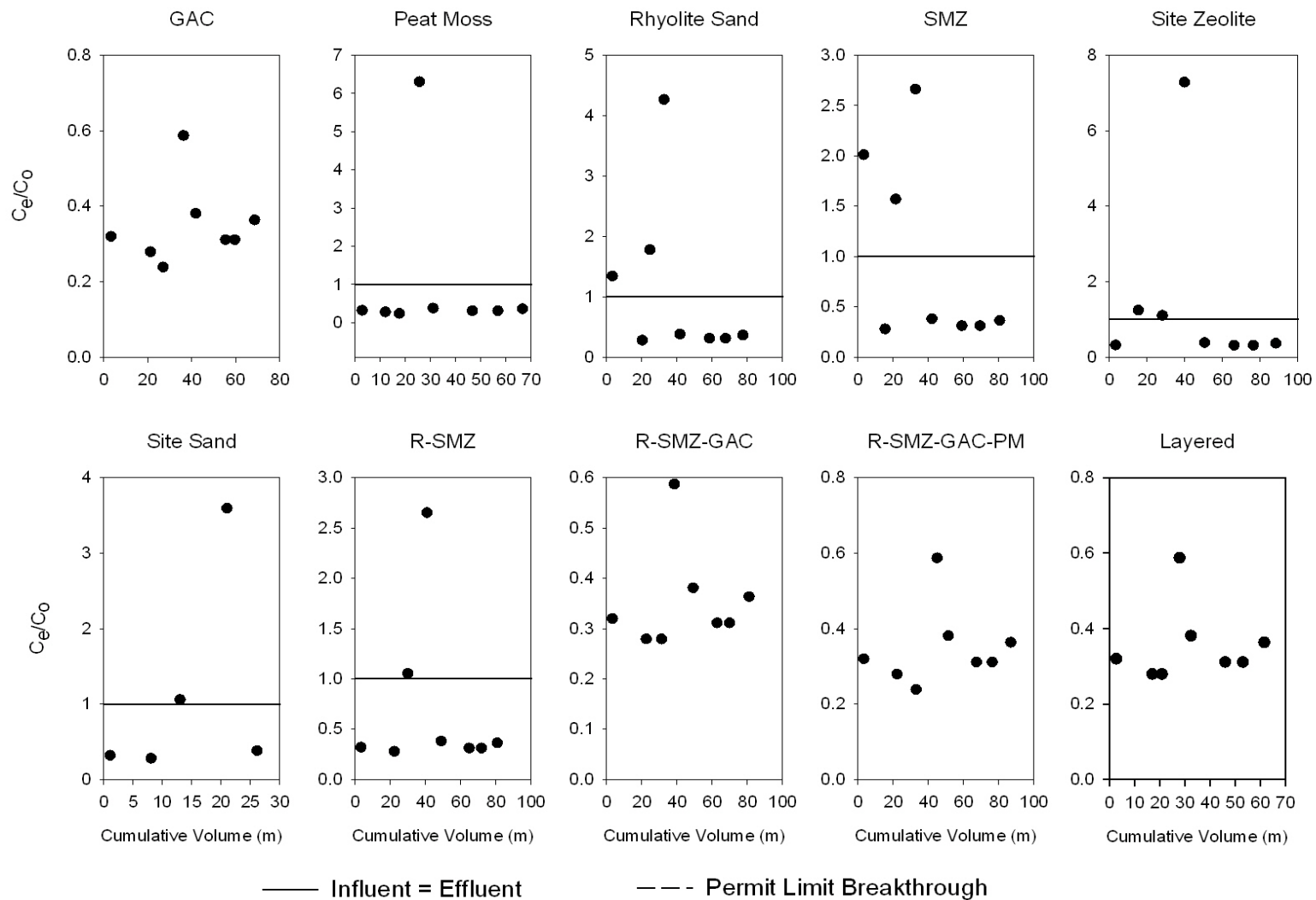


Figure A10-10. Boron (Filtered) Normalized Breakthrough Plots

CADMIUM, TOTAL

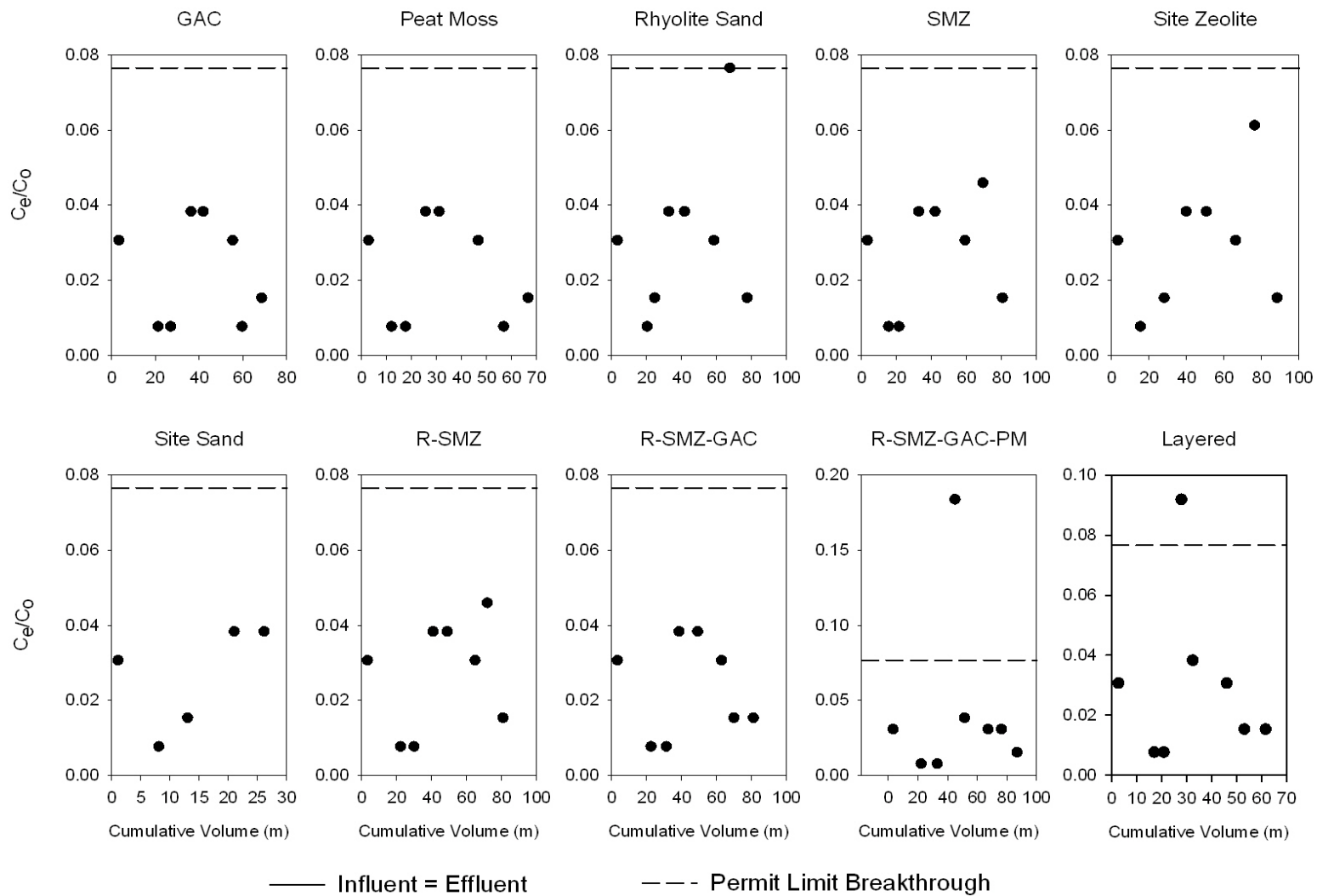


Figure A10-11. Cadmium (Filtered) Normalized Breakthrough Plots

CADMIUM, FILTERED

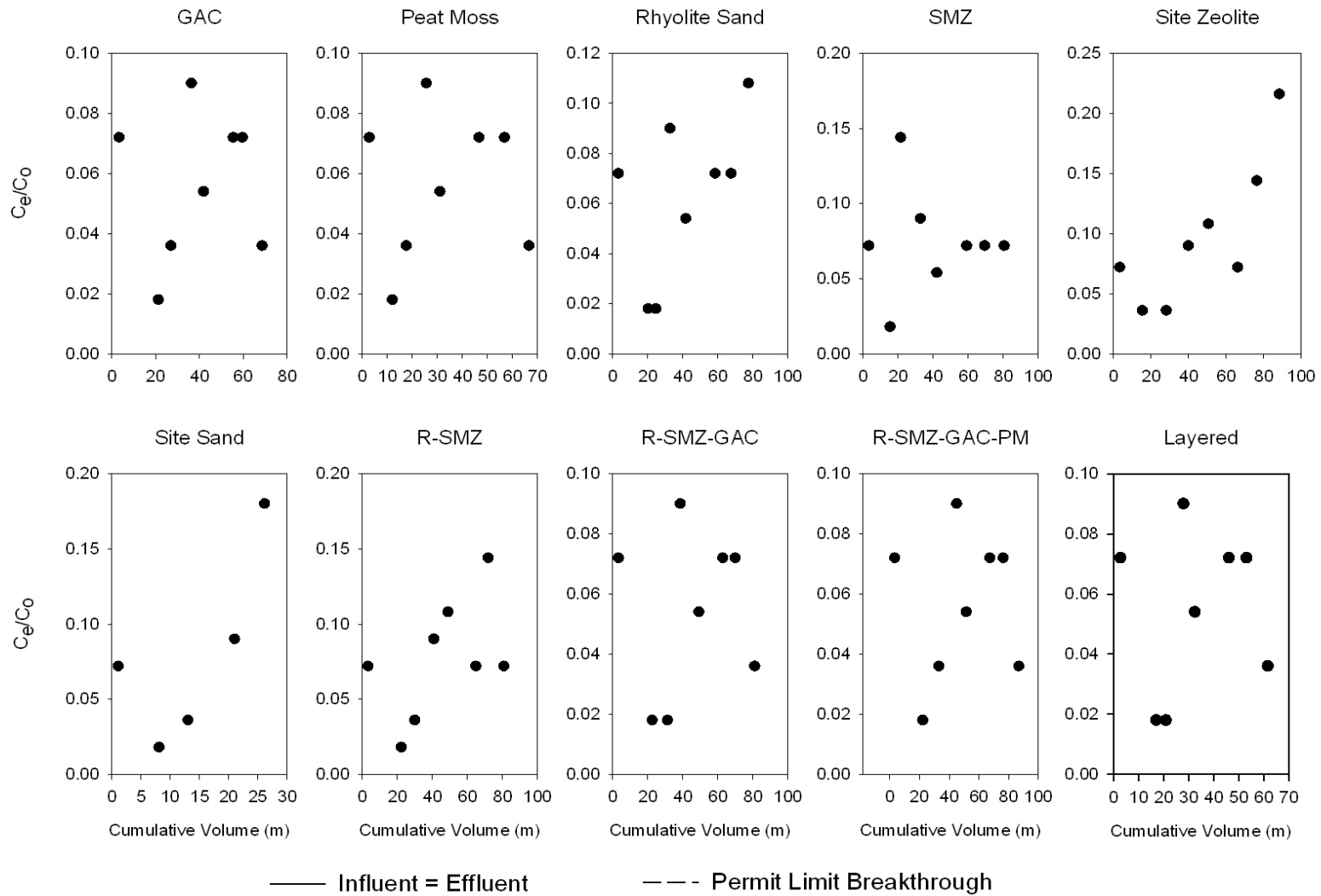


Figure A10-12. Cadmium (Filtered) Normalized Breakthrough Plots

CALCIUM, TOTAL

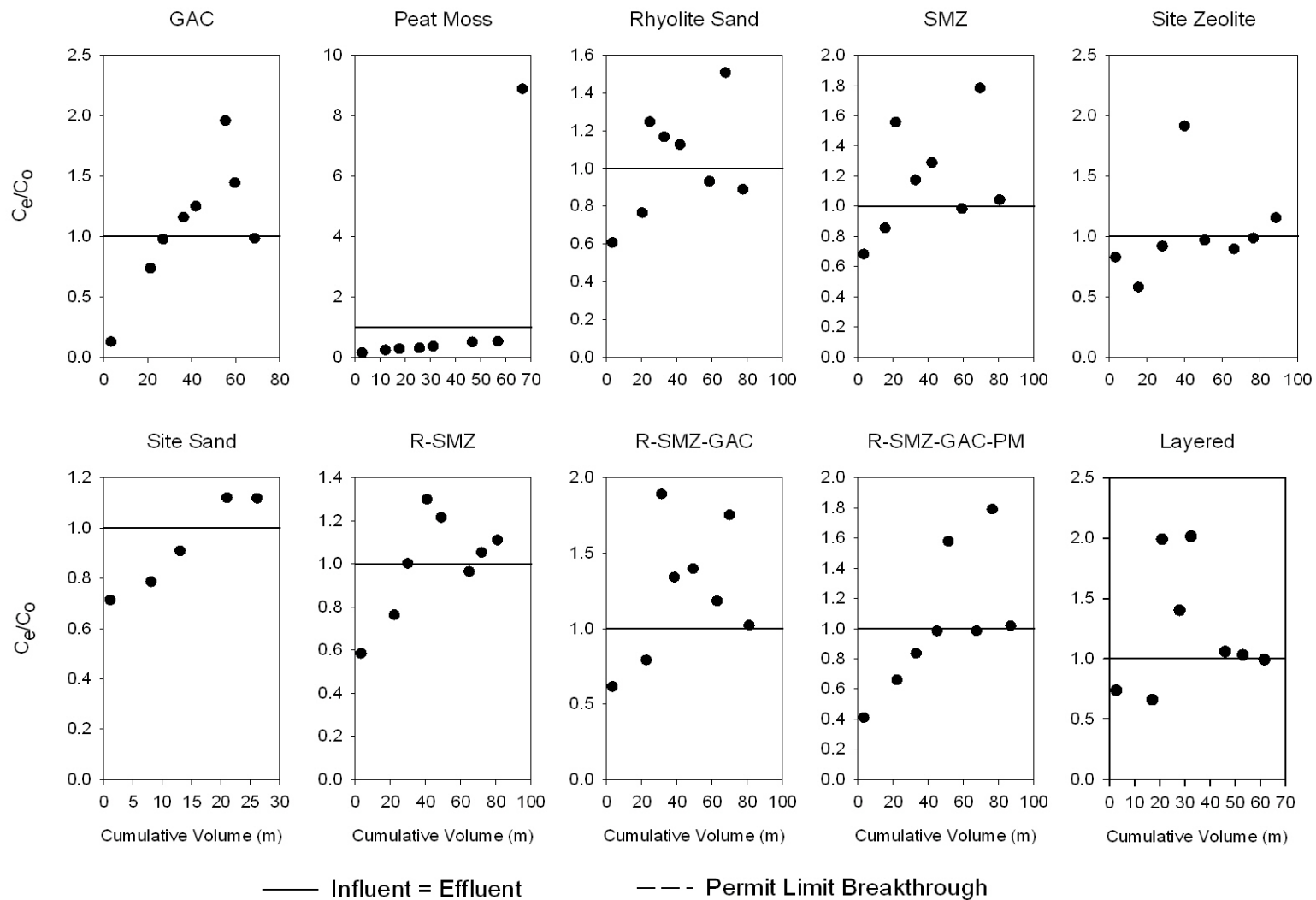
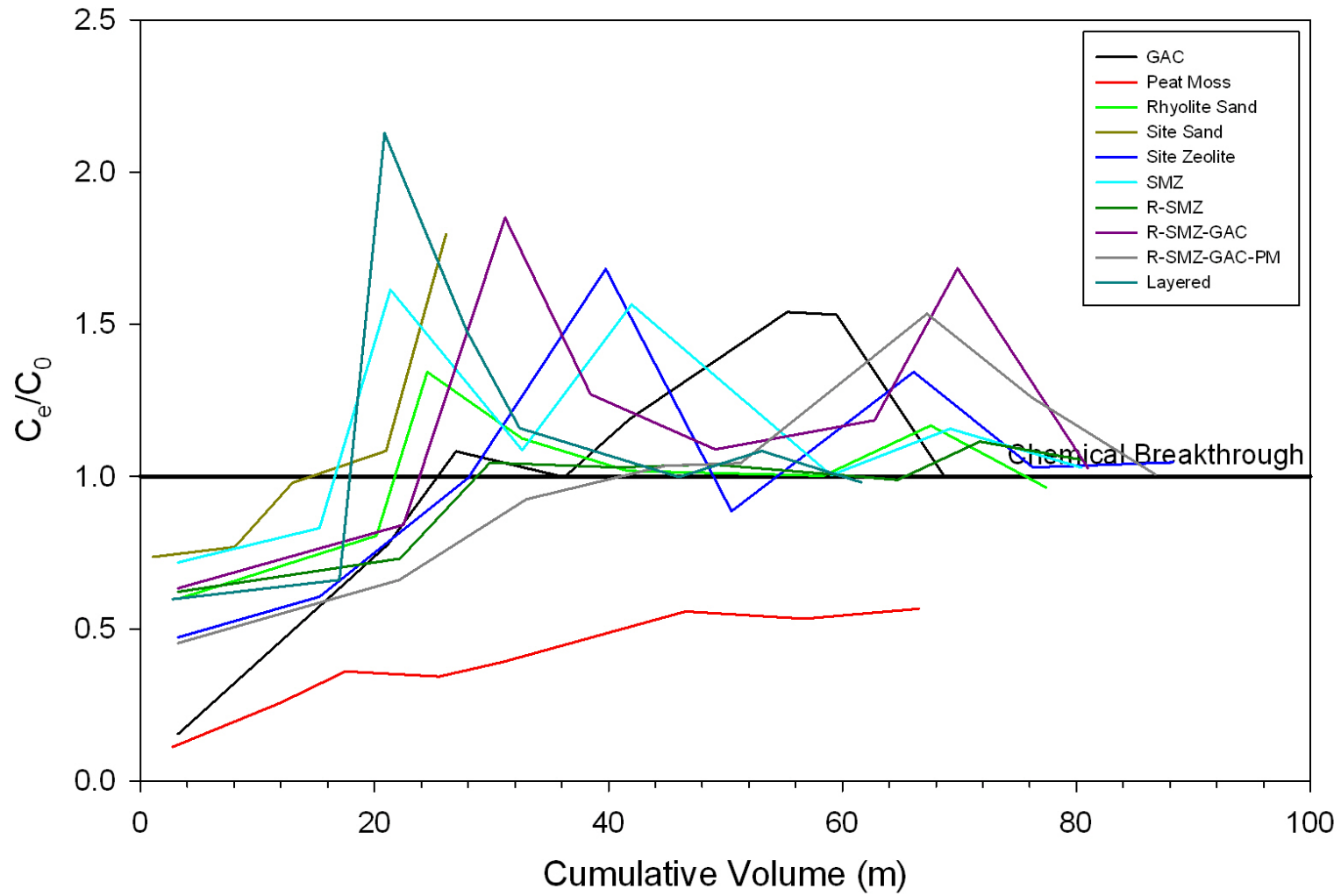


Figure A10-13. Calcium (Total) Normalized Breakthrough Plots

Calcium, Filtered



CALCIUM, FILTERED

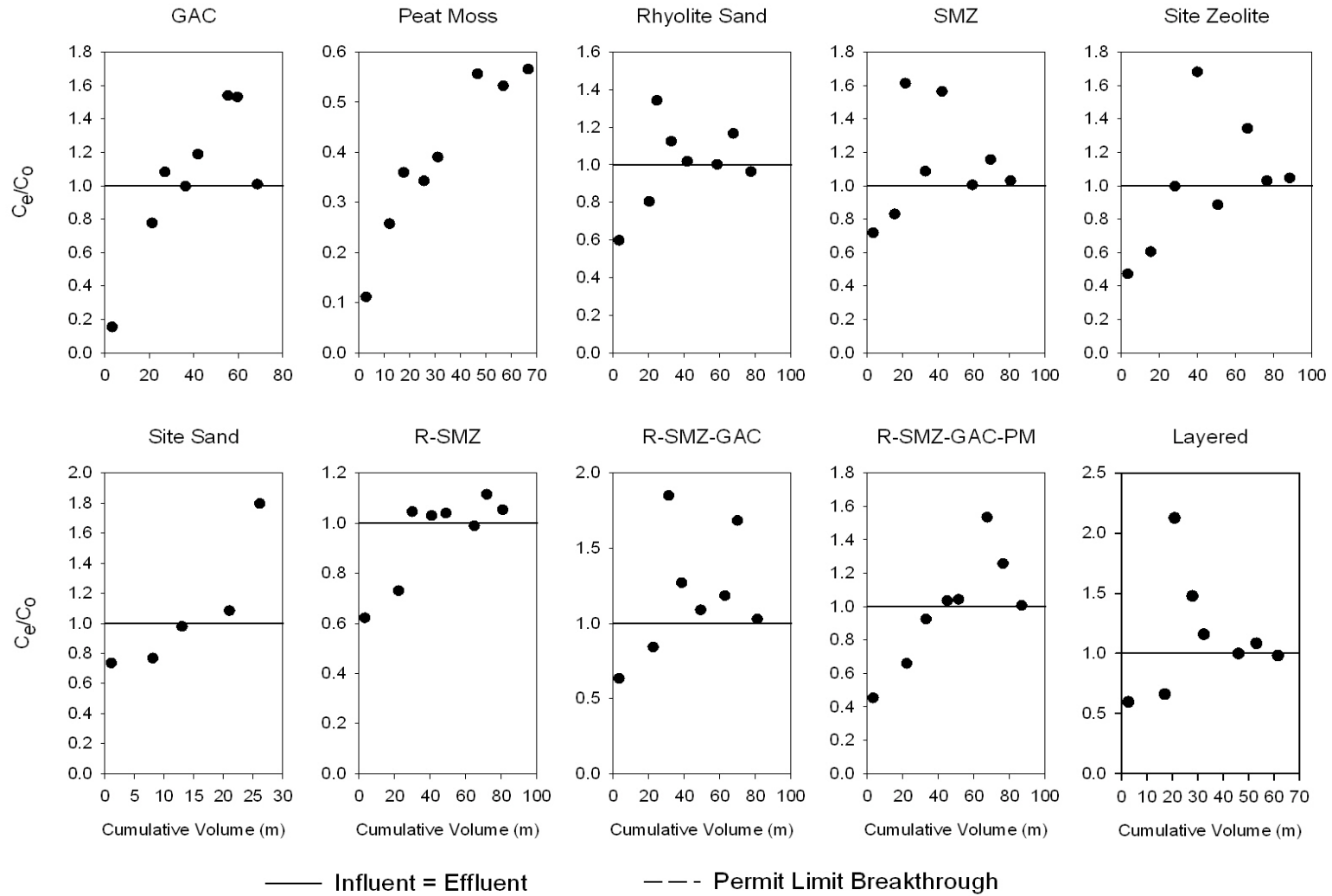
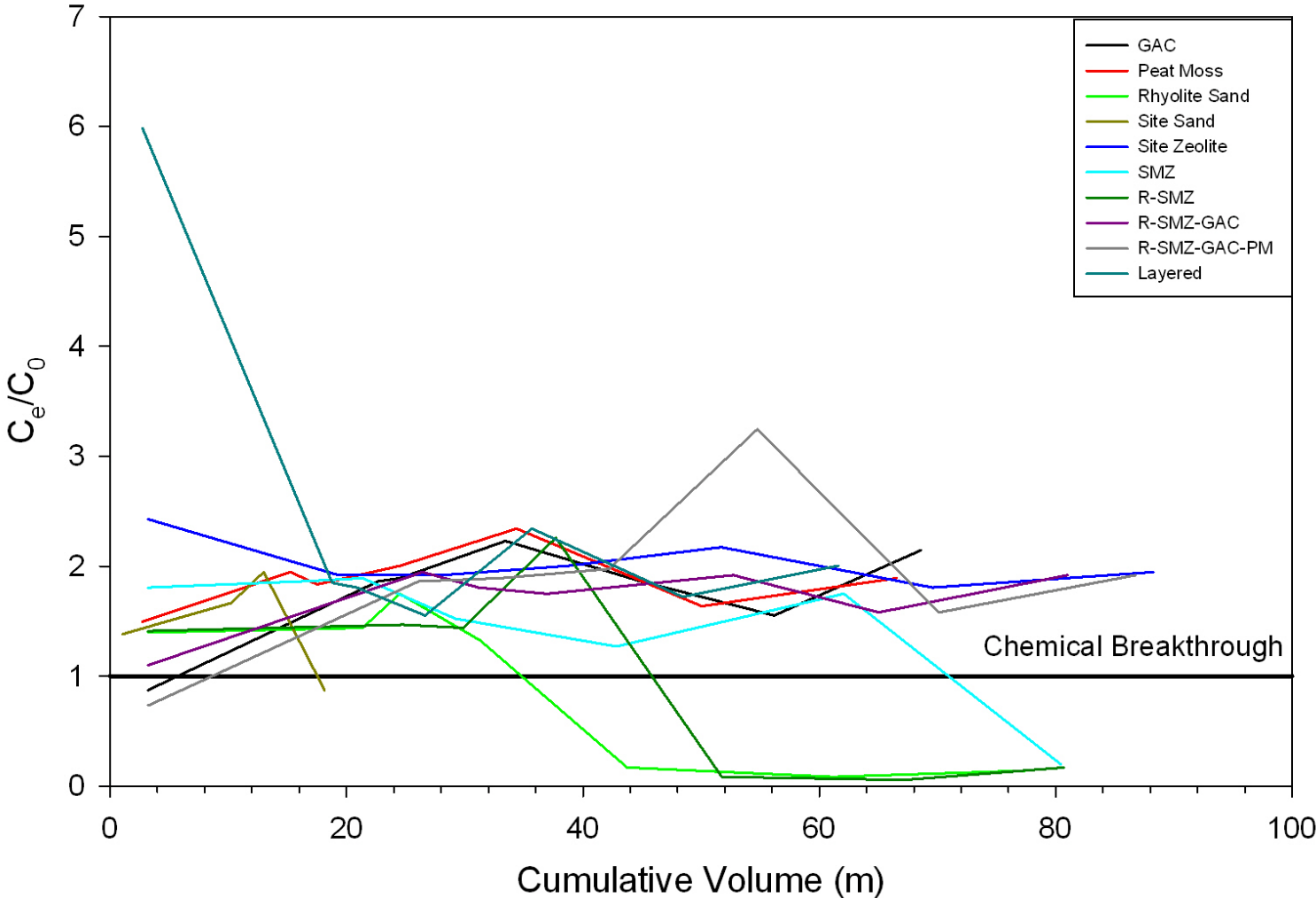


Figure A10-14. Calcium (Filtered) Normalized Breakthrough Plots

Chloride



CHLORIDE

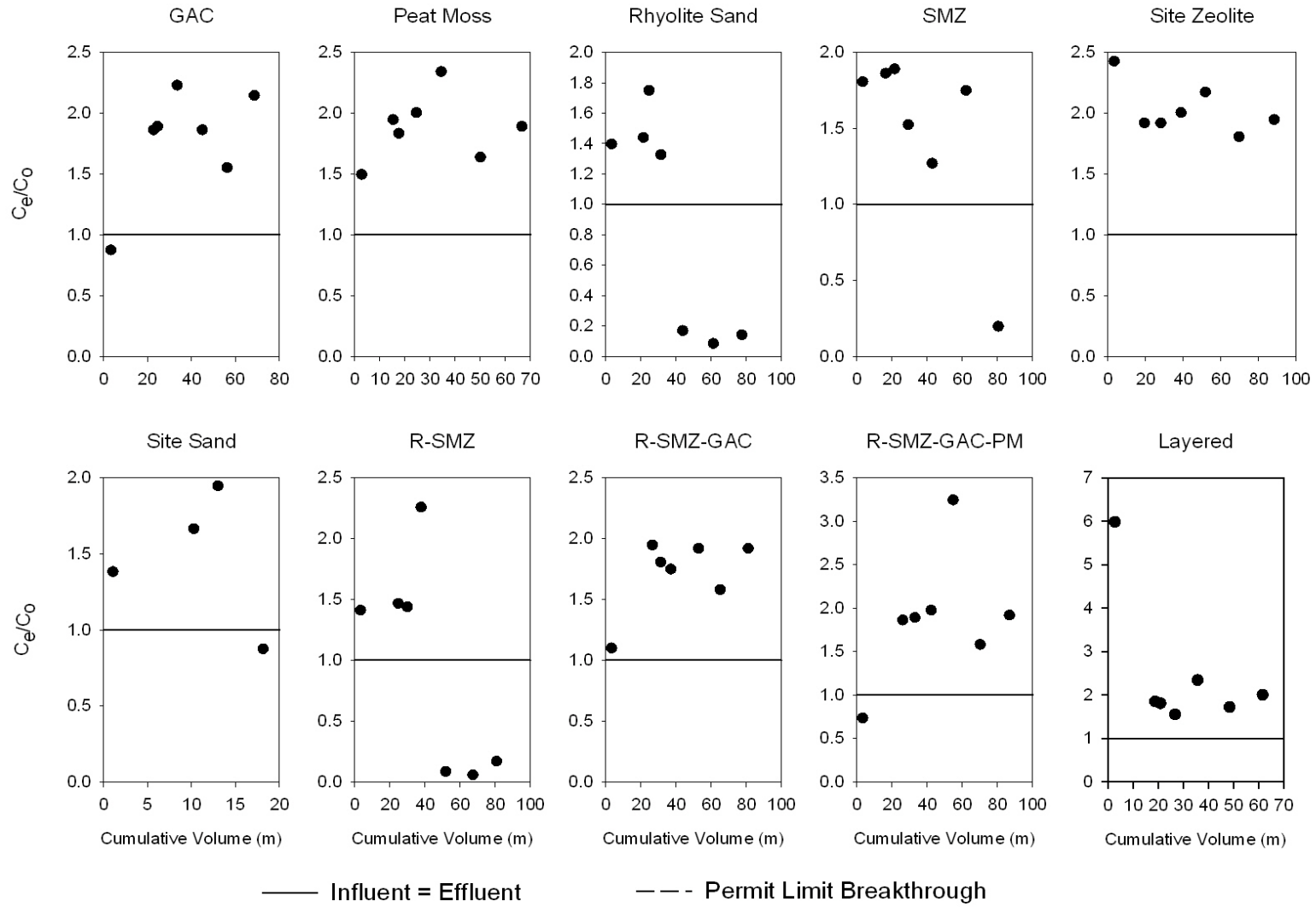
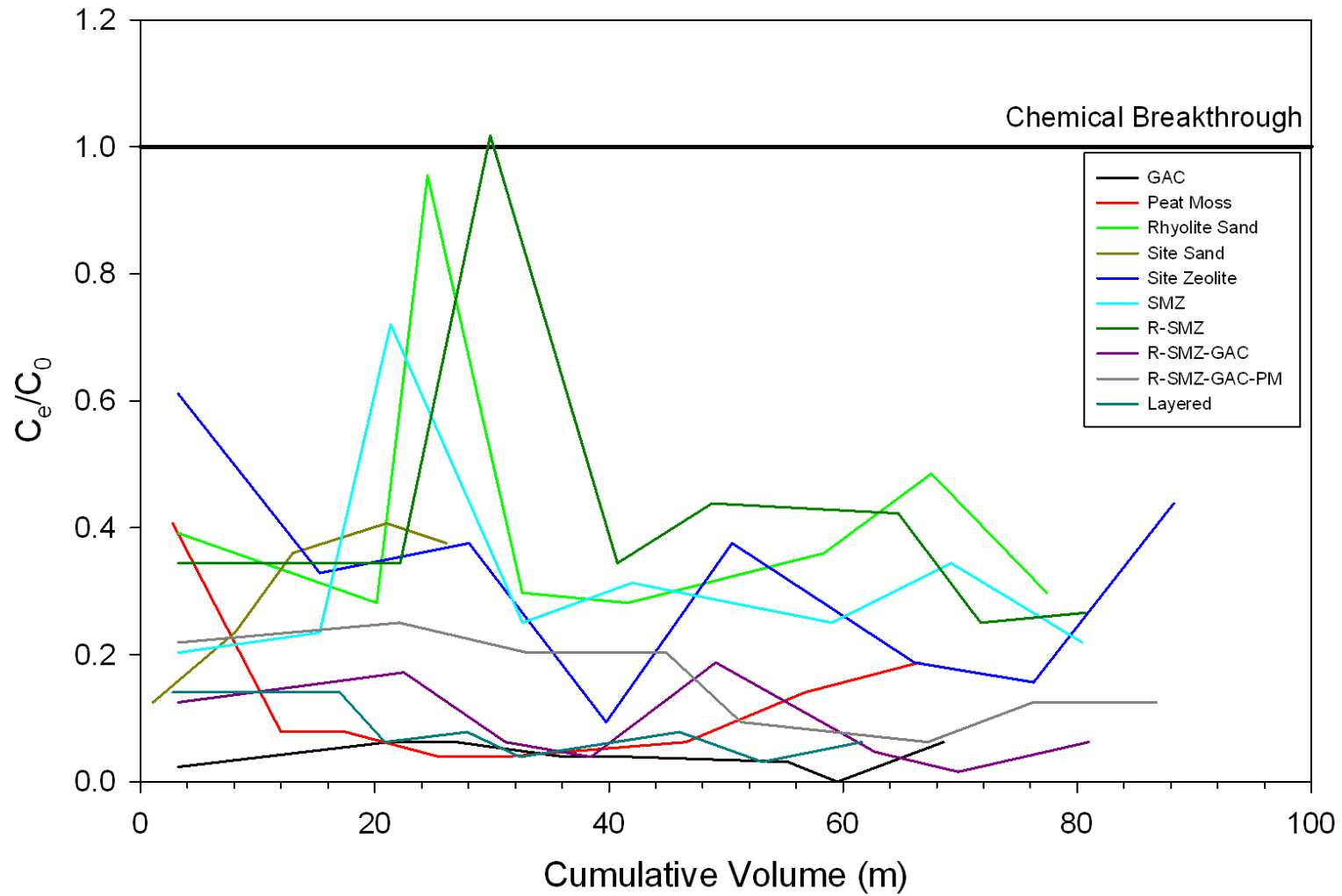


Figure A10-15. Chloride Normalized Breakthrough Plots

Chromium, Total



CHROMIUM, TOTAL

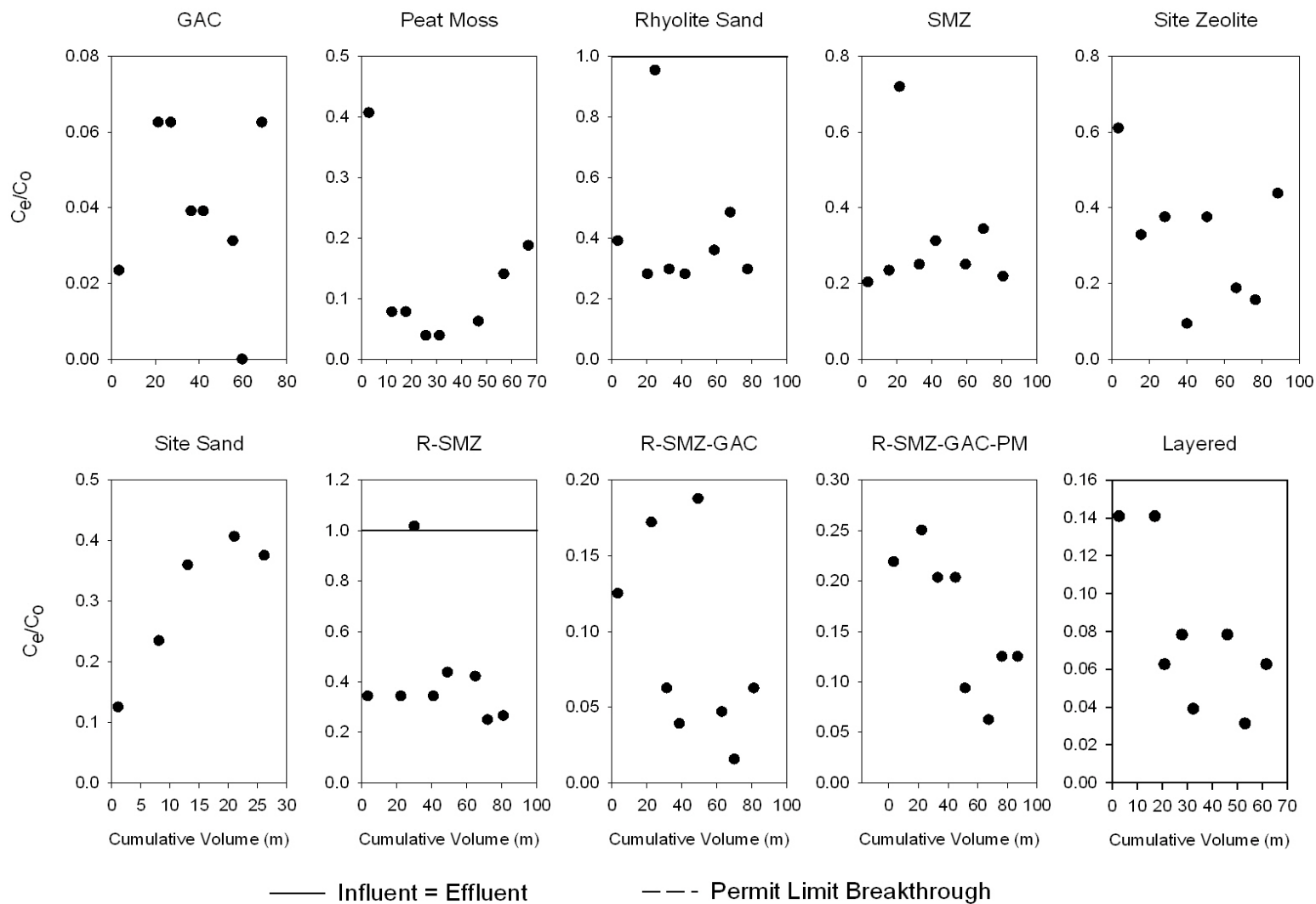
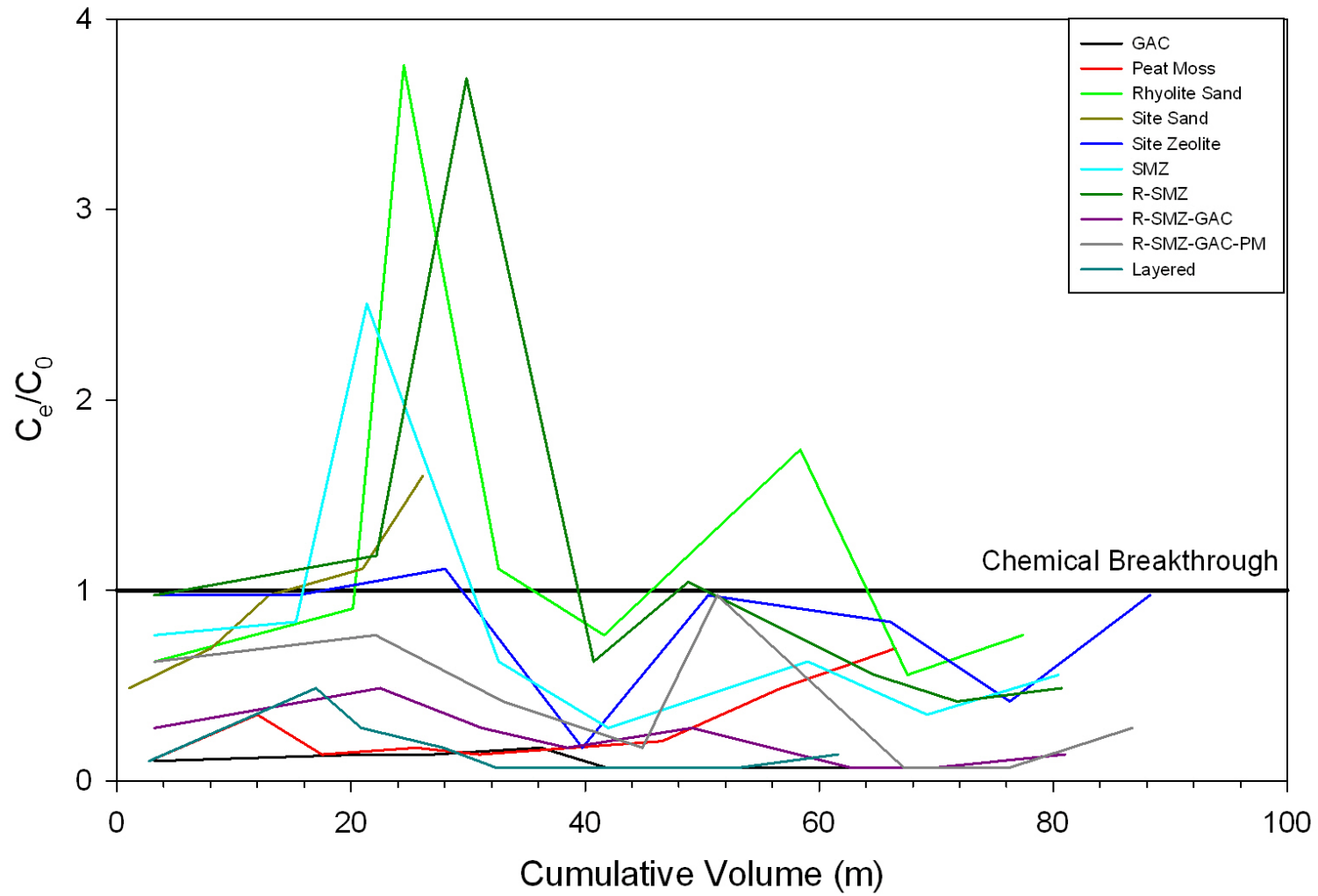


Figure A10-16. Chromium (Total) Normalized Breakthrough Plots

Chromium, Filtered



CHROMIUM, FILTERED

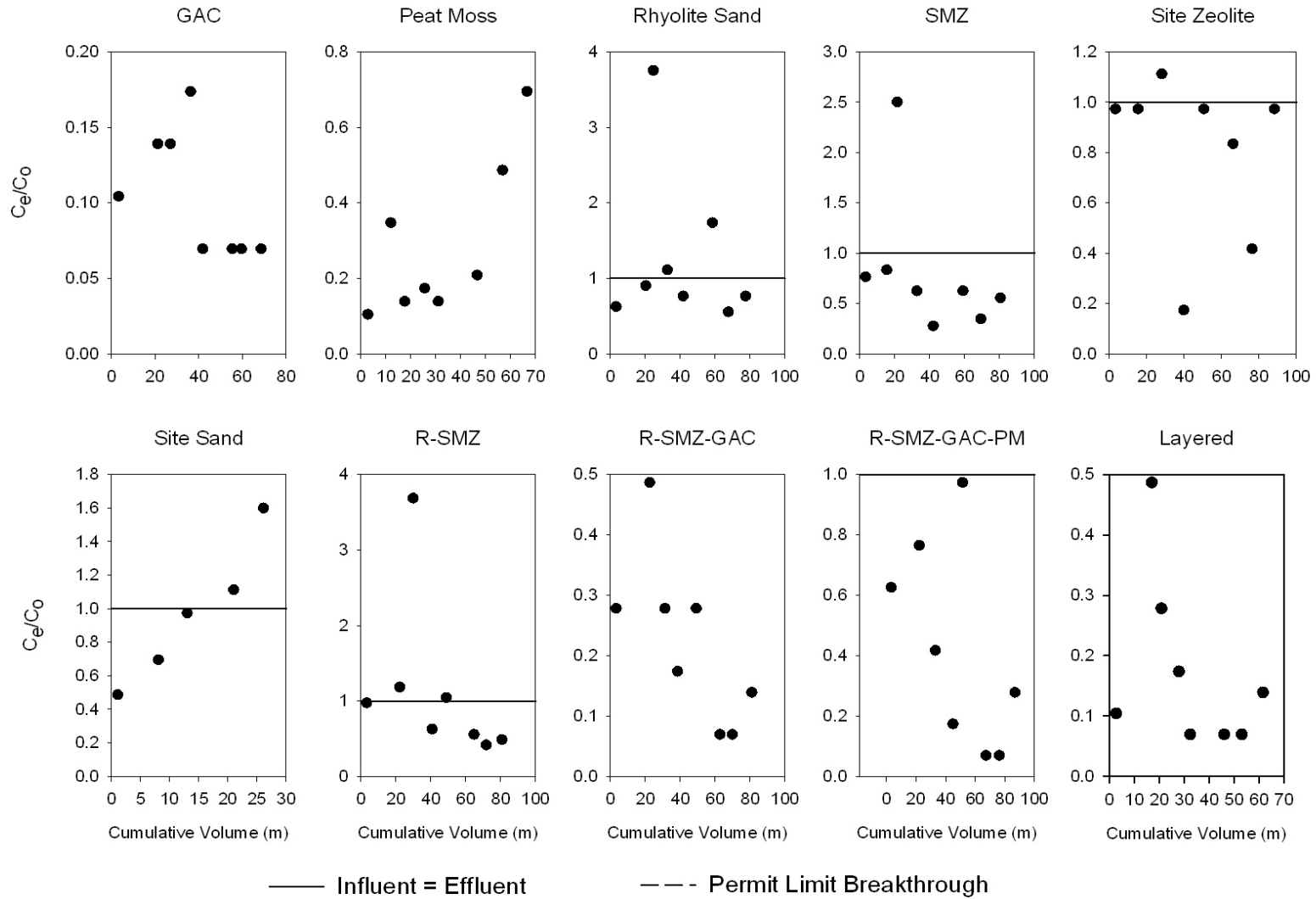
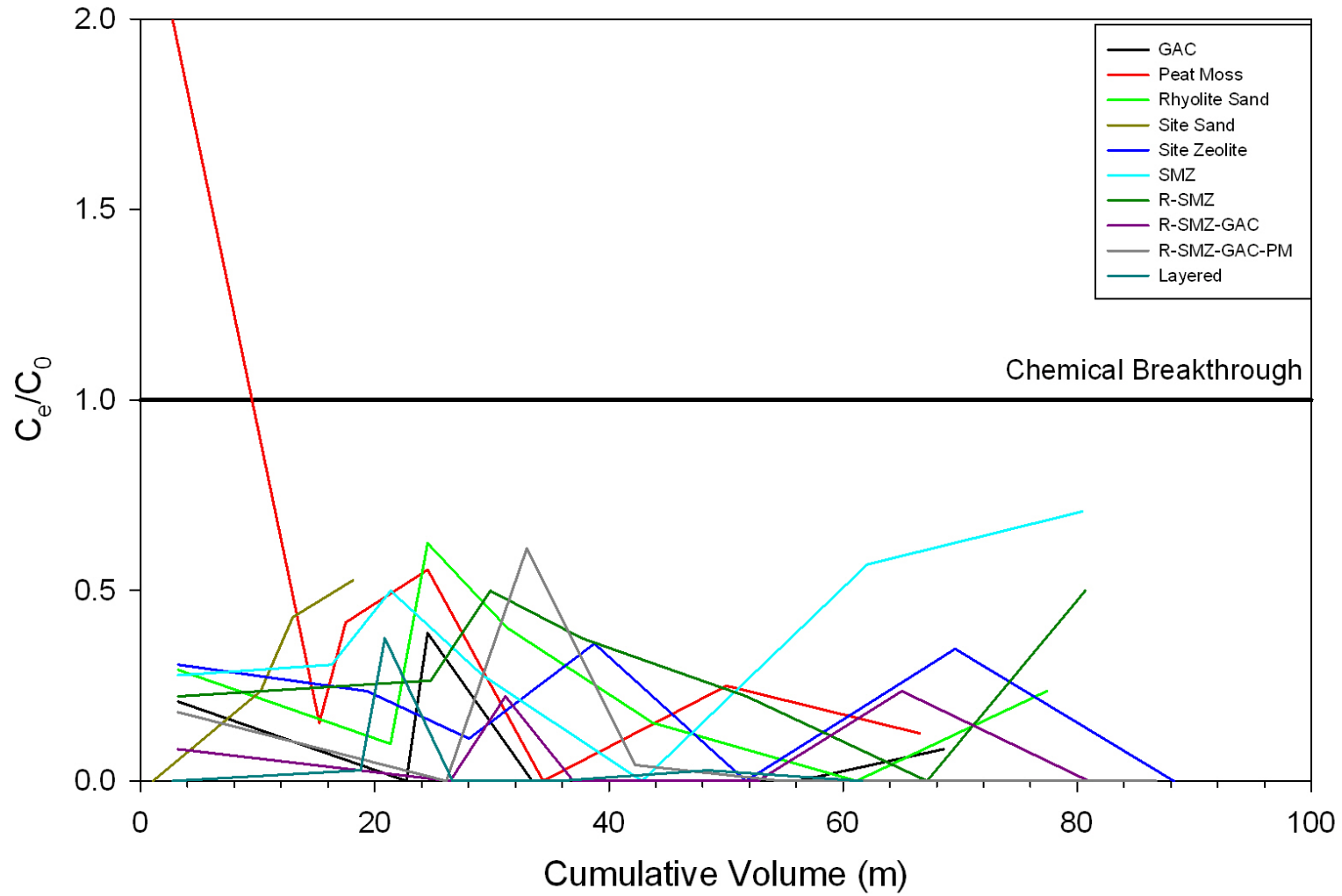


Figure A10-17. Chromium (Filtered) Normalized Breakthrough Plots

Chemical Oxygen Demand



CHEMICAL OXYGEN DEMAND

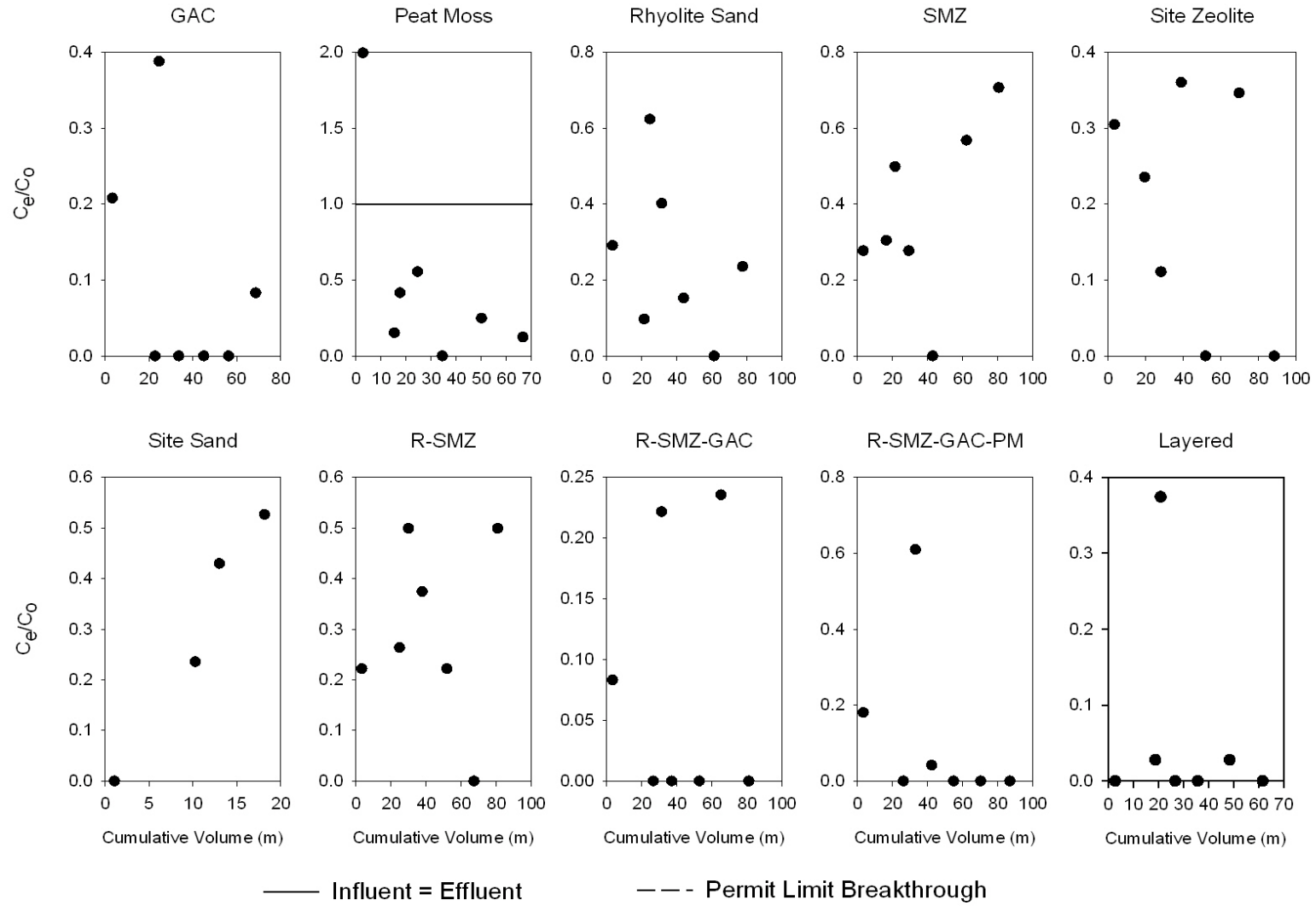
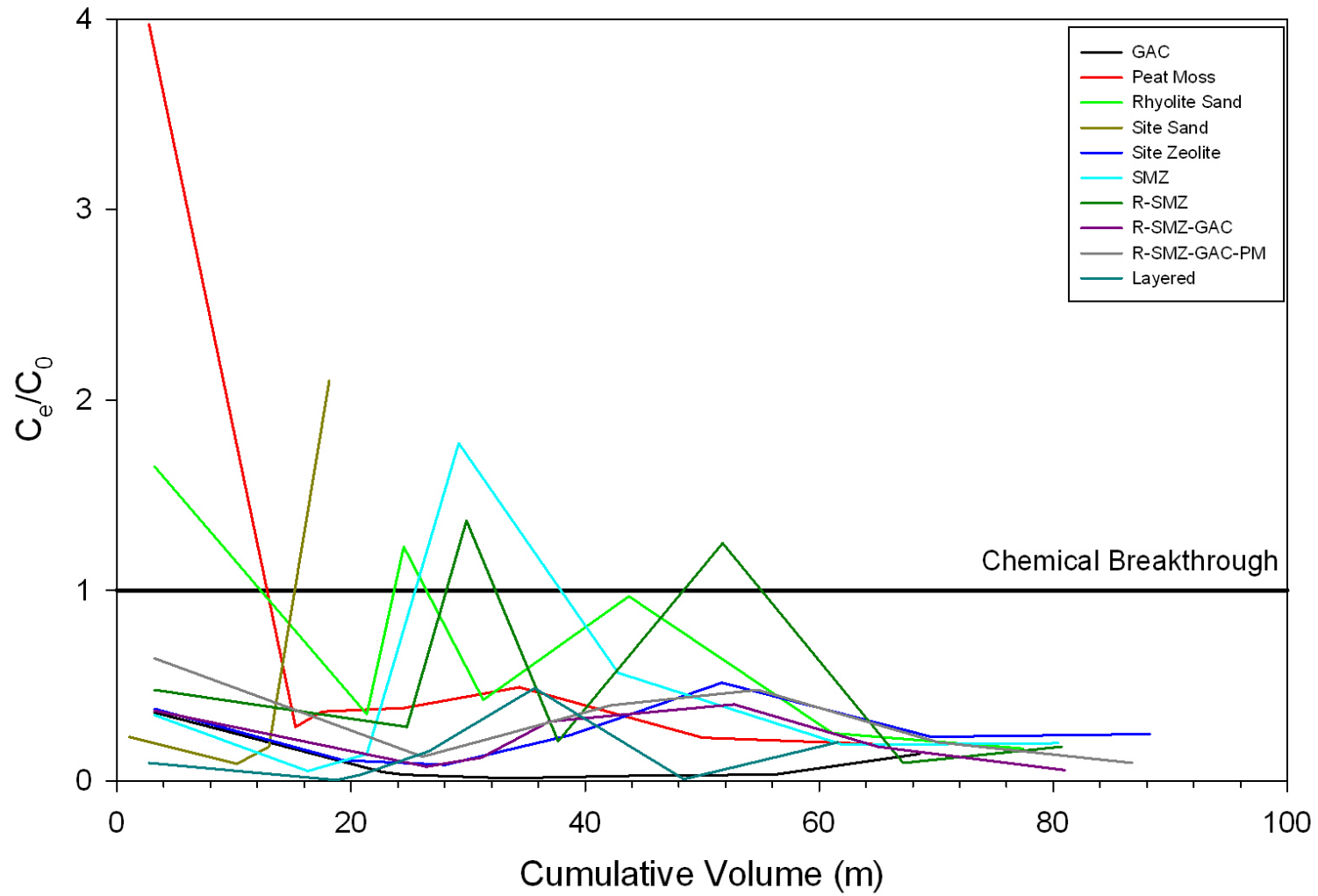


Figure A10-18. Chemical Oxygen Demand Normalized Breakthrough Plots

Color, Apparent



COLOR, APPARENT

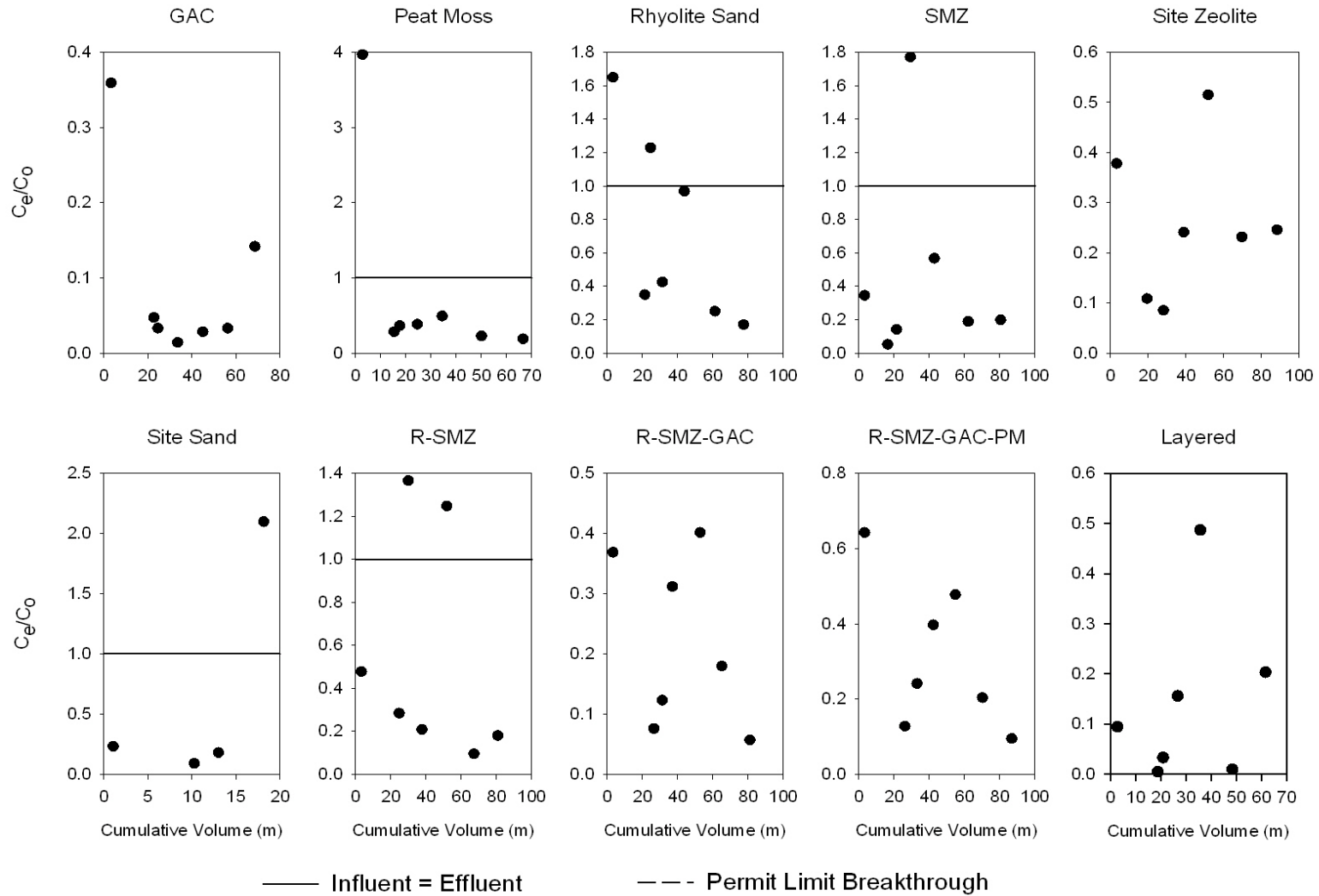
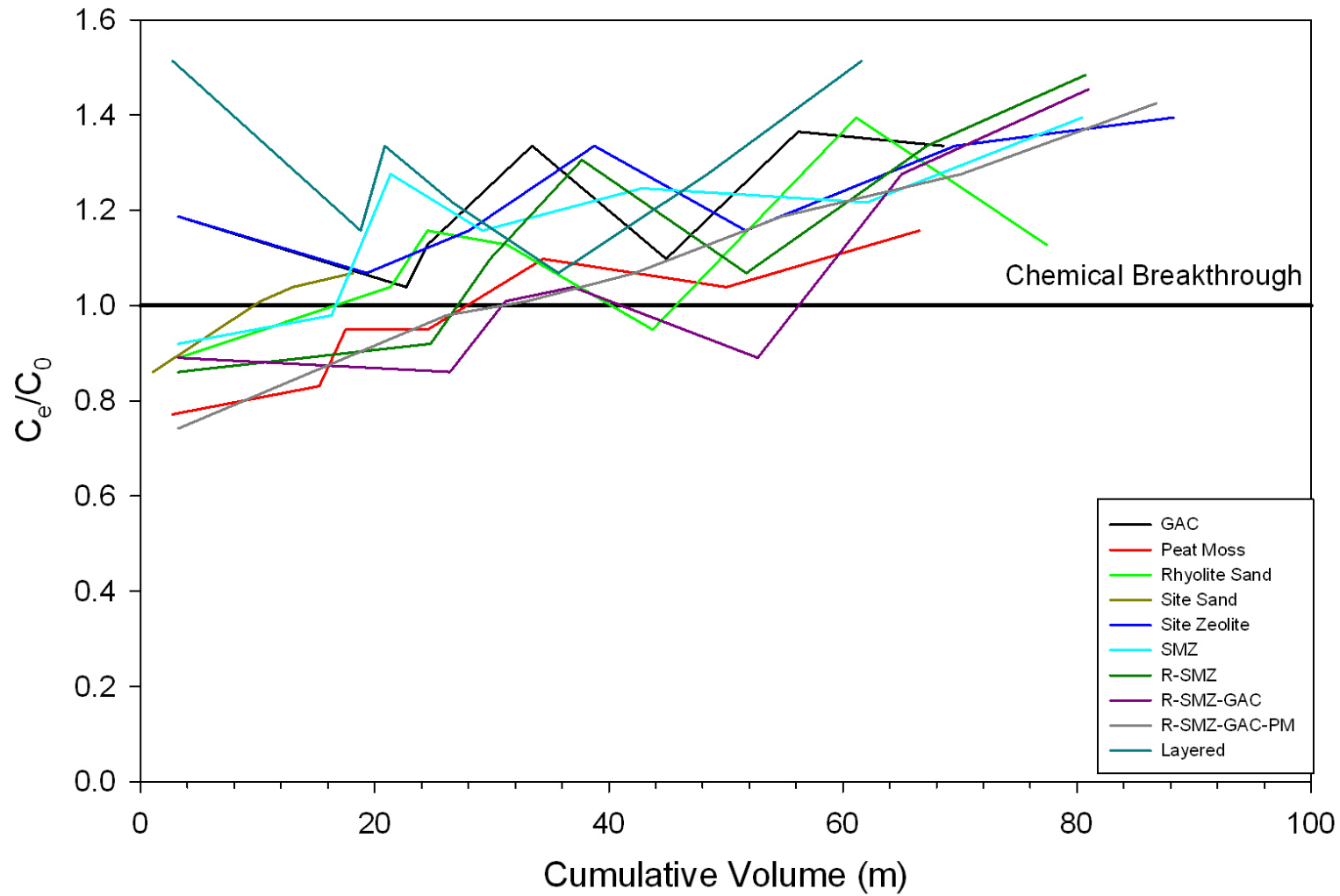


Figure A10-19. Apparent Color Normalized Breakthrough Plots

Conductivity



CONDUCTIVITY

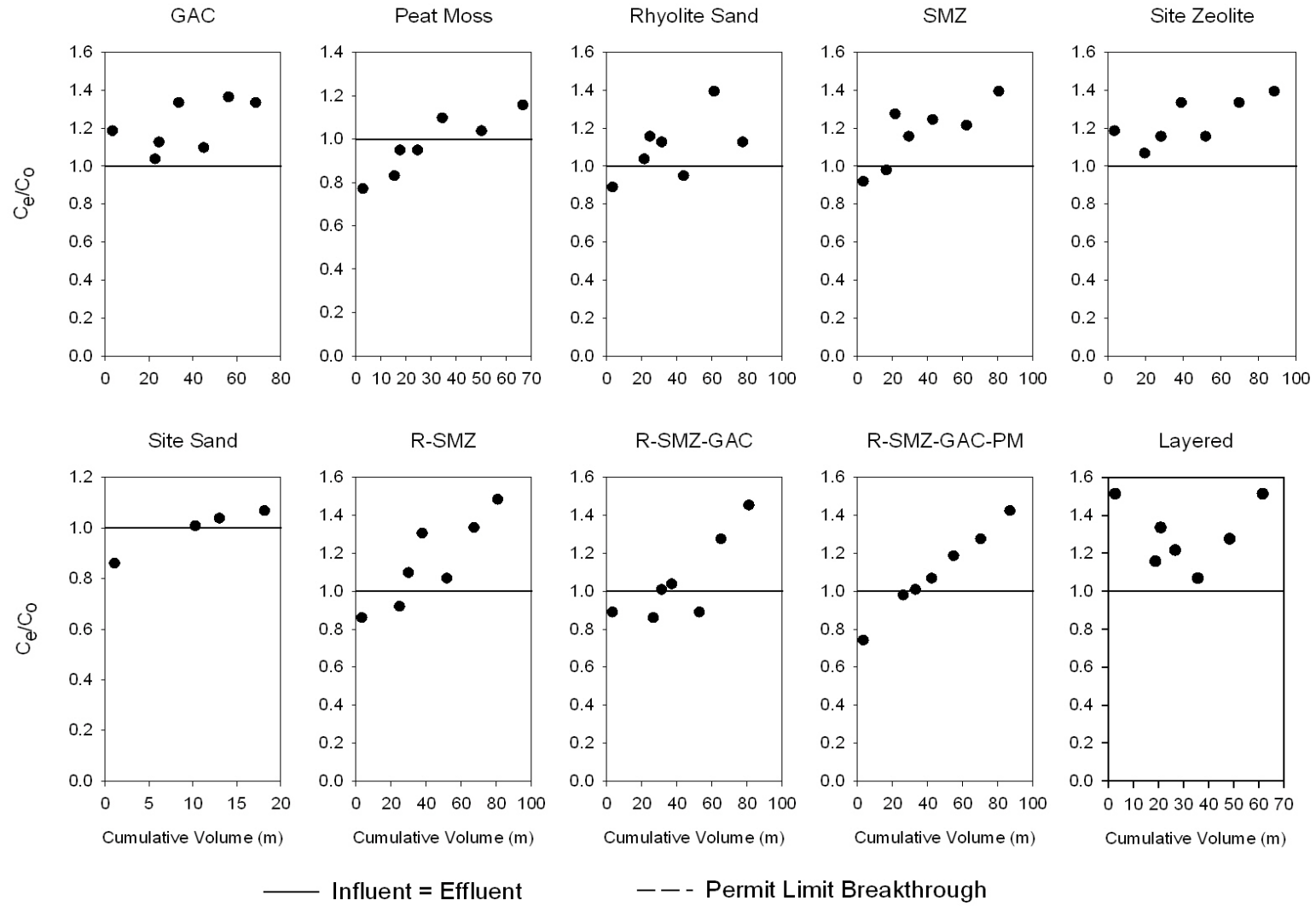
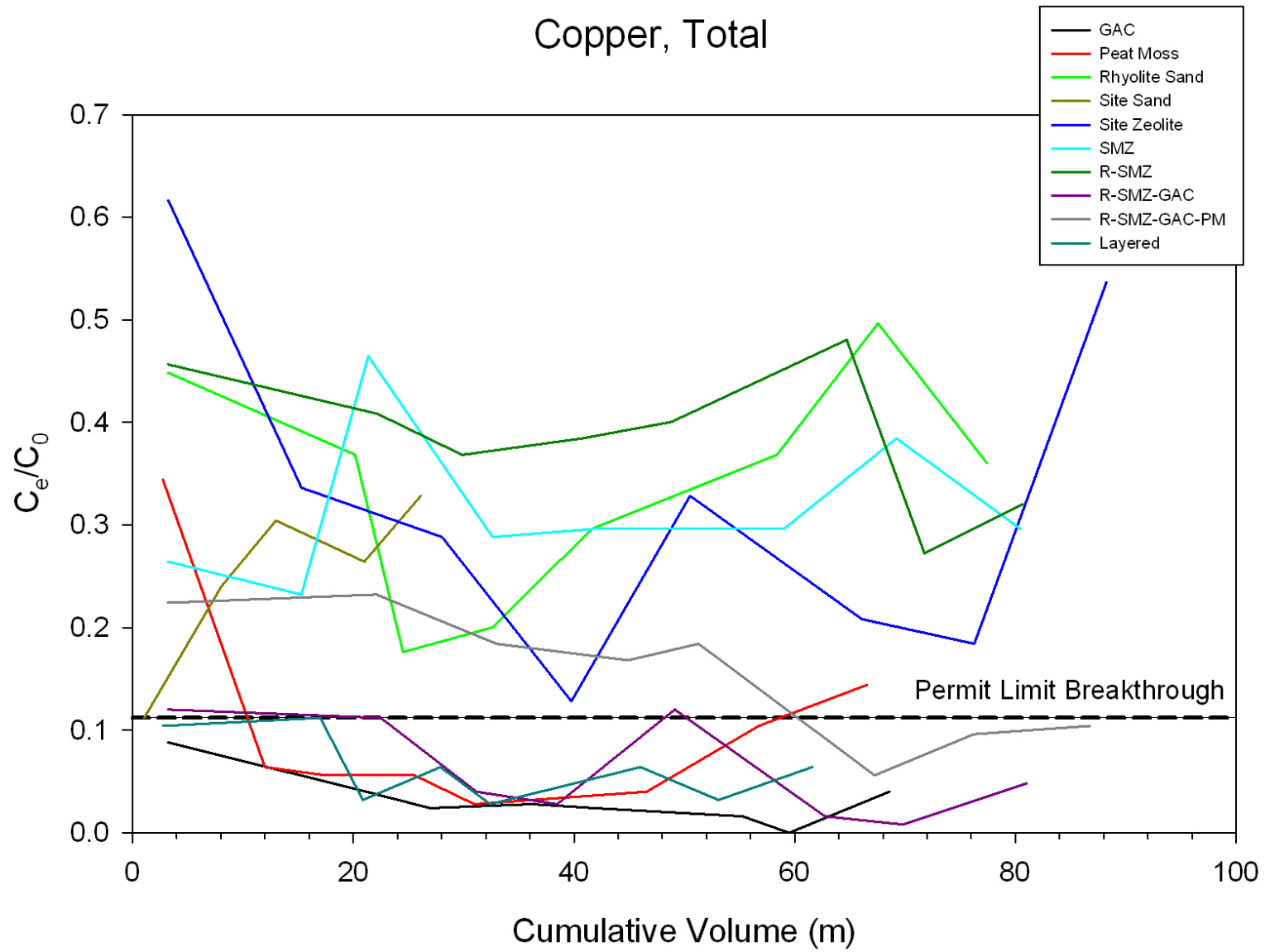


Figure A10-20. Conductivity Normalized Breakthrough Plots

Copper, Total



COPPER, TOTAL

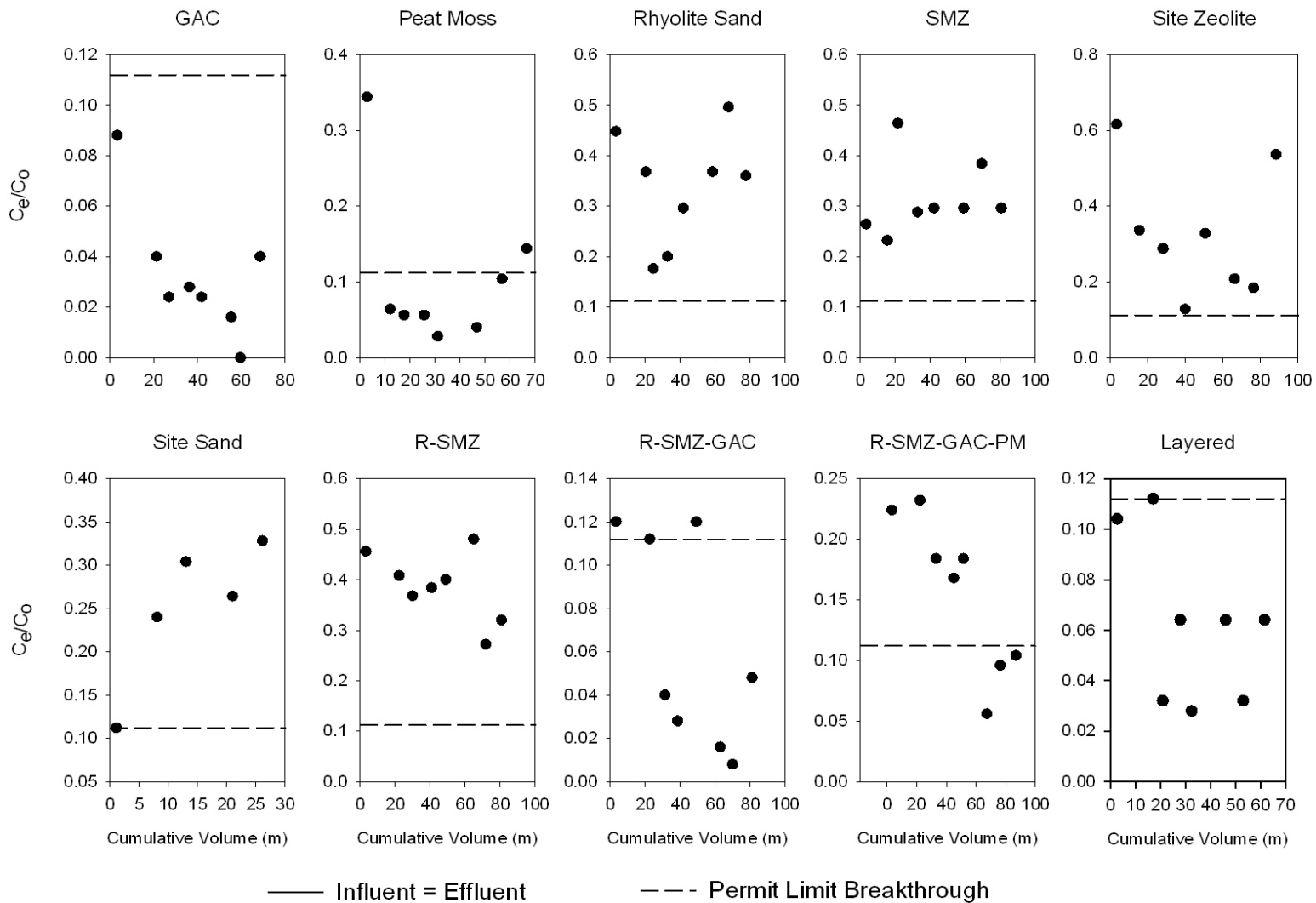
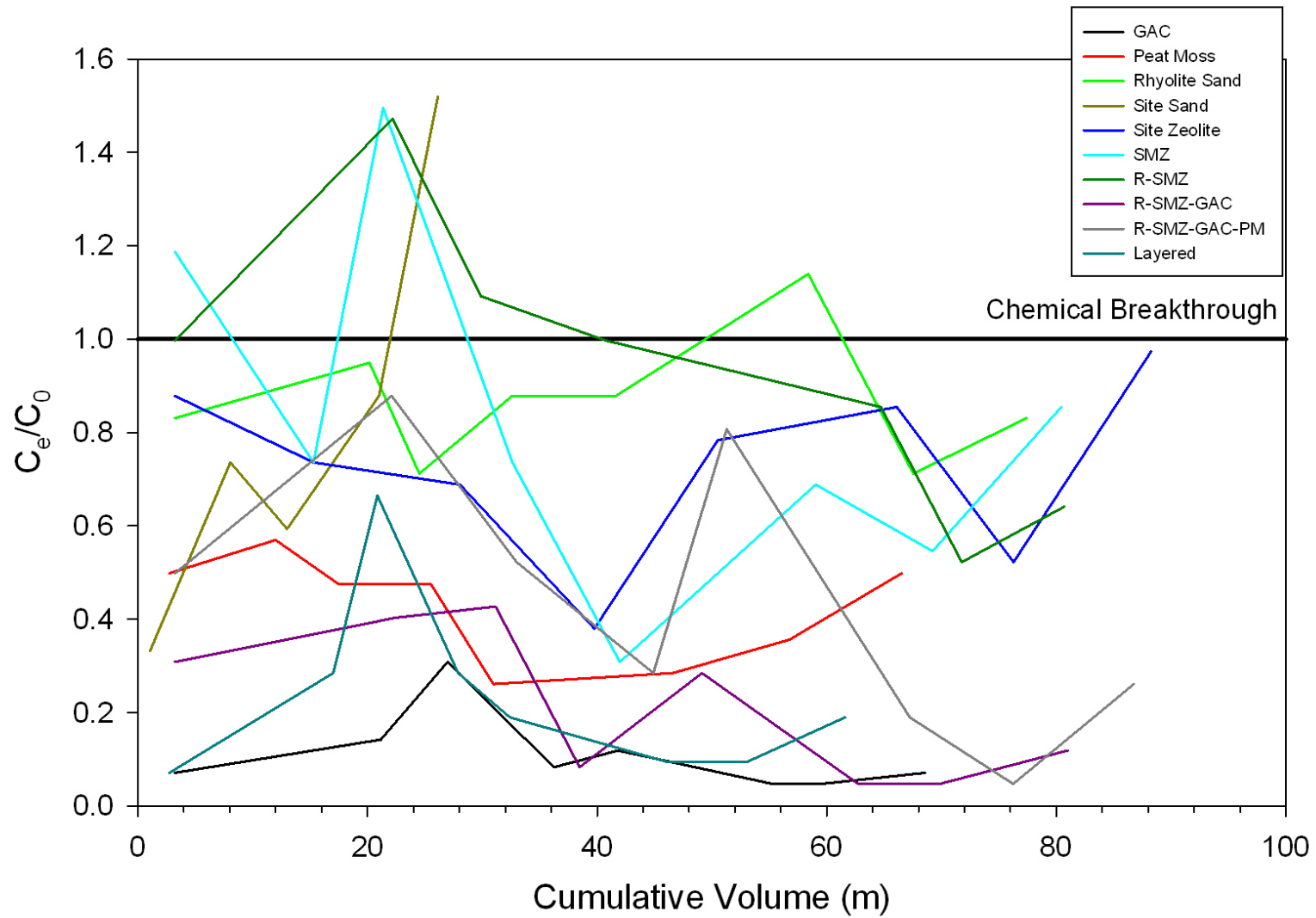


Figure A10-21. Copper (Total) Normalized Breakthrough Plots

Copper, Filtered



COPPER, FILTERED

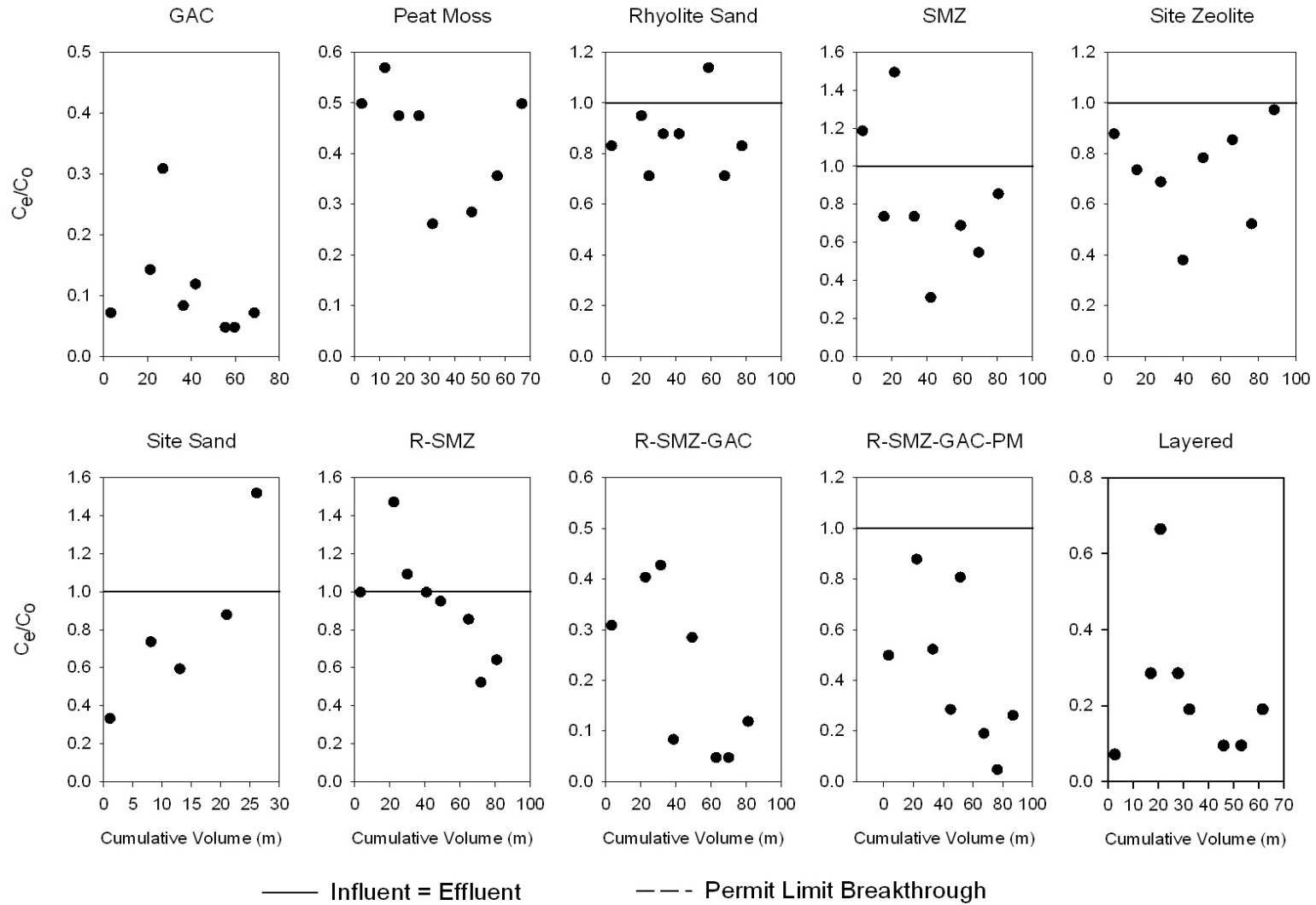
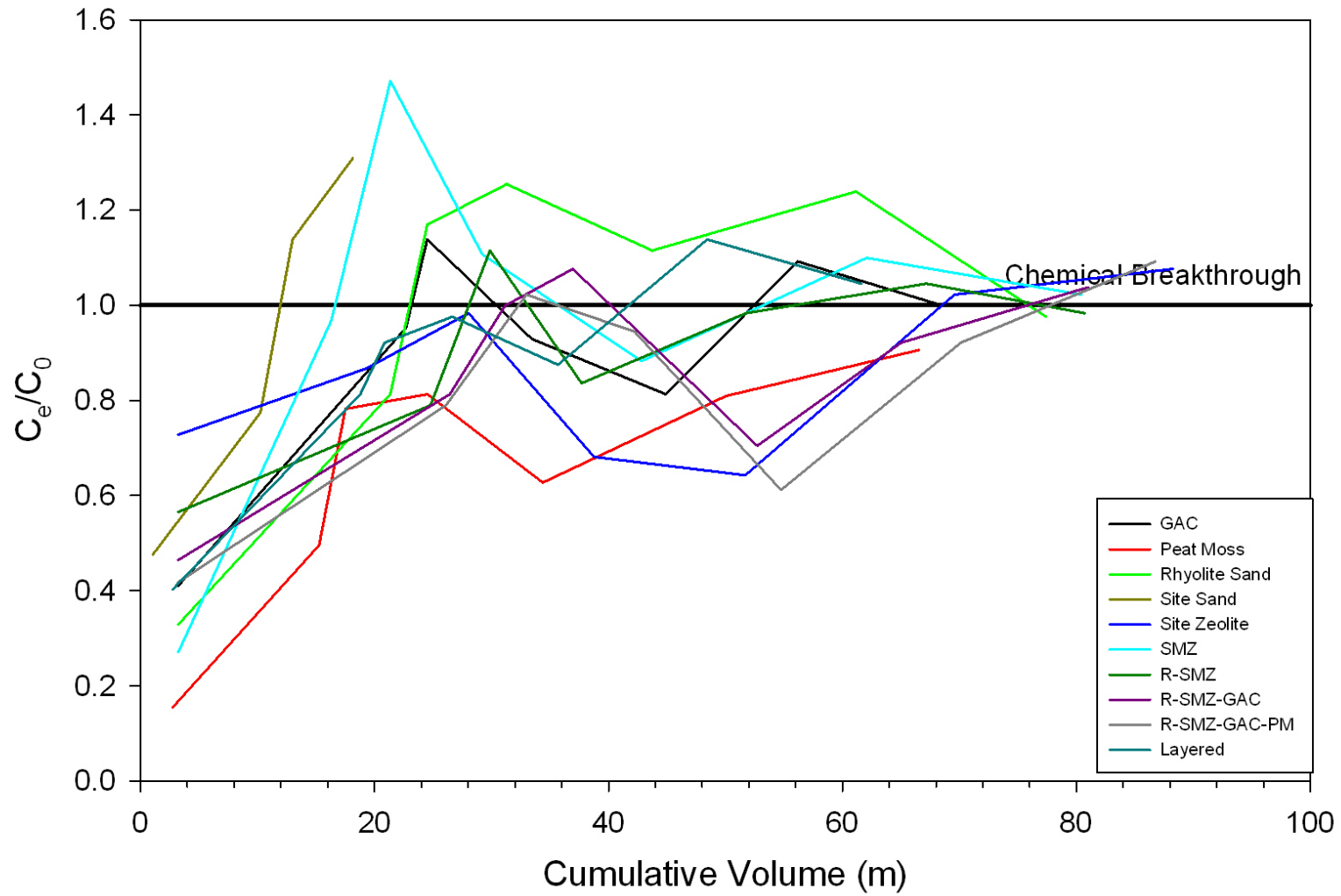


Figure A10-22. Copper (Filtered) Normalized Breakthrough Plots

Fluoride



FLUORIDE

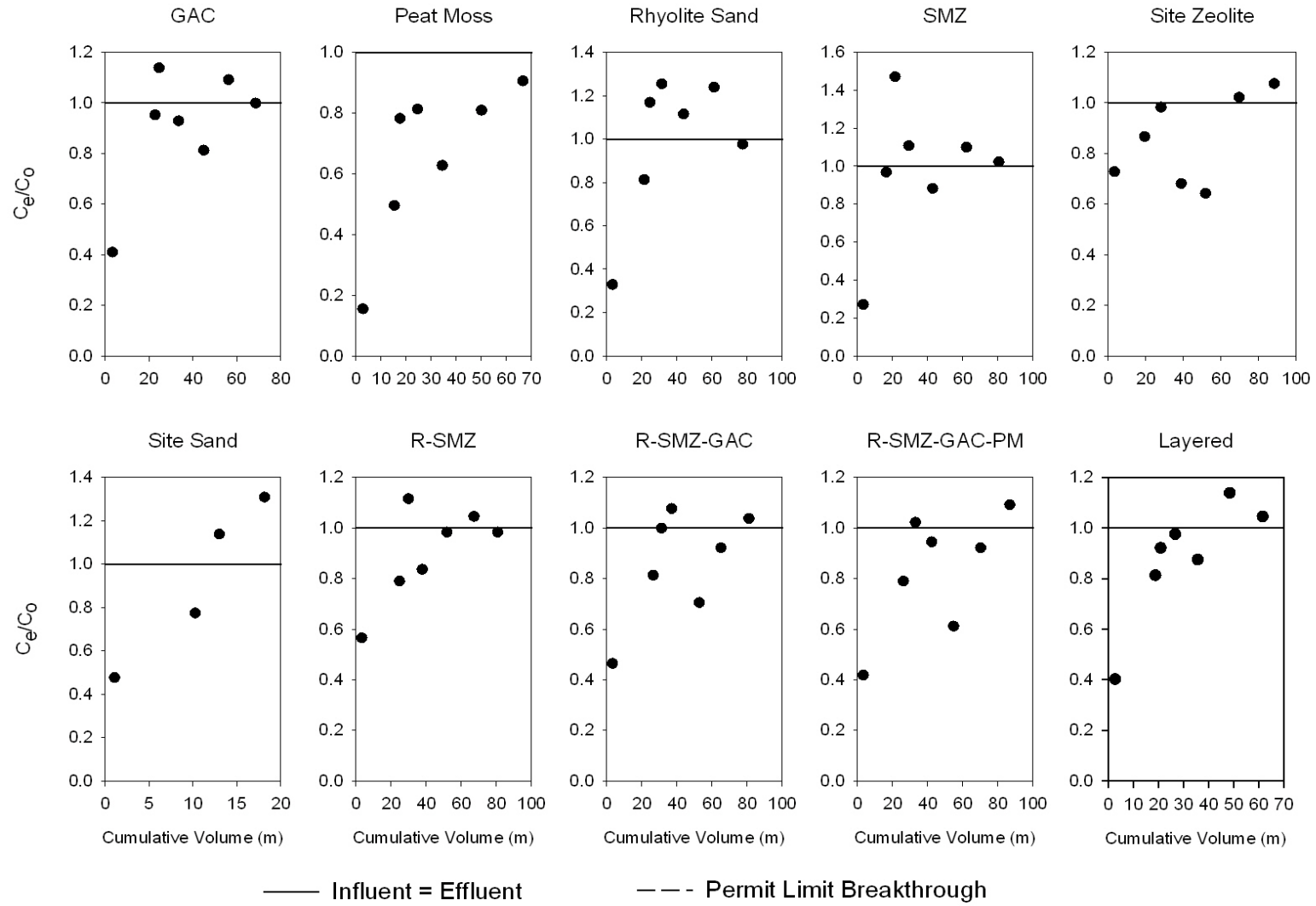
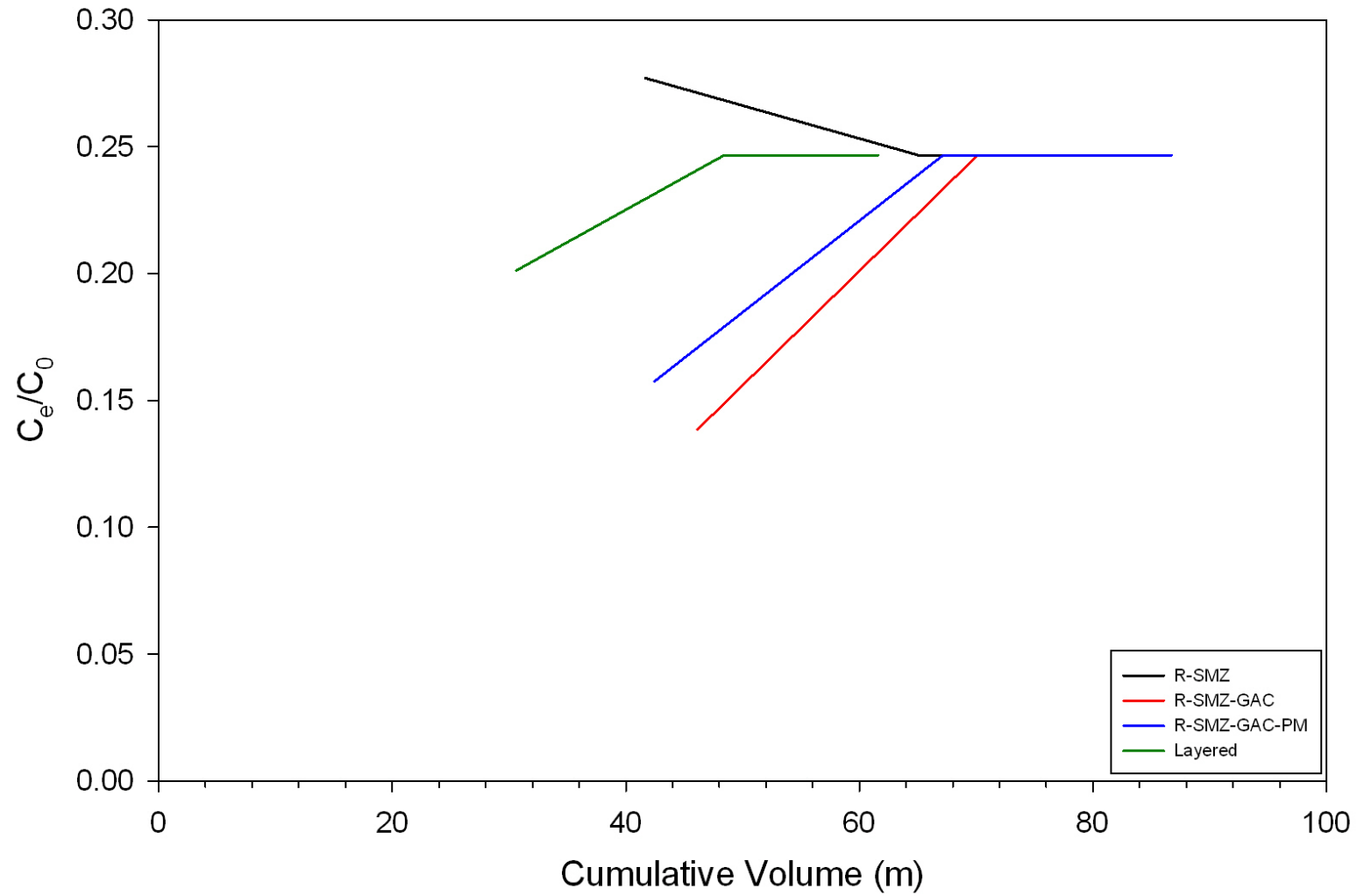


Figure A10-23. Fluoride Normalized Breakthrough Plots

Gross Alpha Radioactivity



GROSS ALPHA RADIOACTIVITY

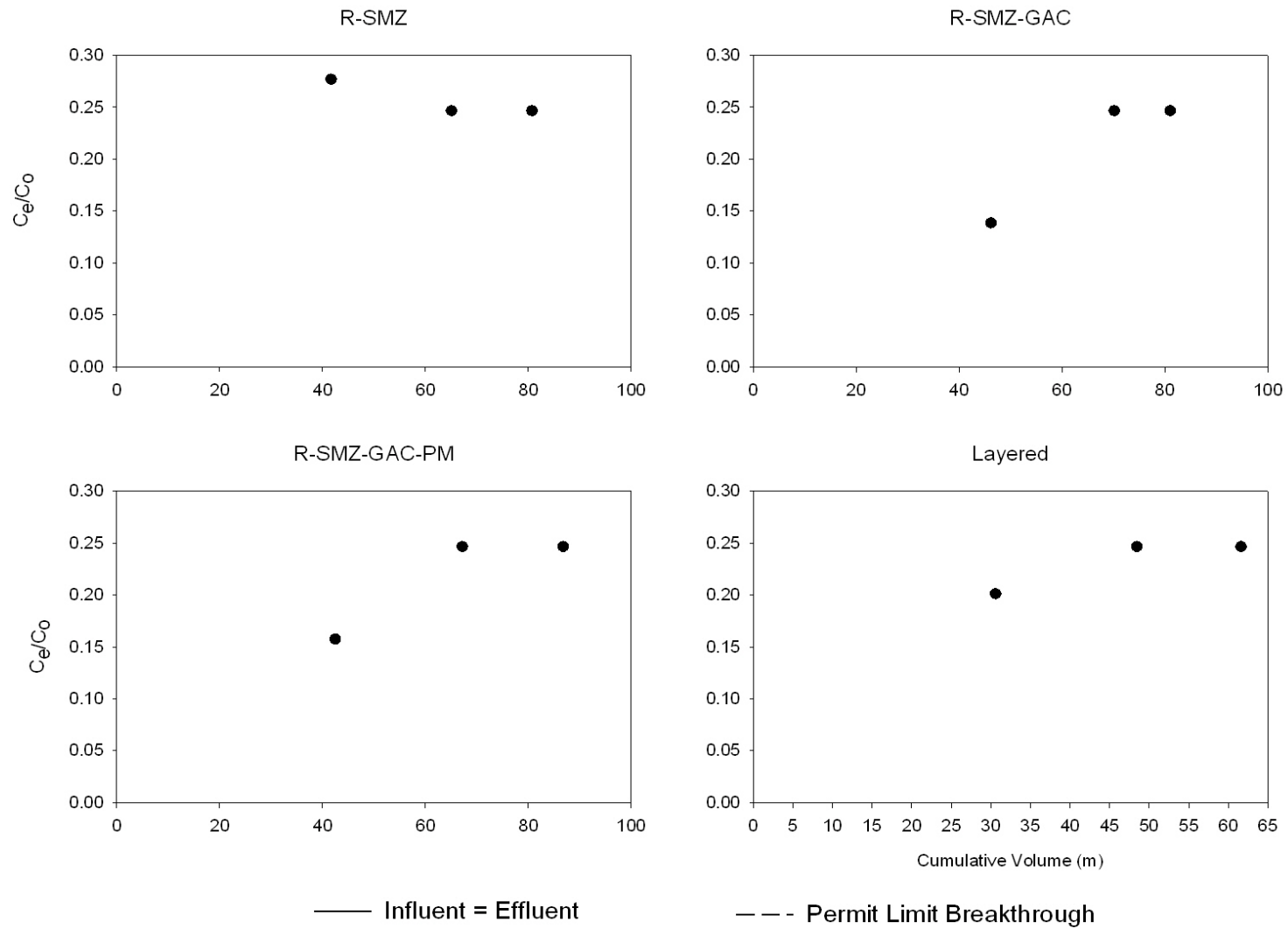
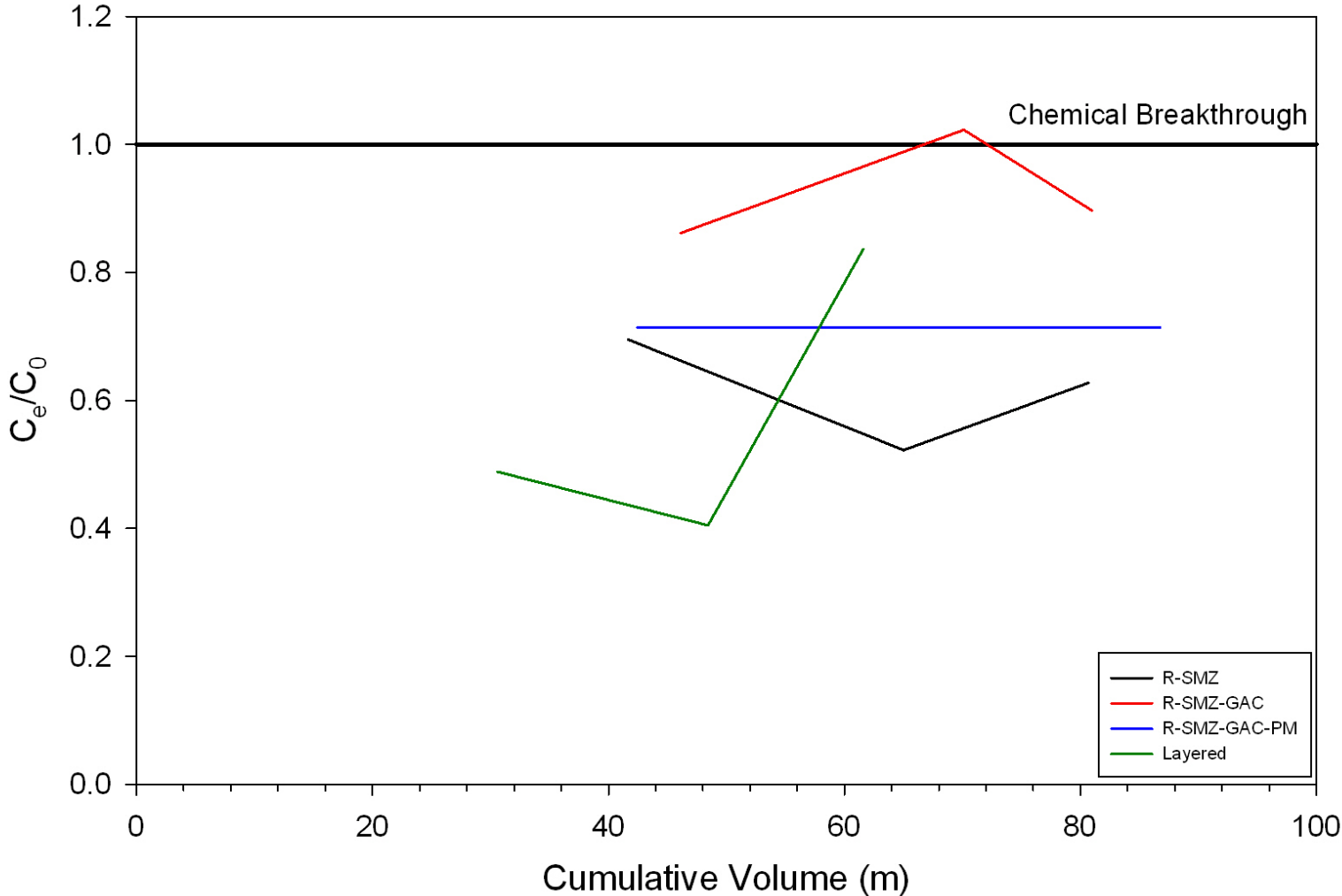


Figure A10-24. Gross Alpha Radioactivity Normalized Breakthrough Plots

Gross Beta Radioactivity



GROSS BETA RADIOACTIVITY

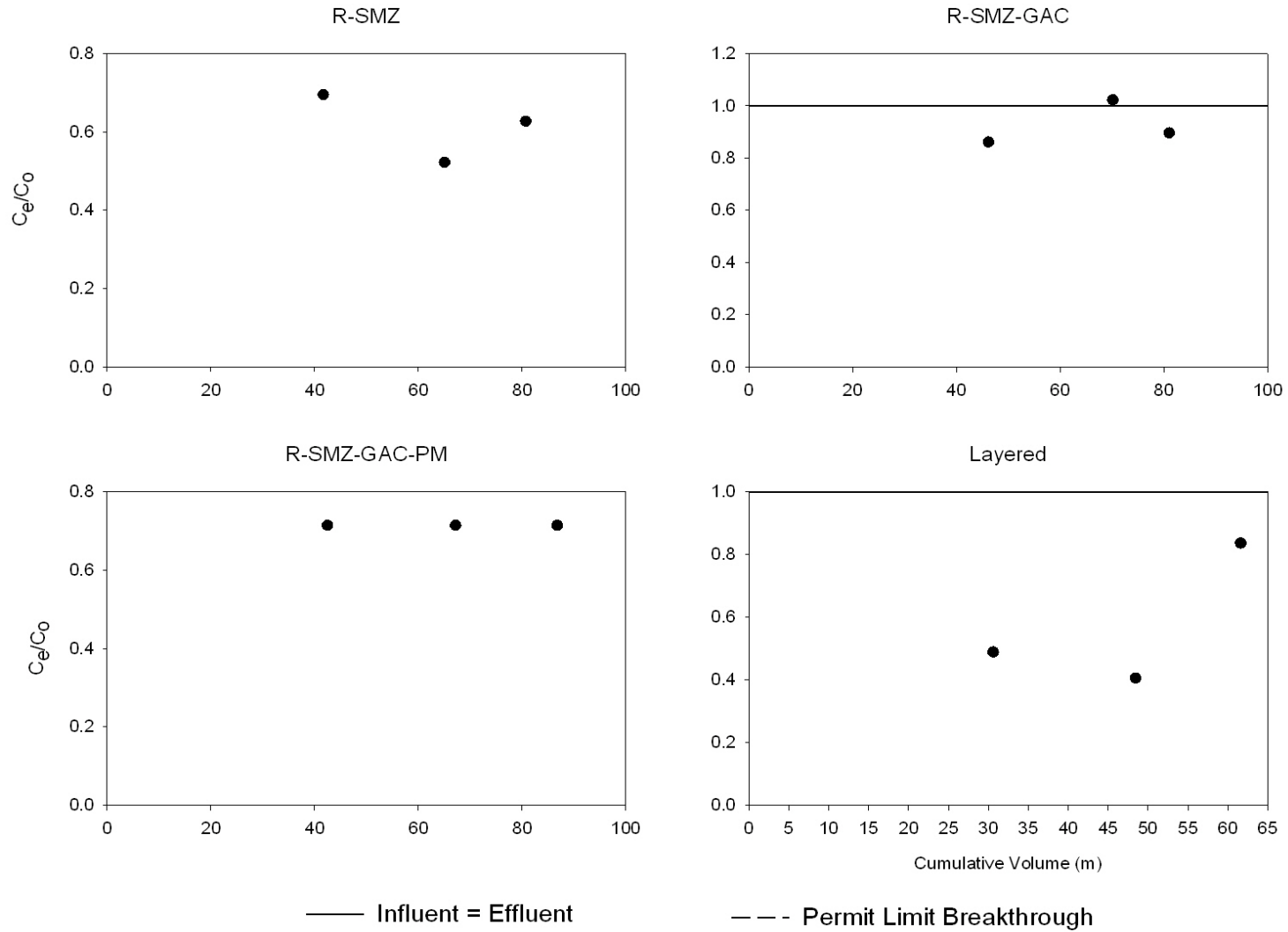
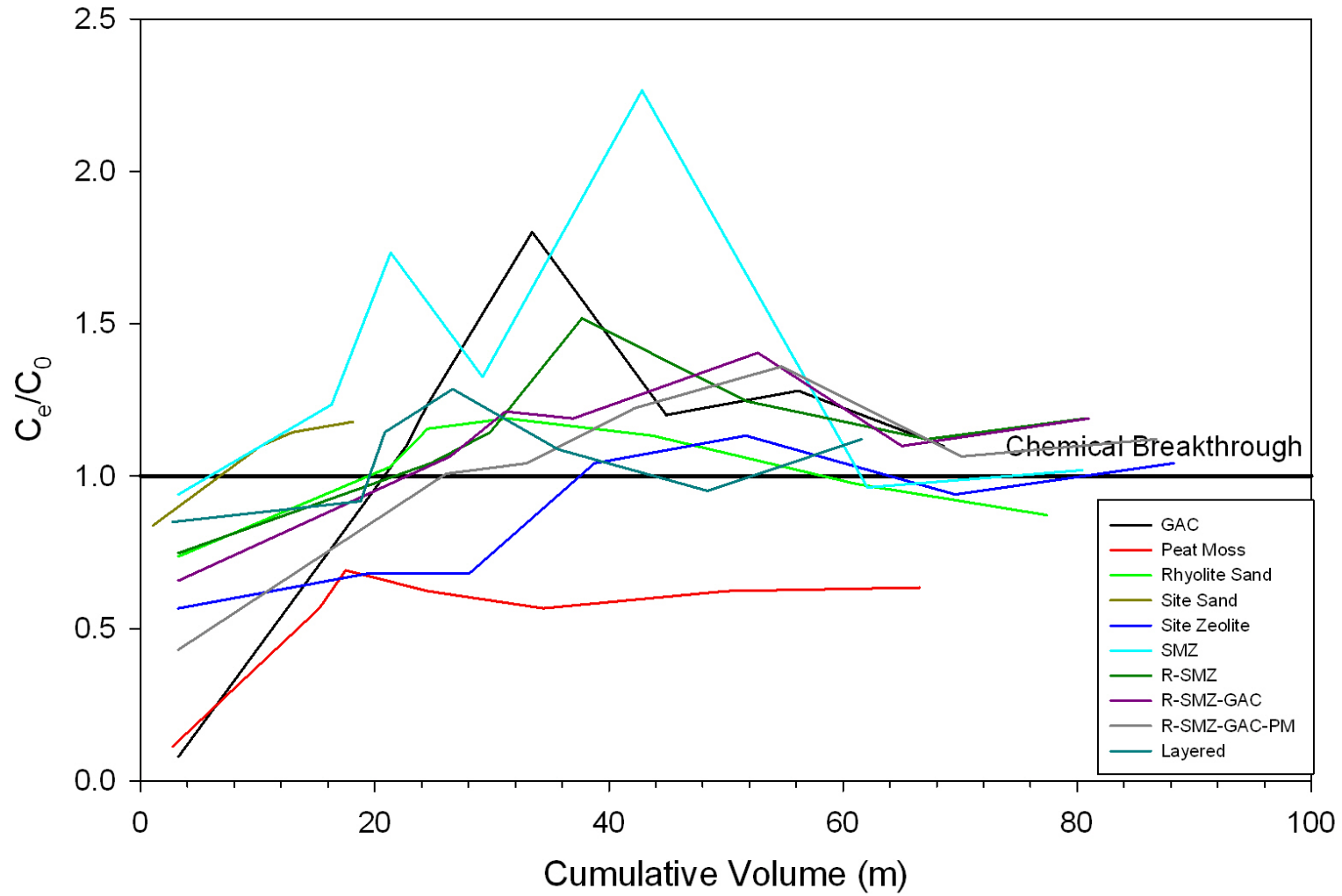


Figure A10-25. Gross Beta Radioactivity Normalized Breakthrough Plots

Hardness



HARDNESS

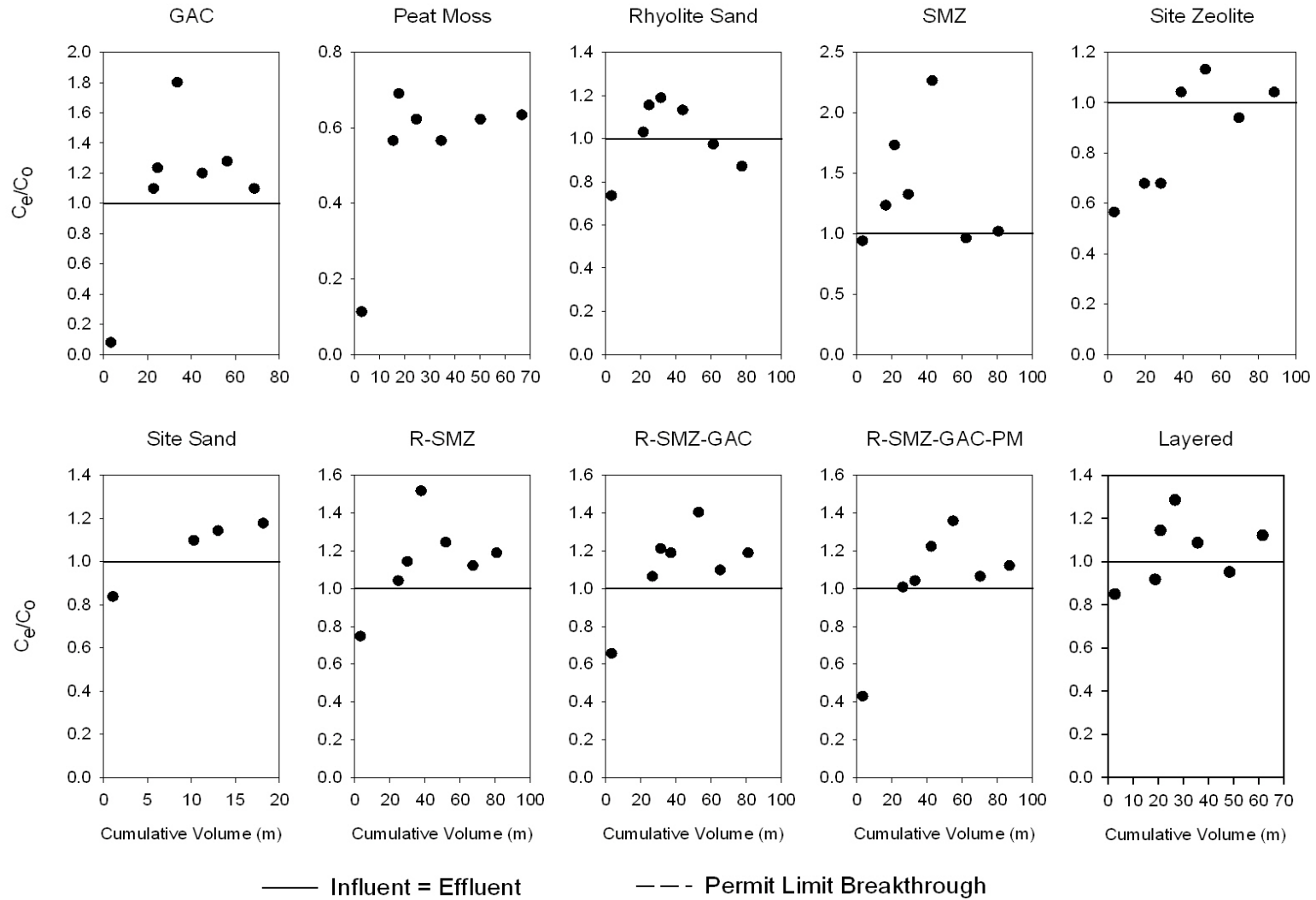
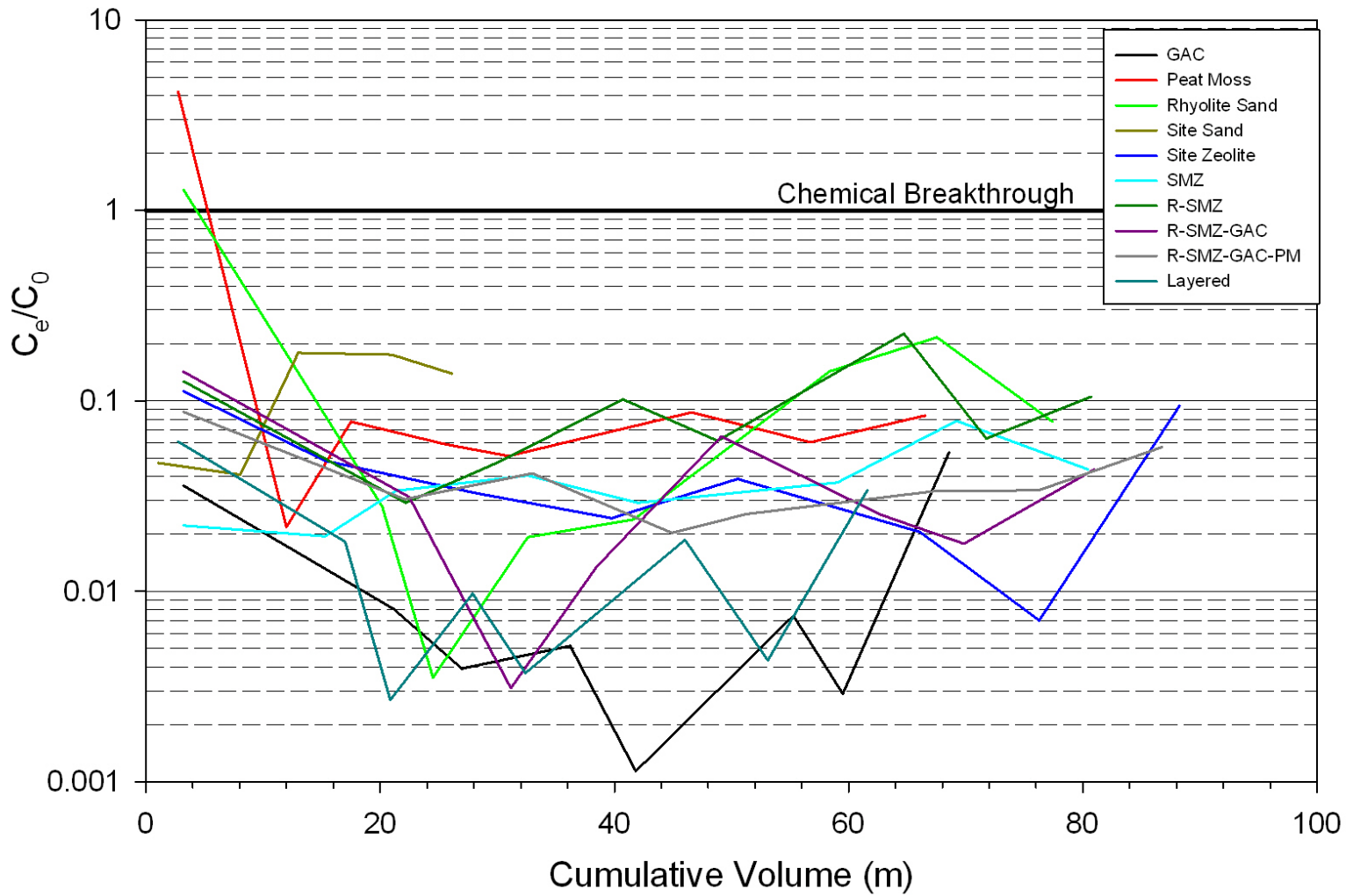


Figure A10-26. Hardness Normalized Breakthrough Plots

Iron, Total



IRON, TOTAL

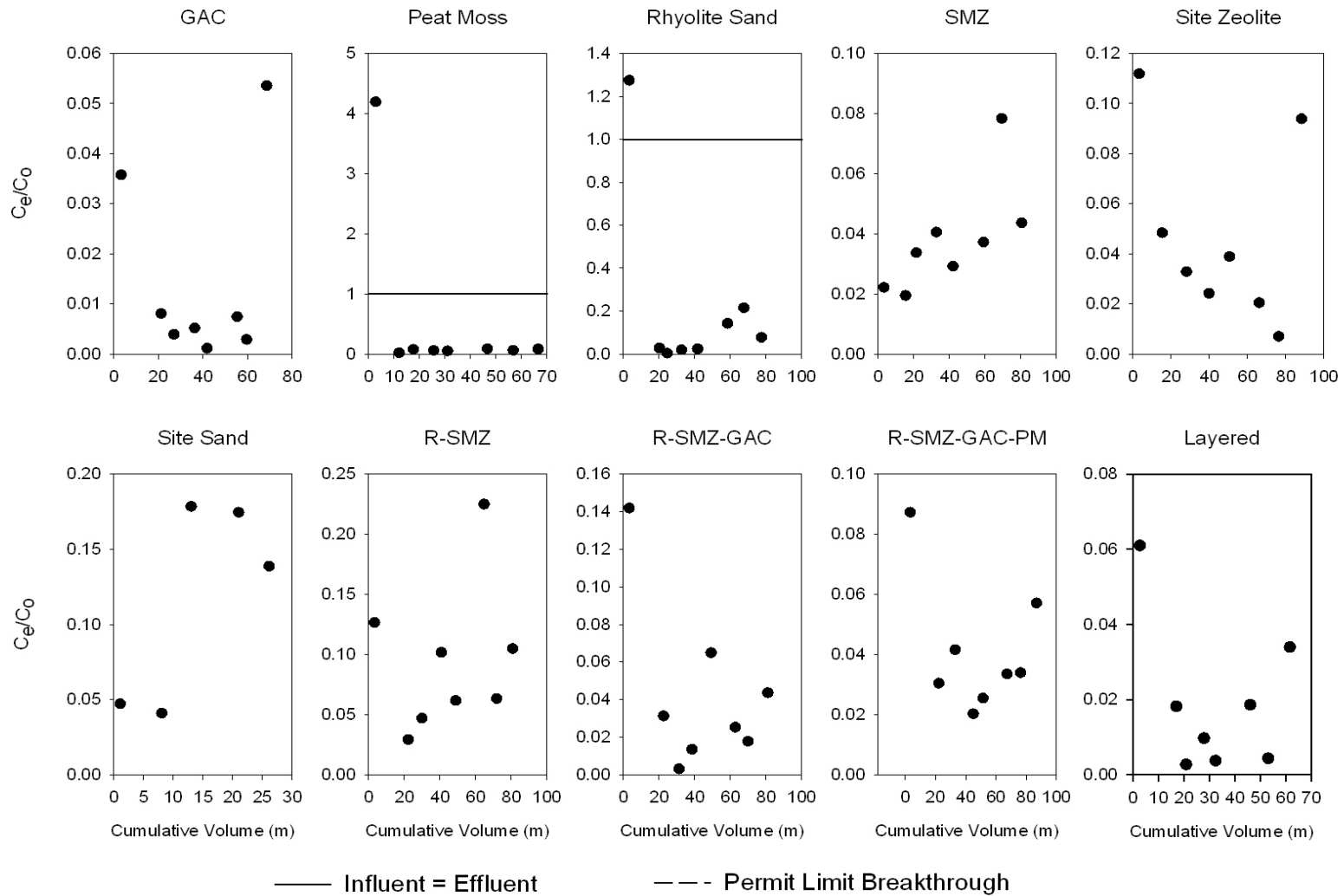
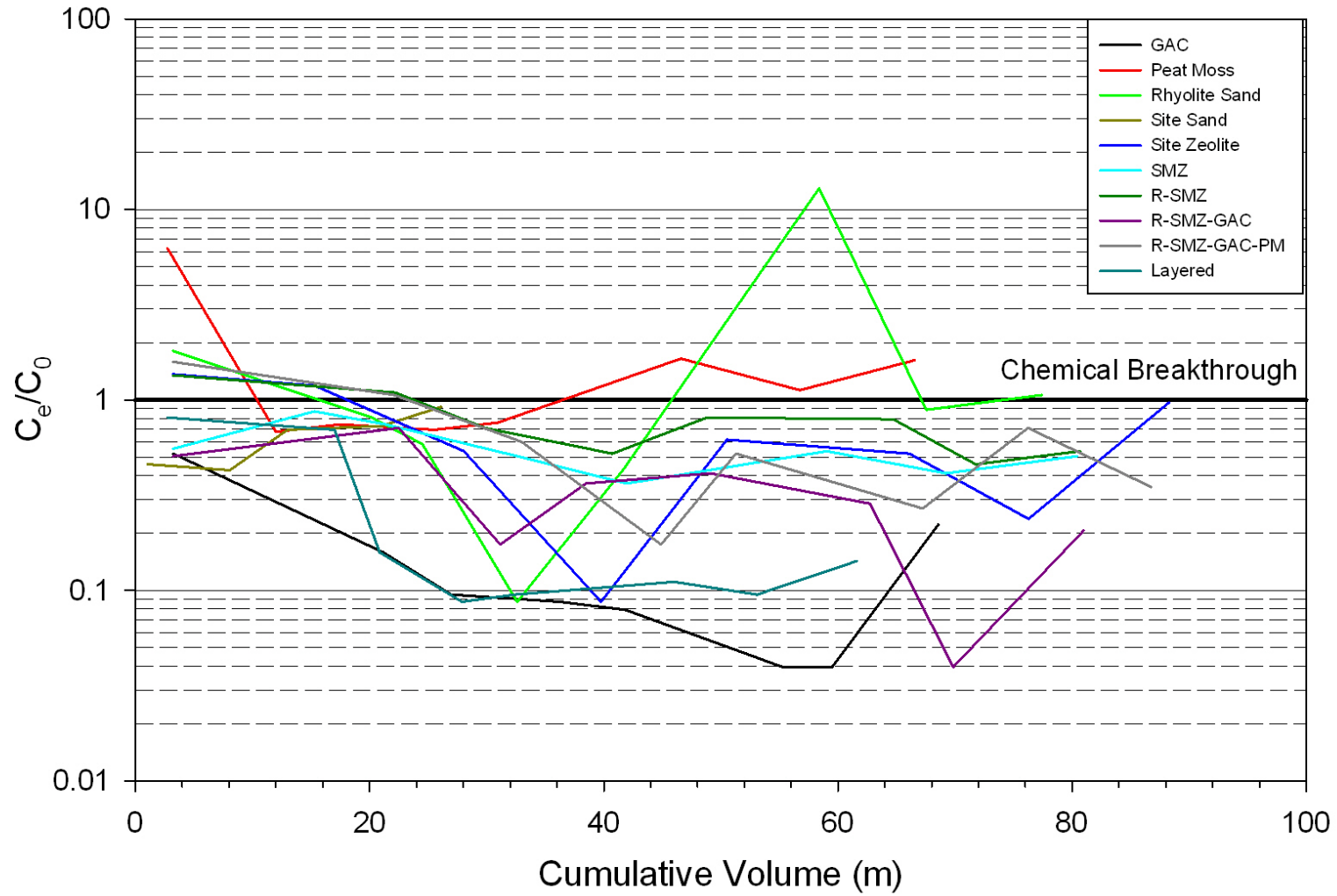


Figure A10-27. Iron (Total) Normalized Breakthrough Plots

Iron, Filtered



IRON, FILTERED

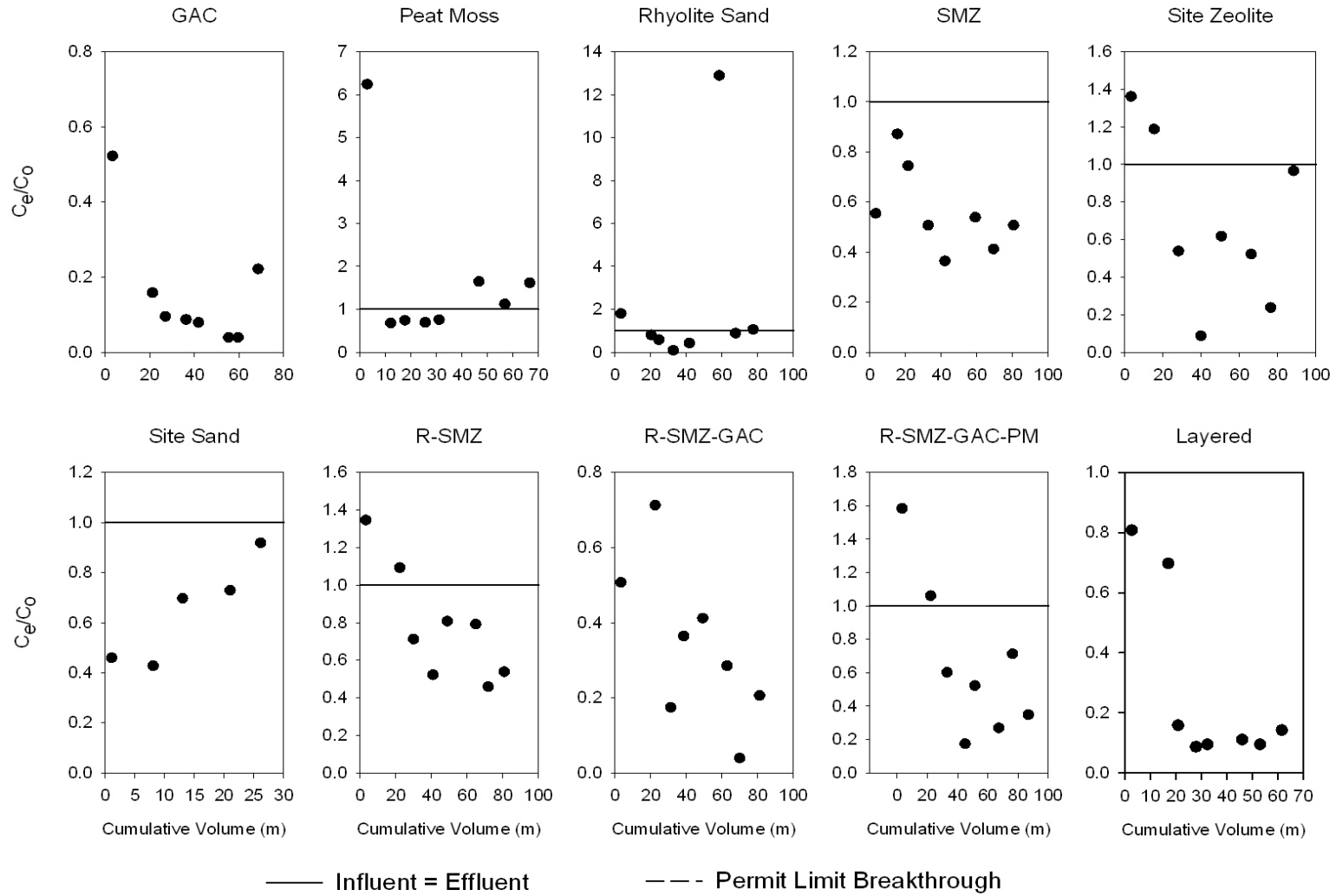


Figure A10-28. Iron (Filtered) Normalized Breakthrough Plots

LEAD, TOTAL

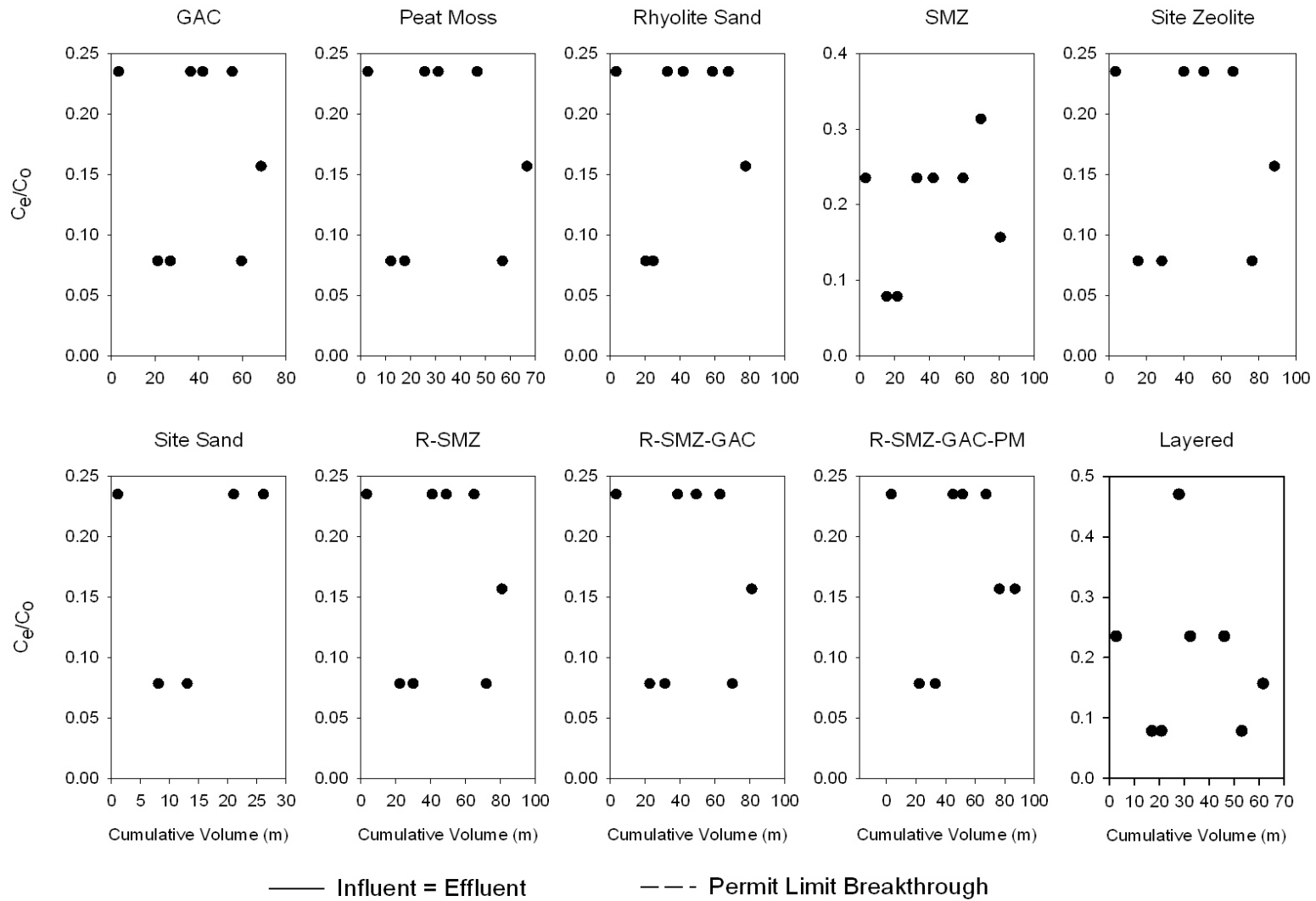
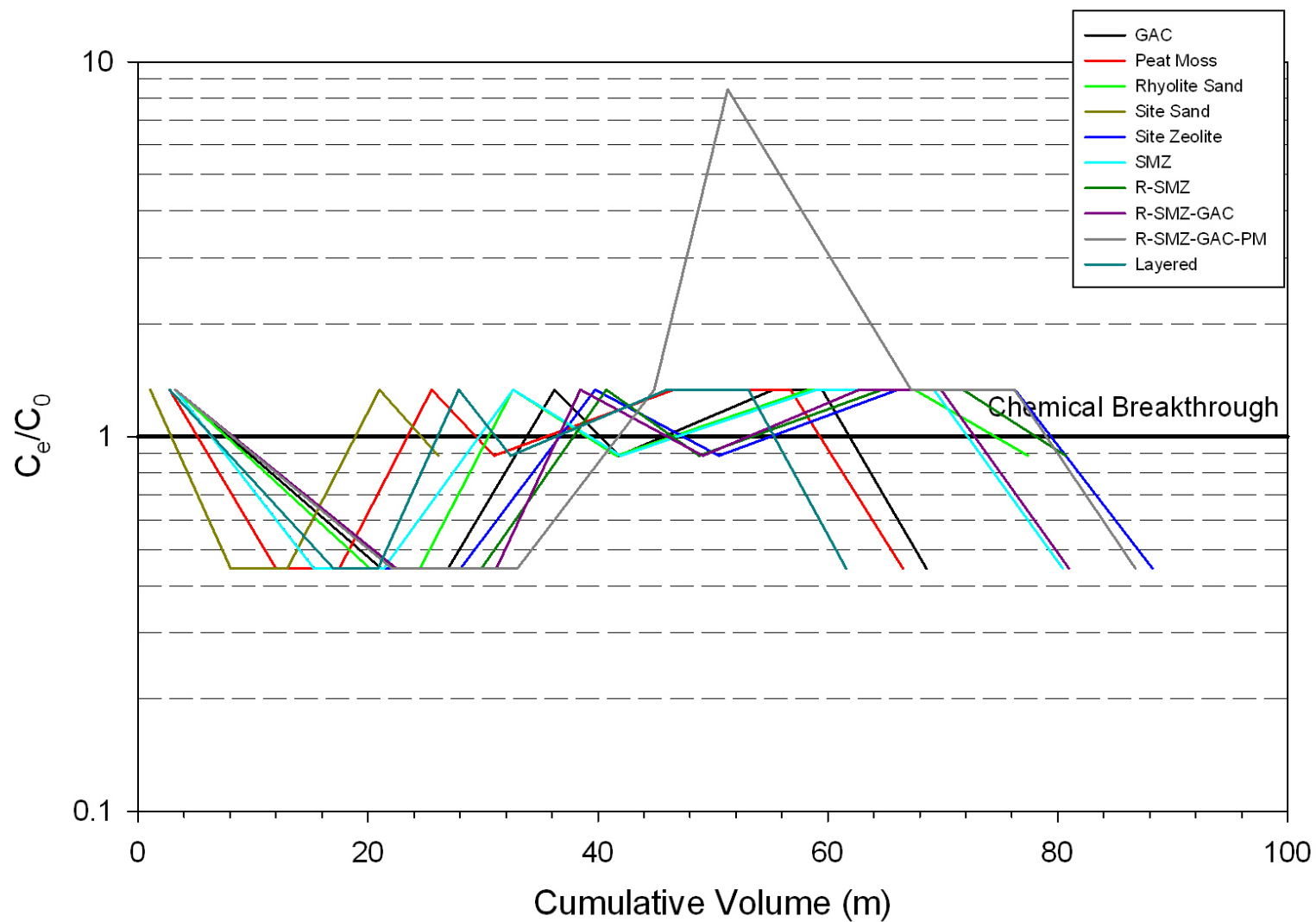


Figure A10-29. Lead (Total) Normalized Breakthrough Plots

Lead, Filtered



LEAD, FILTERED

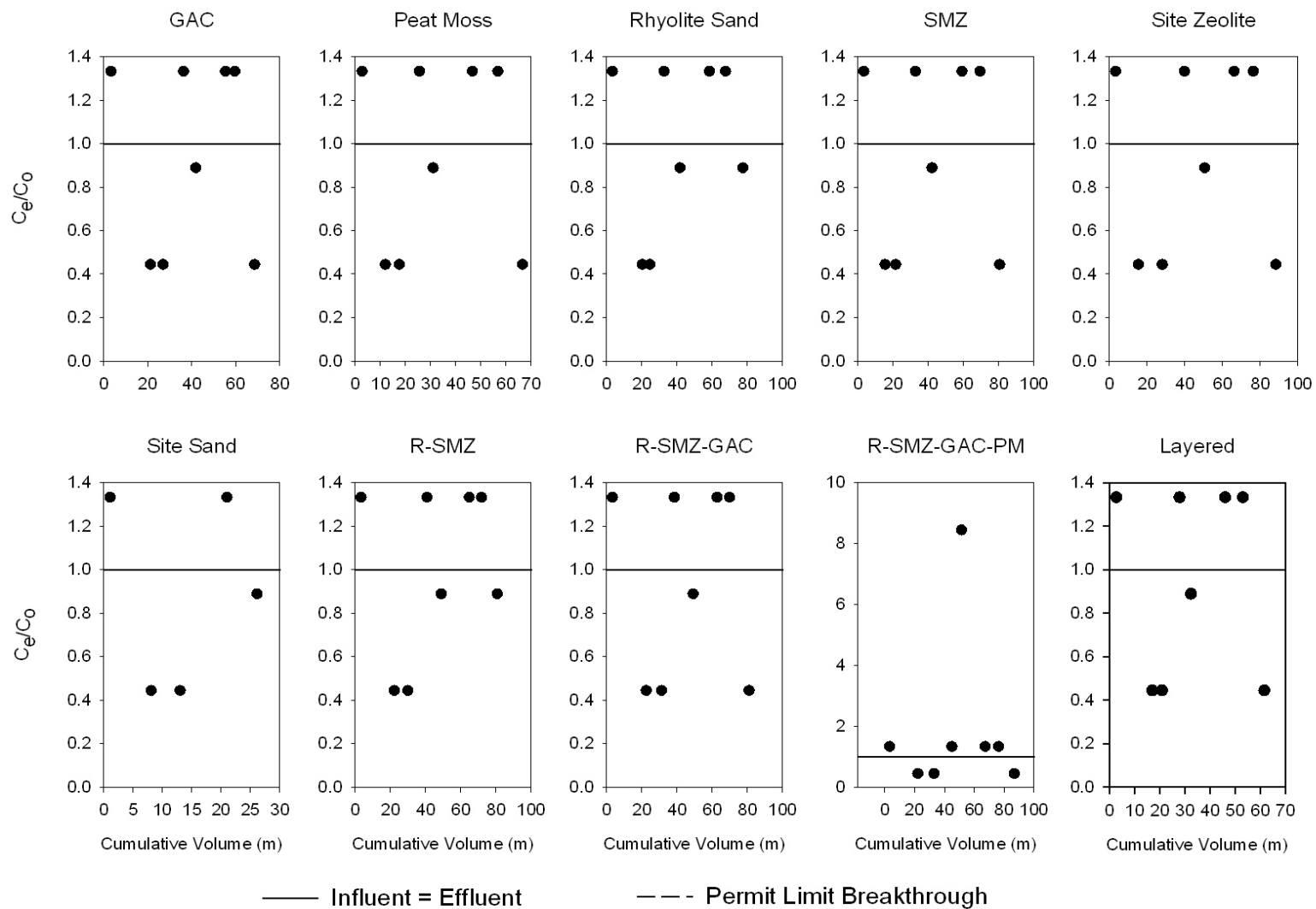
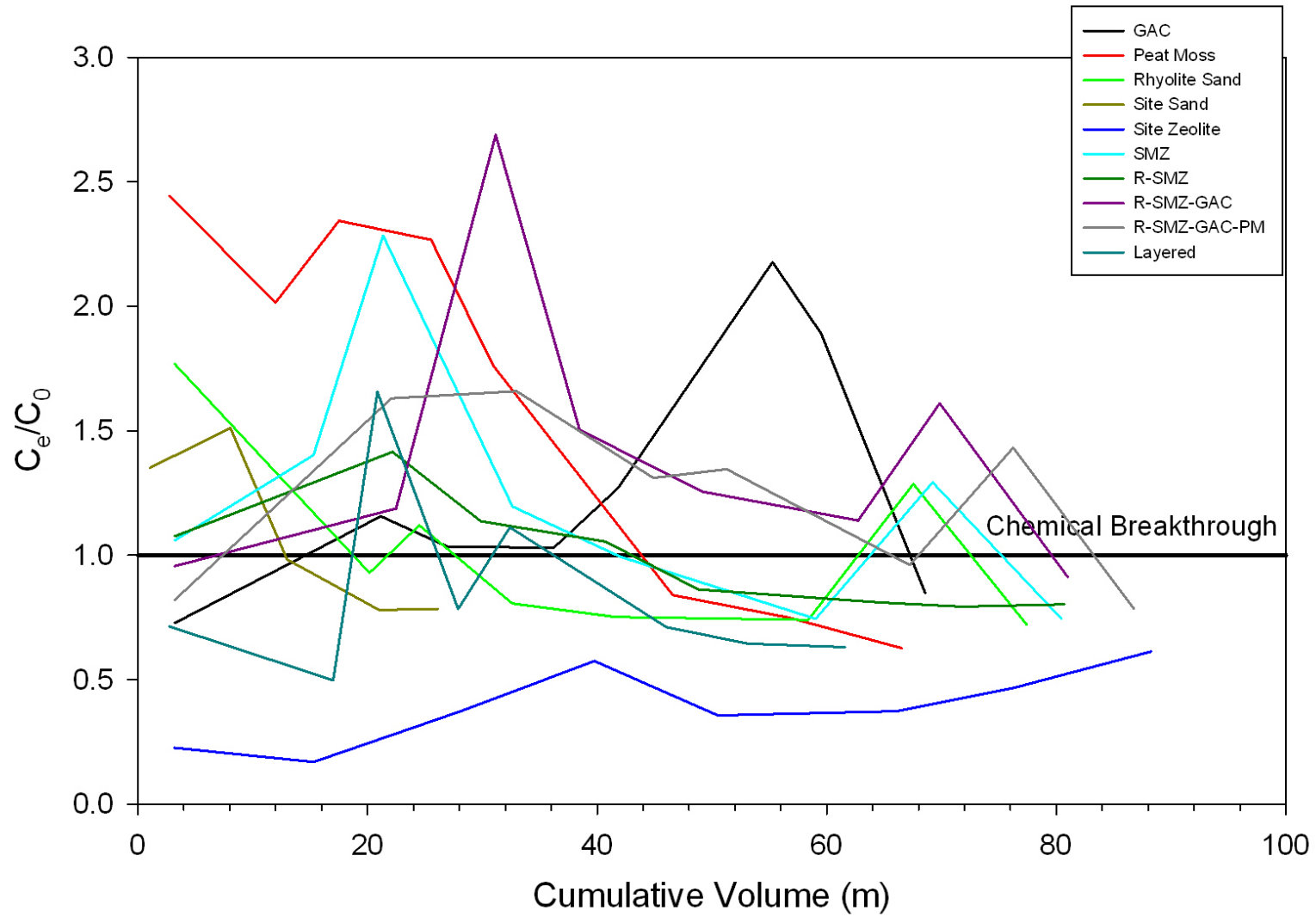


Figure A10-30. Lead (Filtered) Normalized Breakthrough Plots

Magnesium, Total



MAGNESIUM, TOTAL

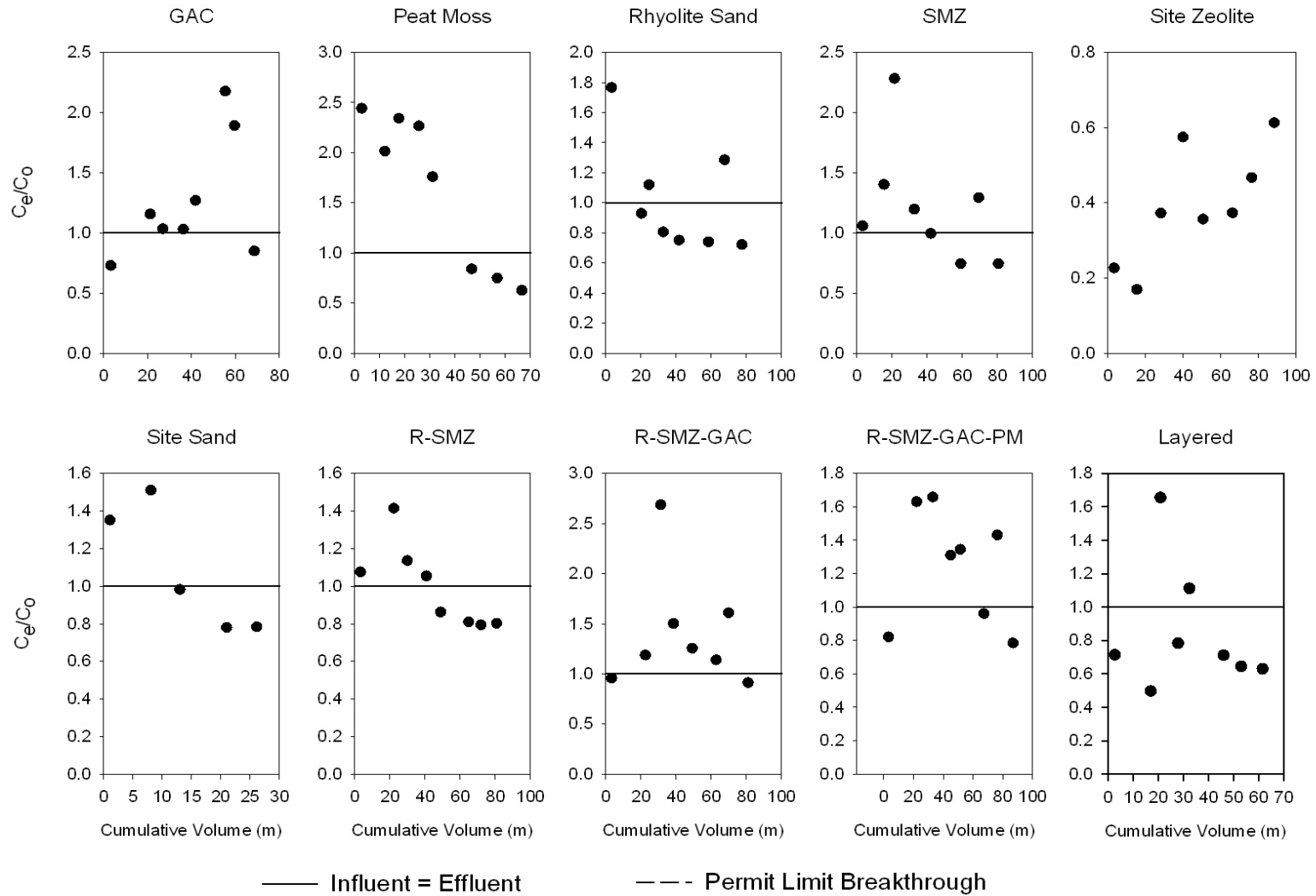
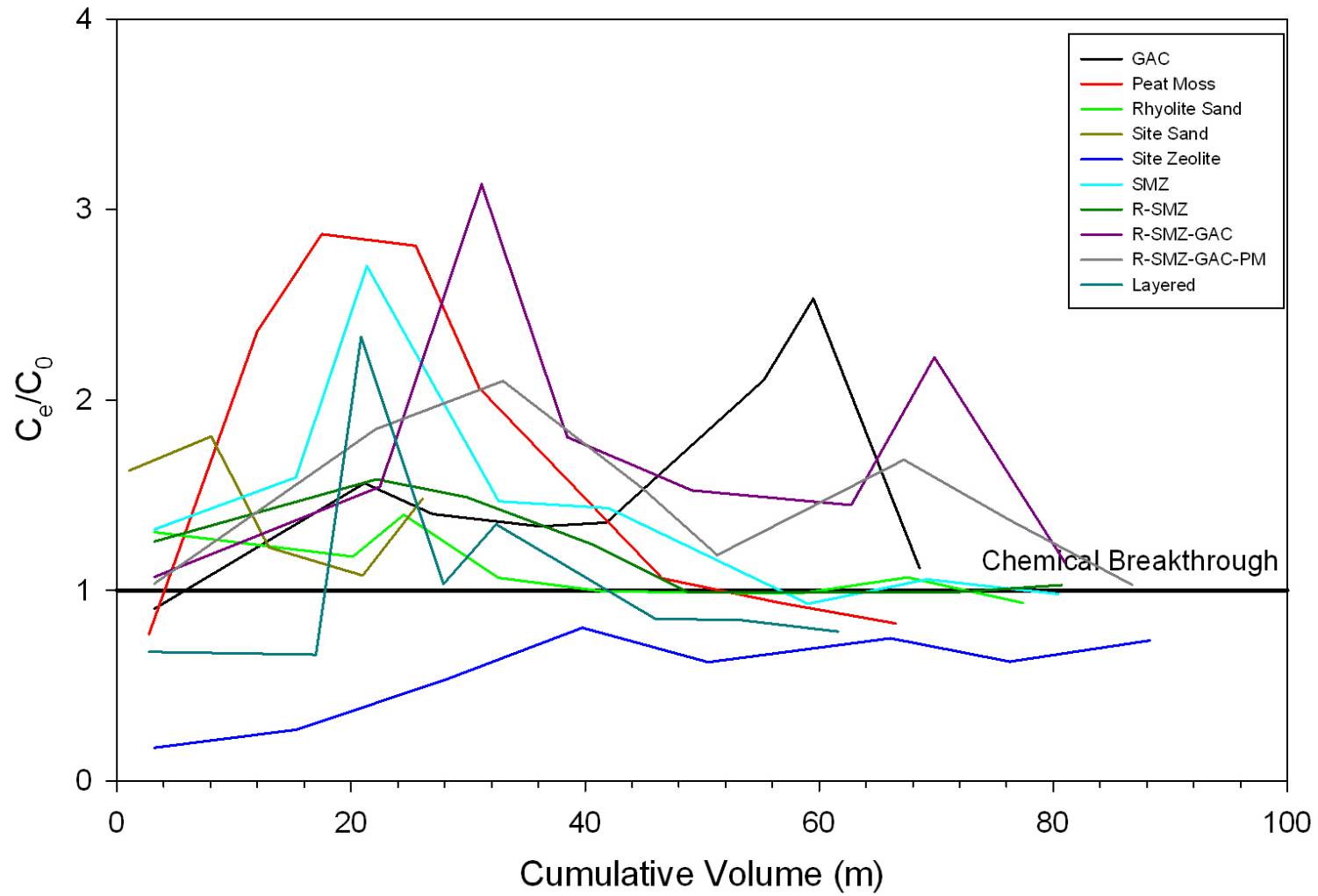


Figure A10-31. Magnesium (Total) Normalized Breakthrough Plots

Magnesium, Filtered



MAGNESIUM, FILTERED

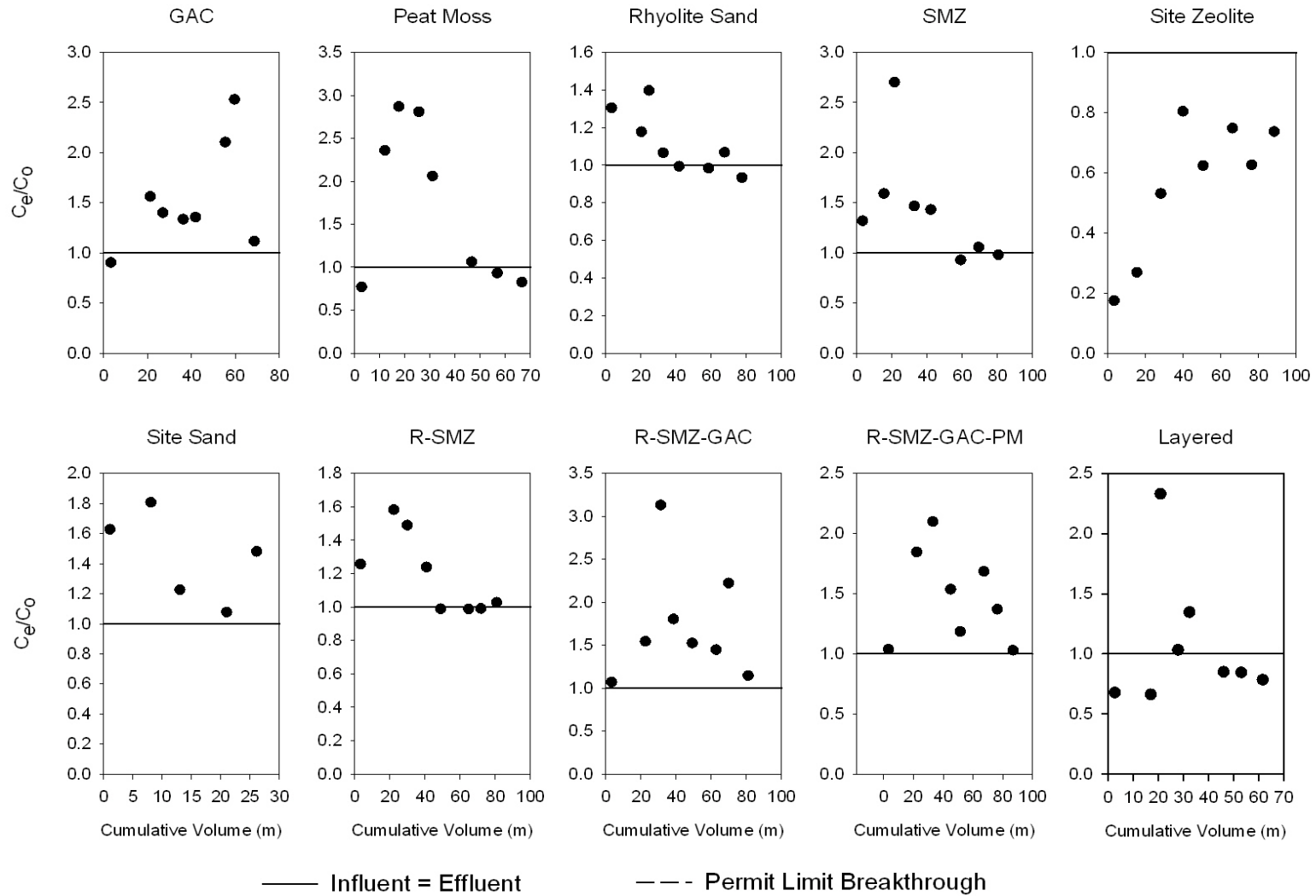
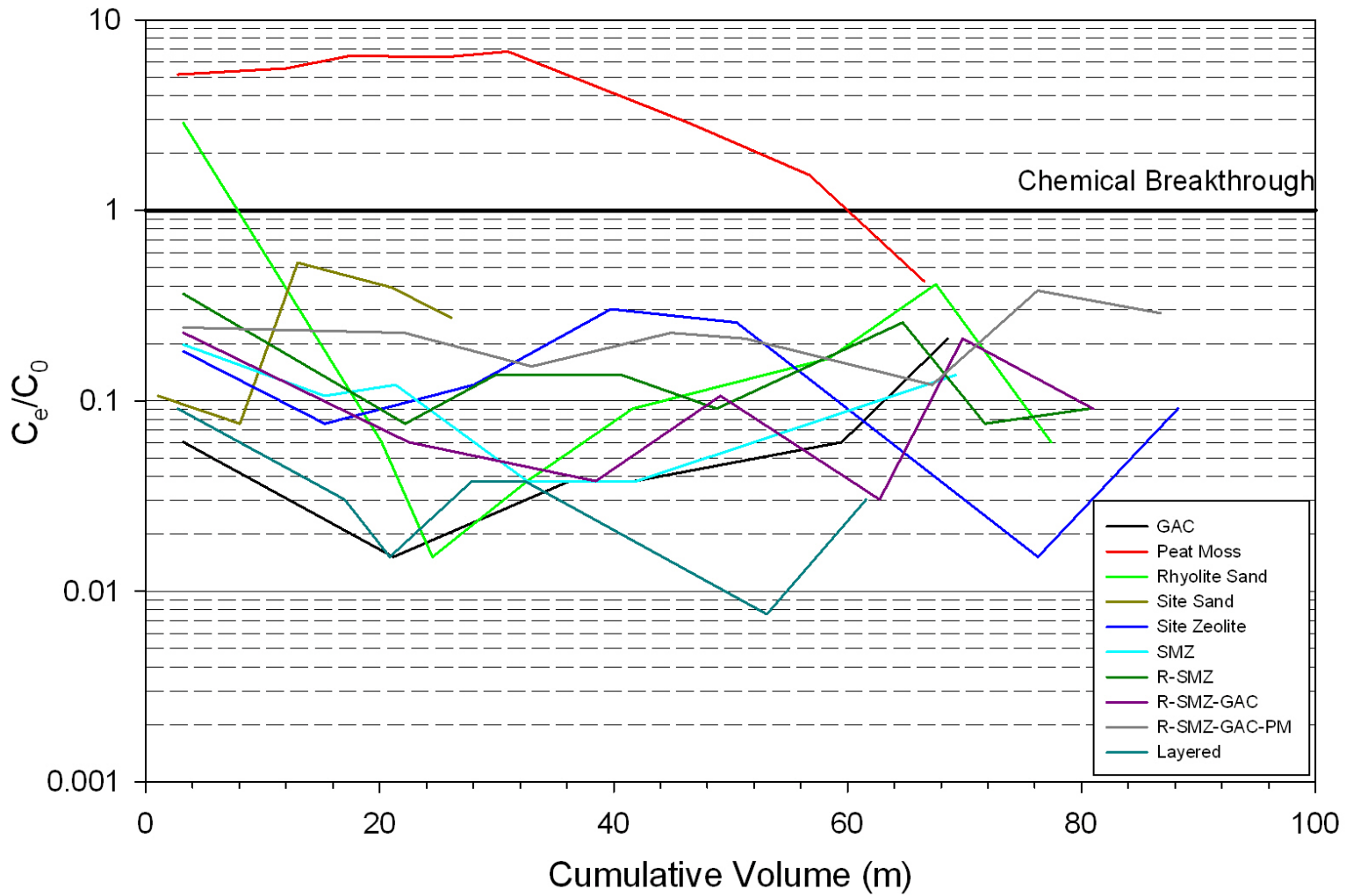


Figure A10-32. Magnesium (Filtered) Normalized Breakthrough Plots

Manganese, Total



MANGANESE, TOTAL

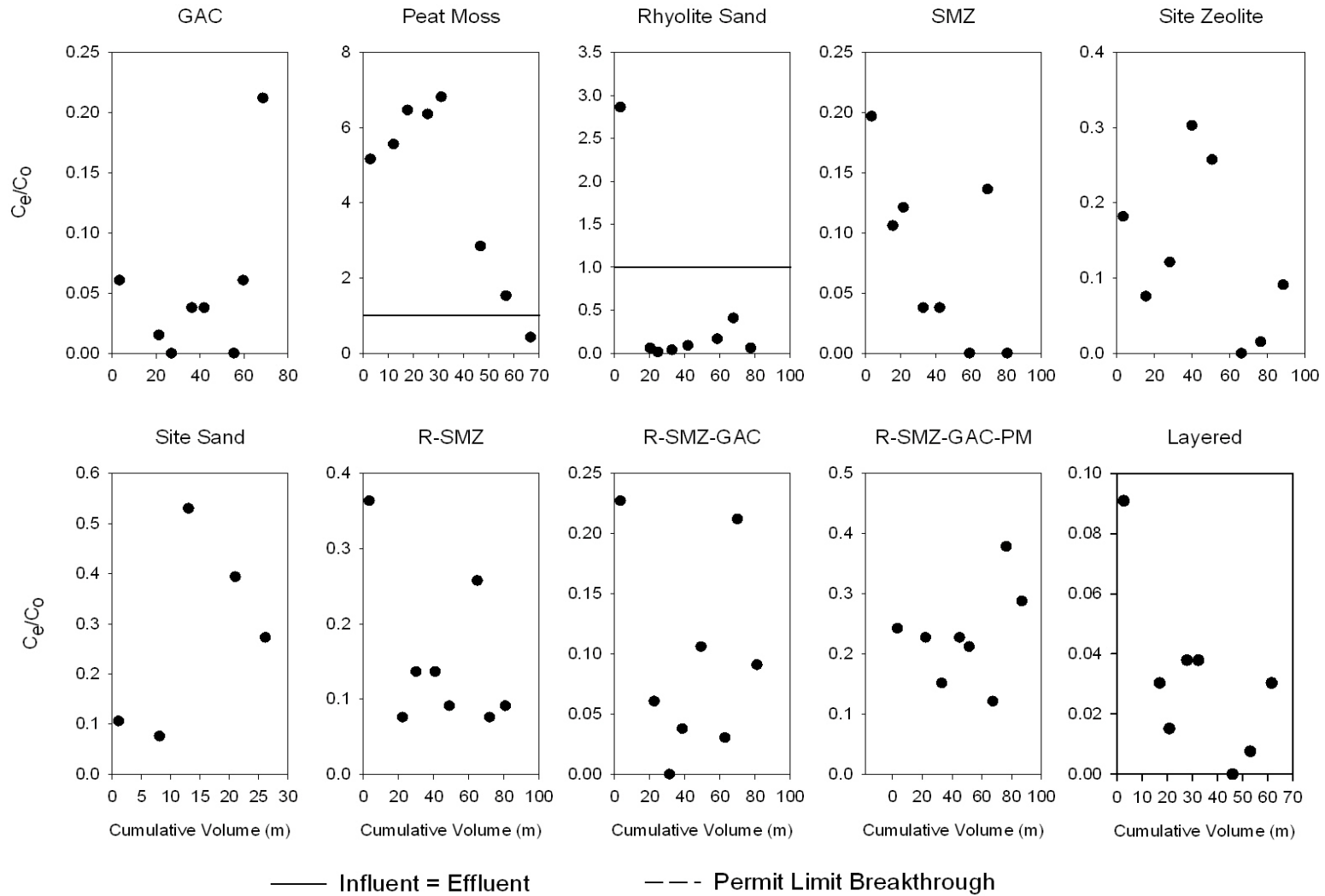


Figure A10-33. Manganese (Total) Normalized Breakthrough Plots

MANGANESE, FILTERED

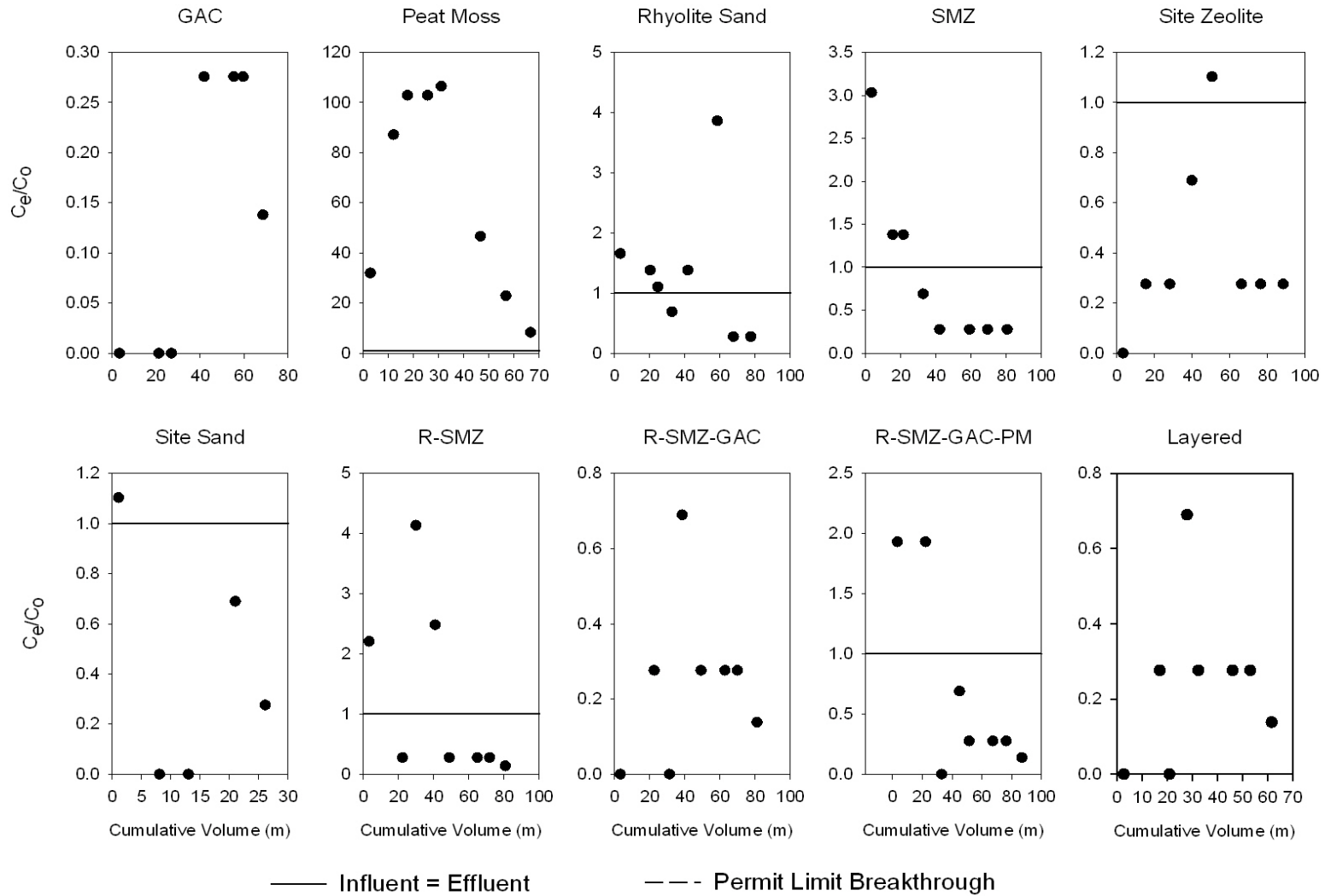
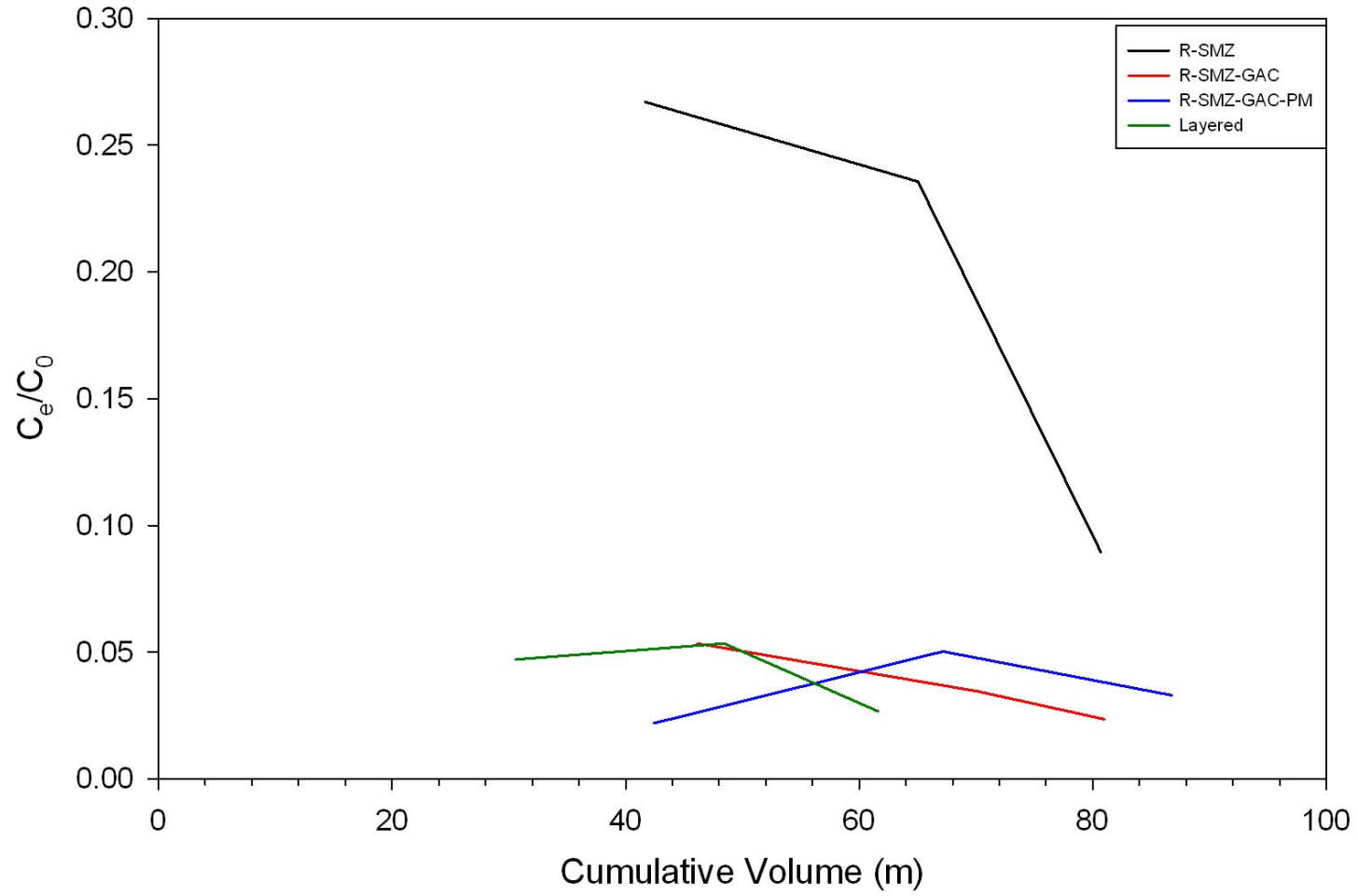


Figure A10-34. Manganese (Filtered) Normalized Breakthrough Plots

Mercury, Total



MERCURY, TOTAL

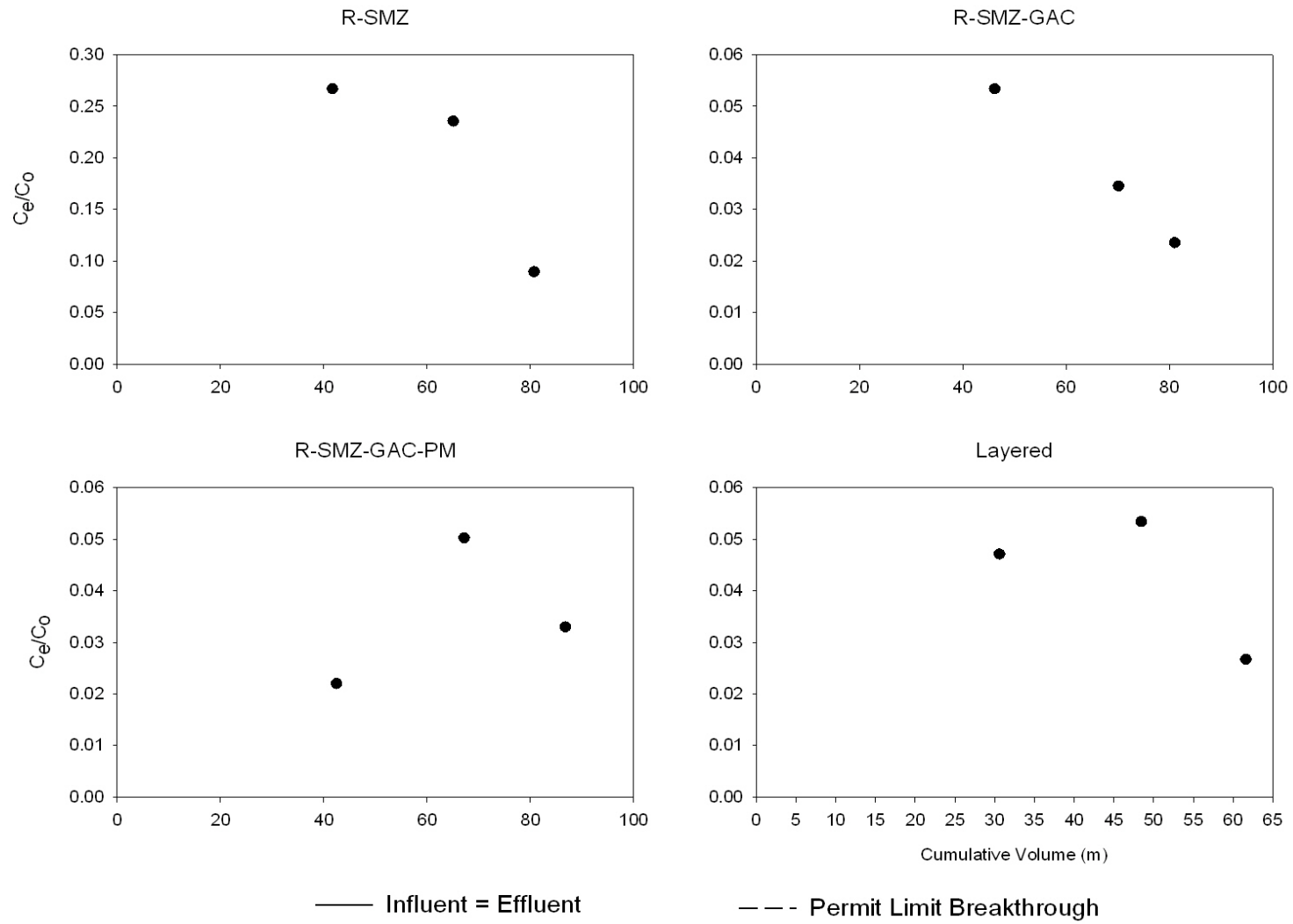
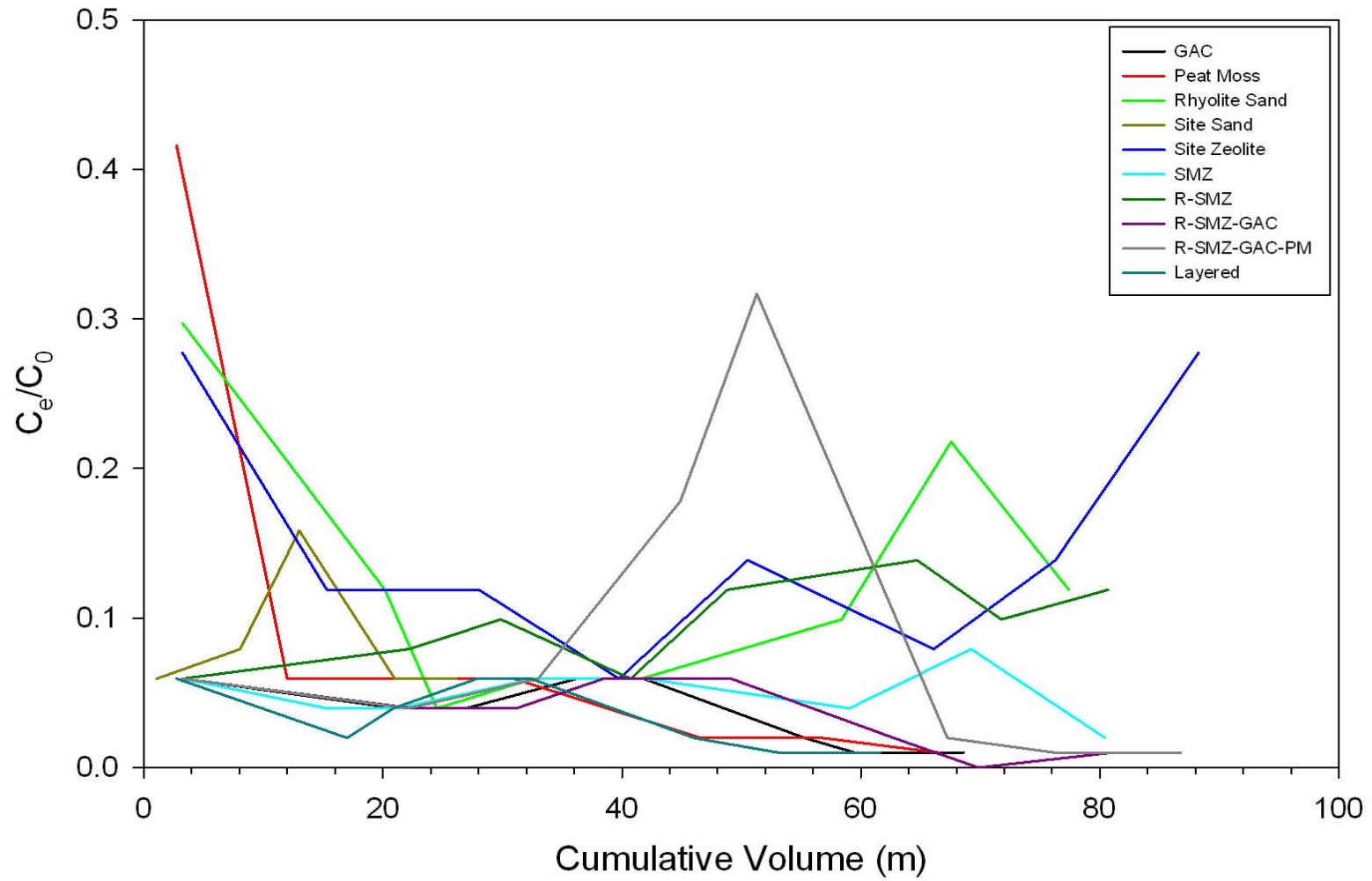


Figure A10-35. Mercury (Total) Normalized Breakthrough Plots

Nickel, Total



NICKEL, TOTAL

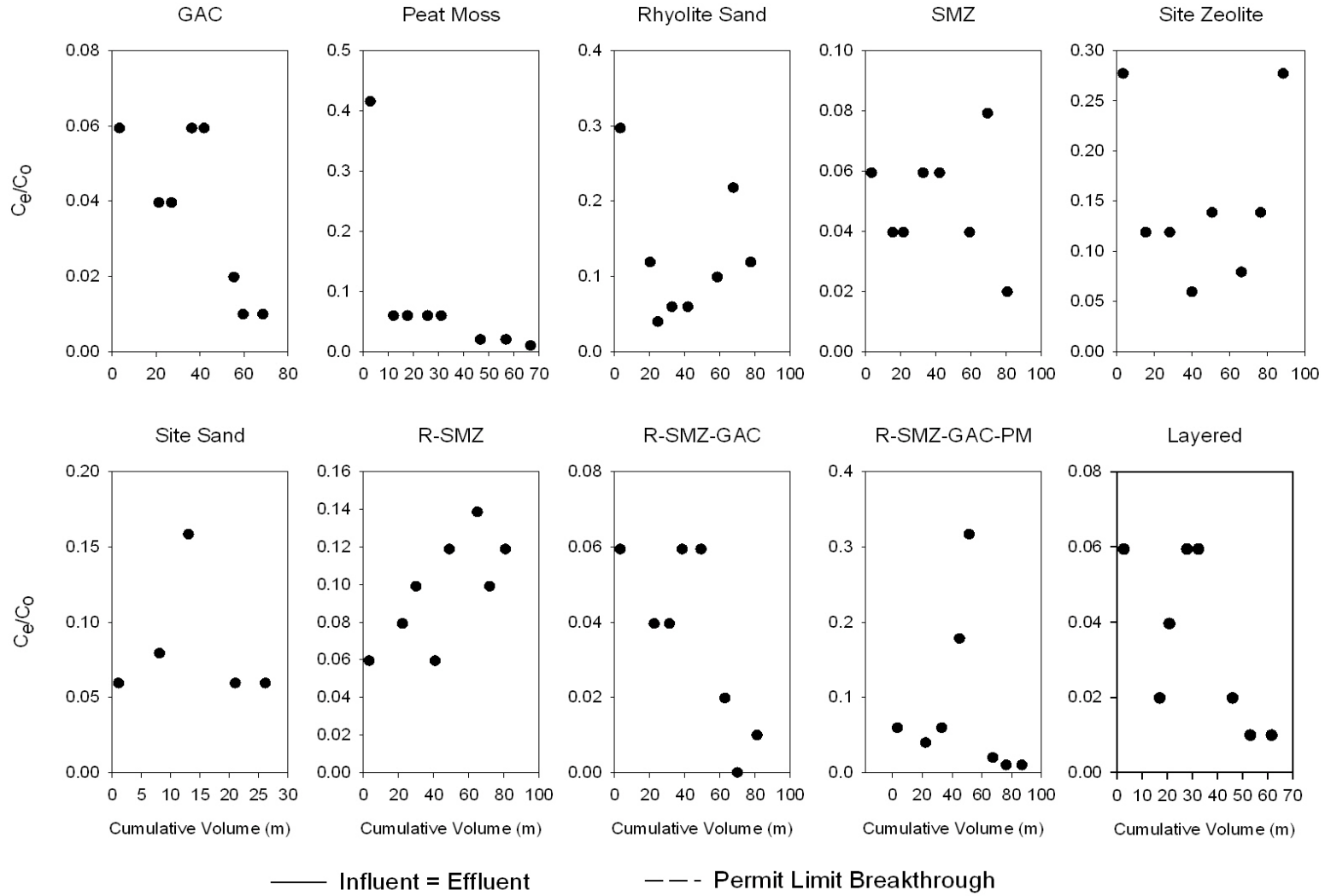
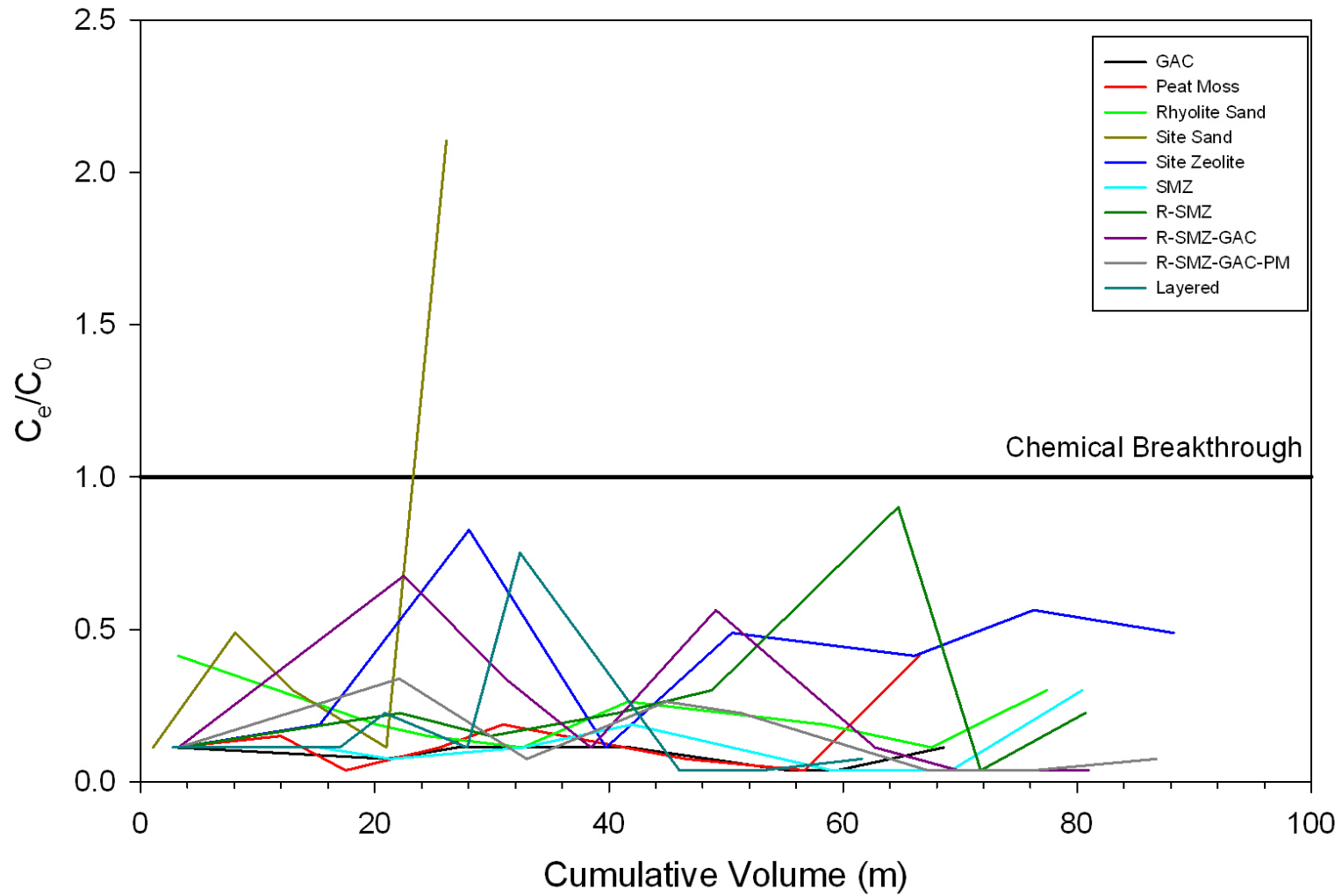


Figure A10-36. Nickel (Total) Normalized Breakthrough Plots

Nickel, Filtered



NICKEL, FILTERED

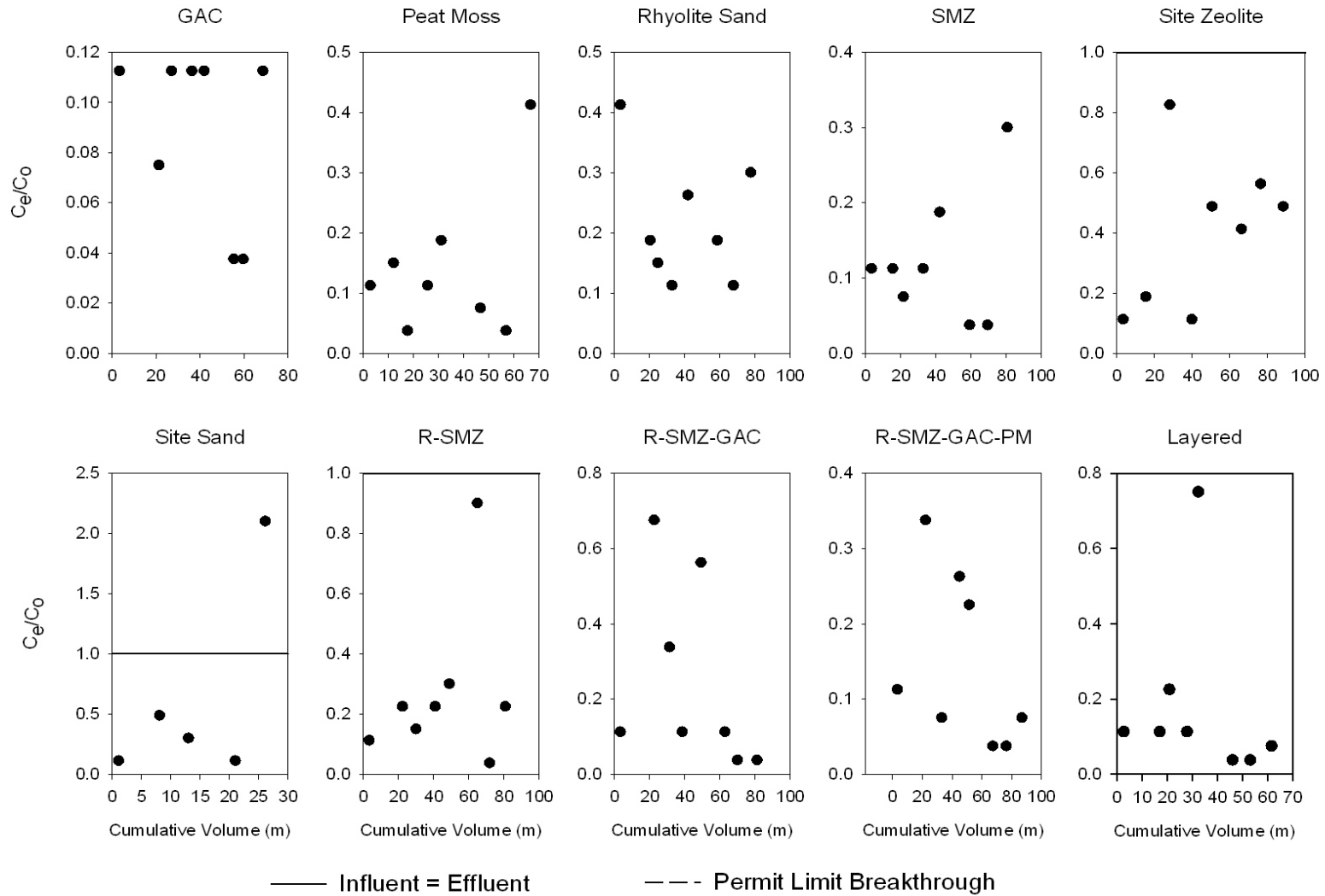
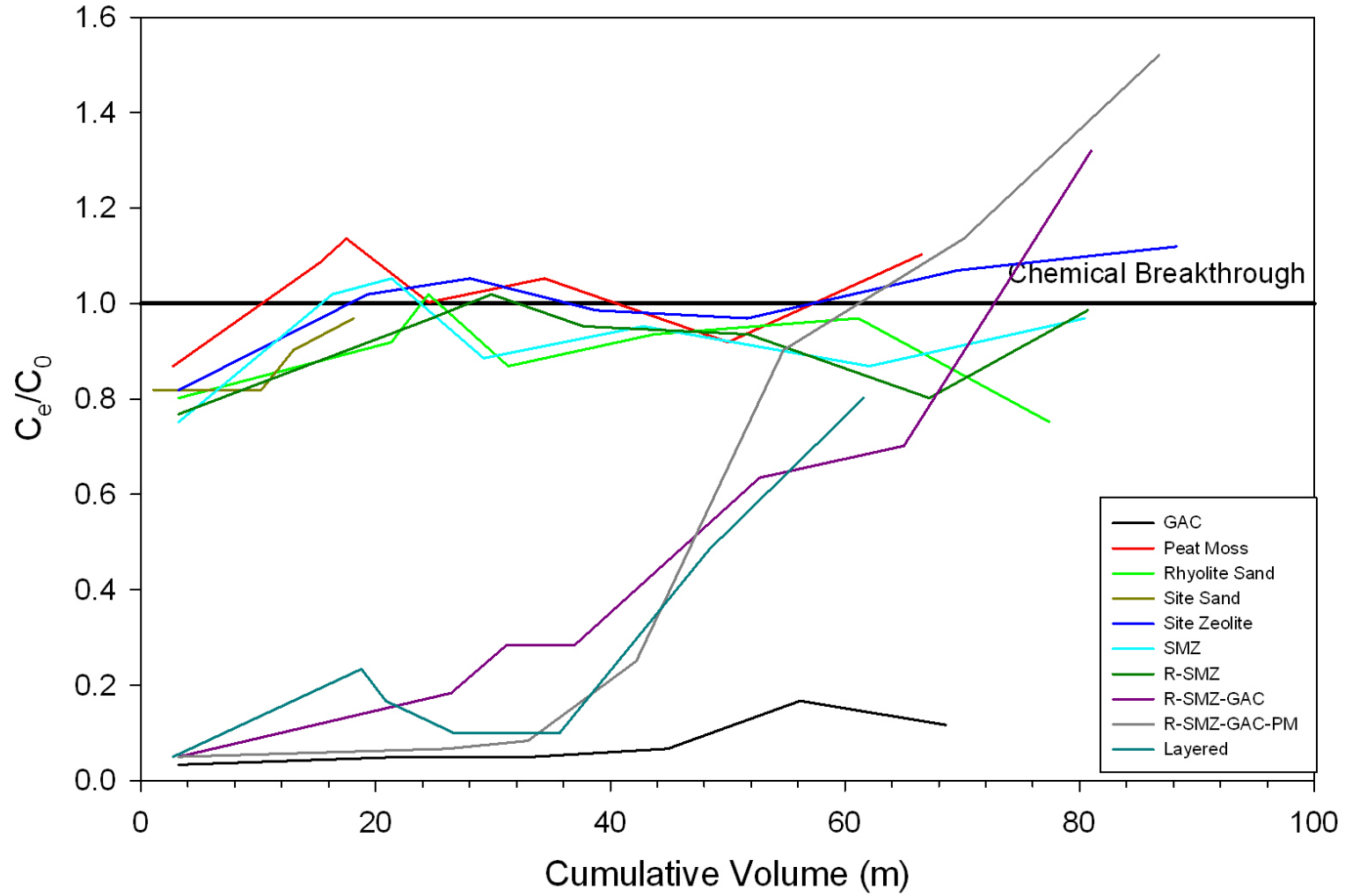


Figure A10-37. Nickel (Filtered) Normalized Breakthrough Plots

Nitrate



NITRATE

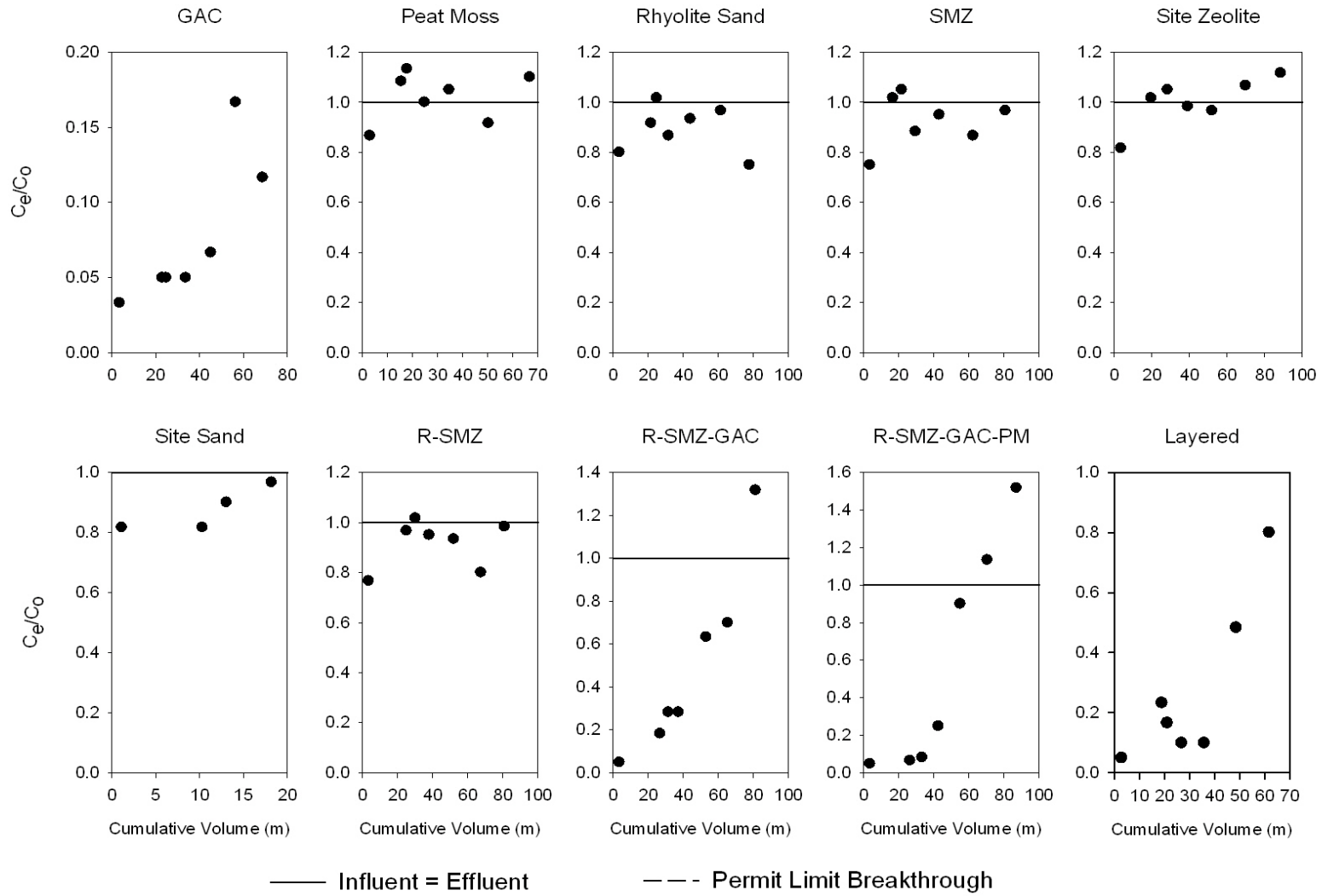
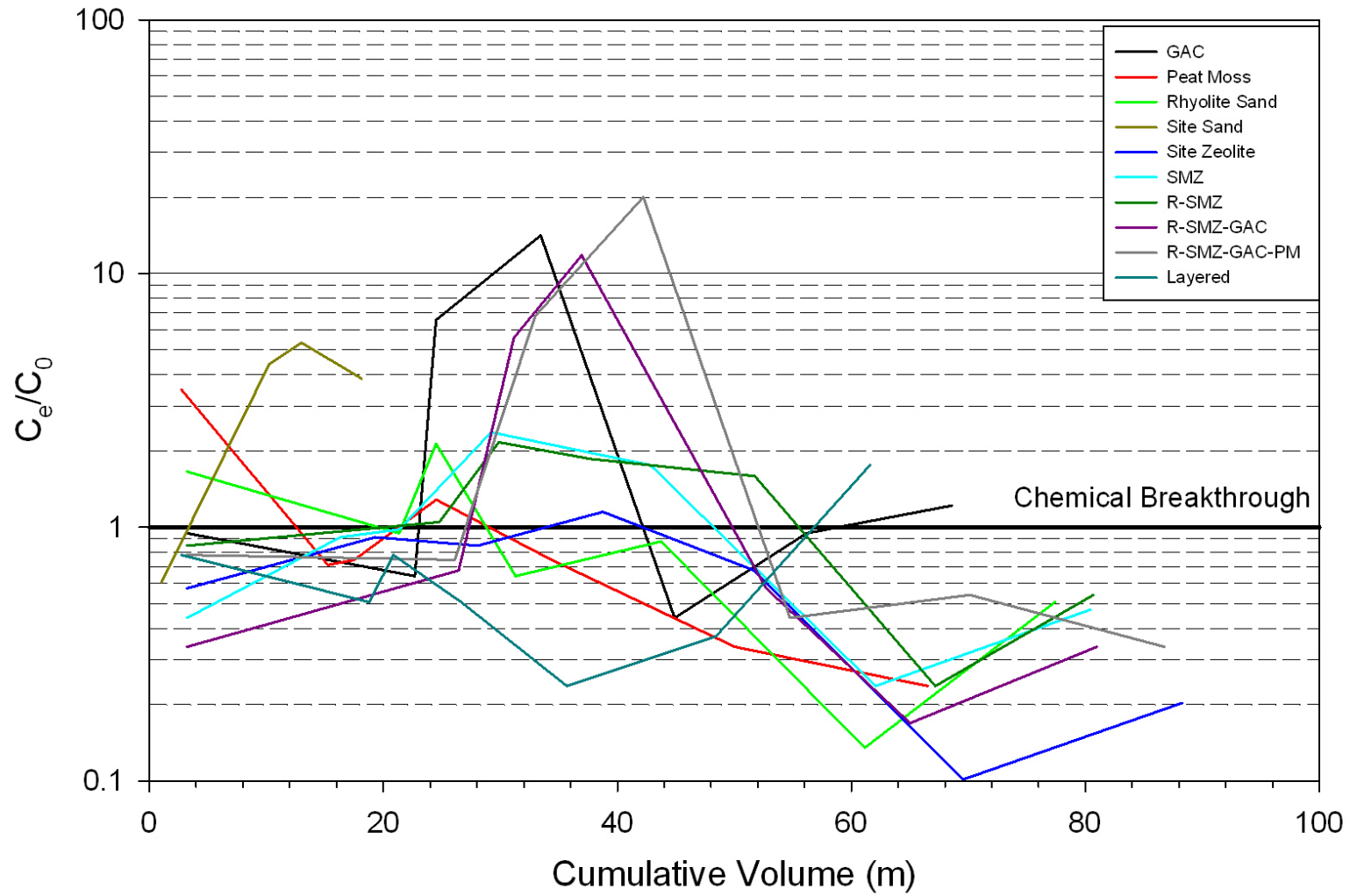


Figure A10-38. Nitrate Normalized Breakthrough Plots

Nitrite



NITRITE

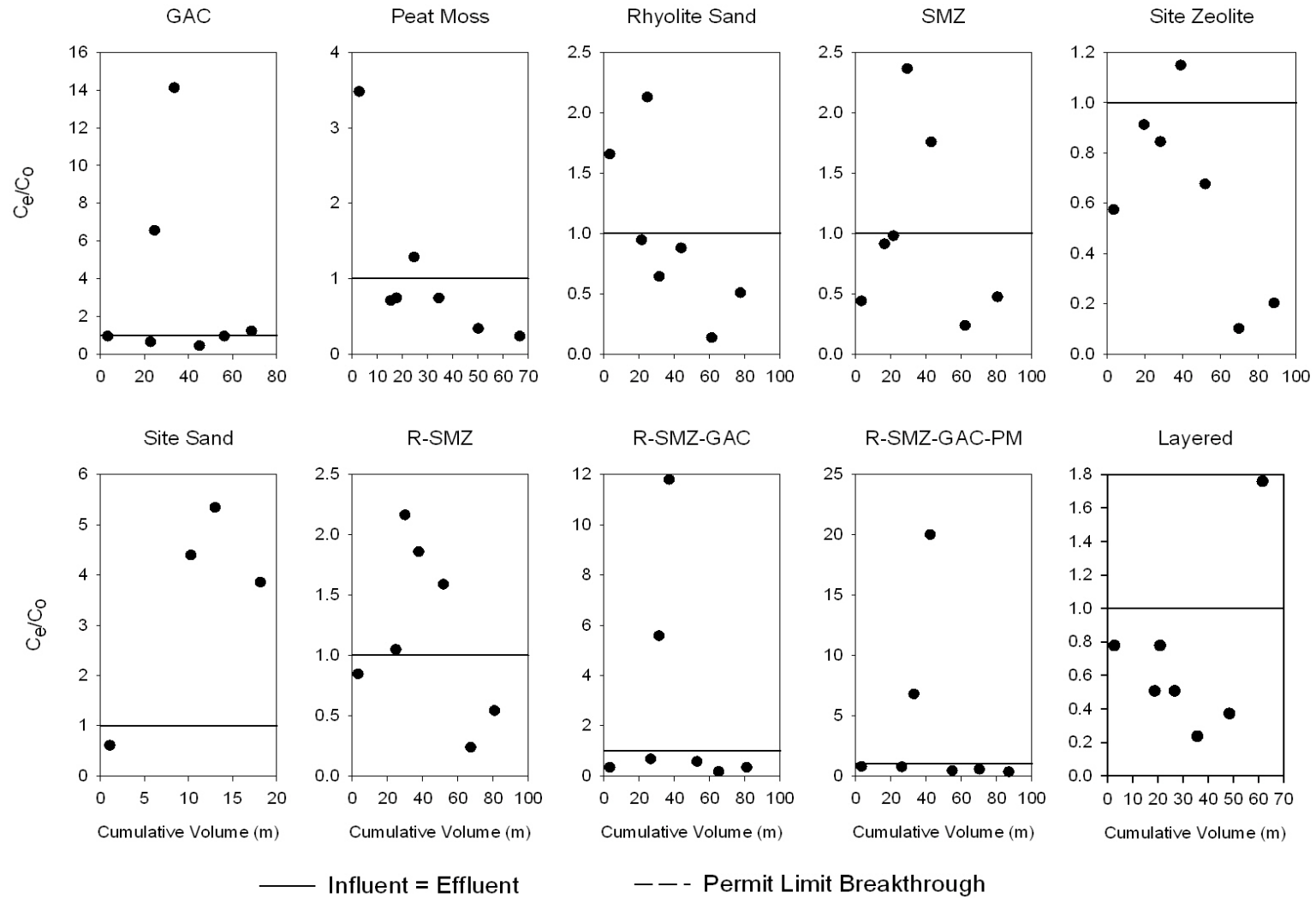
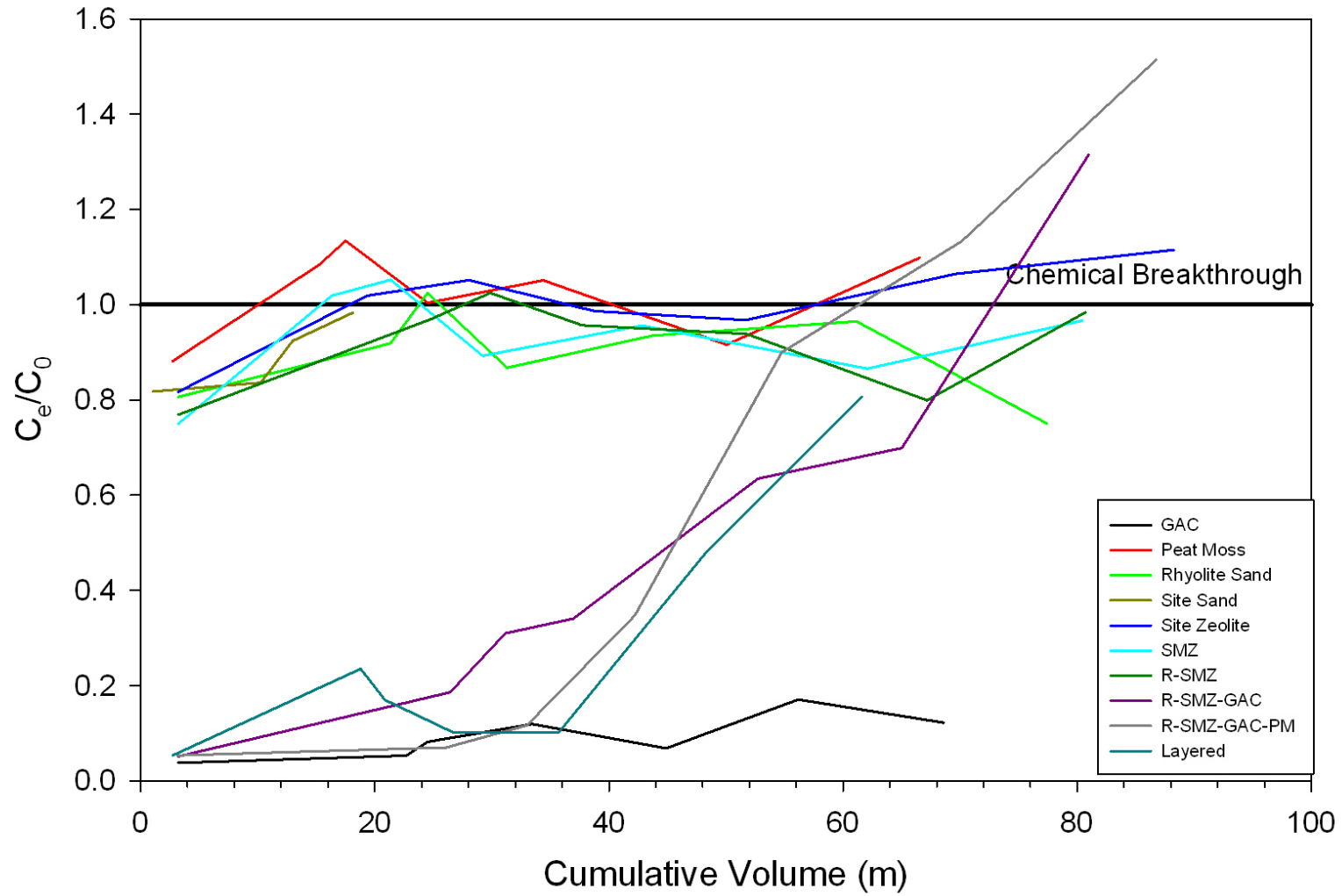


Figure A10-39. Nitrite Normalized Breakthrough Plots

Nitrite + Nitrate



NITRITE + NITRATE

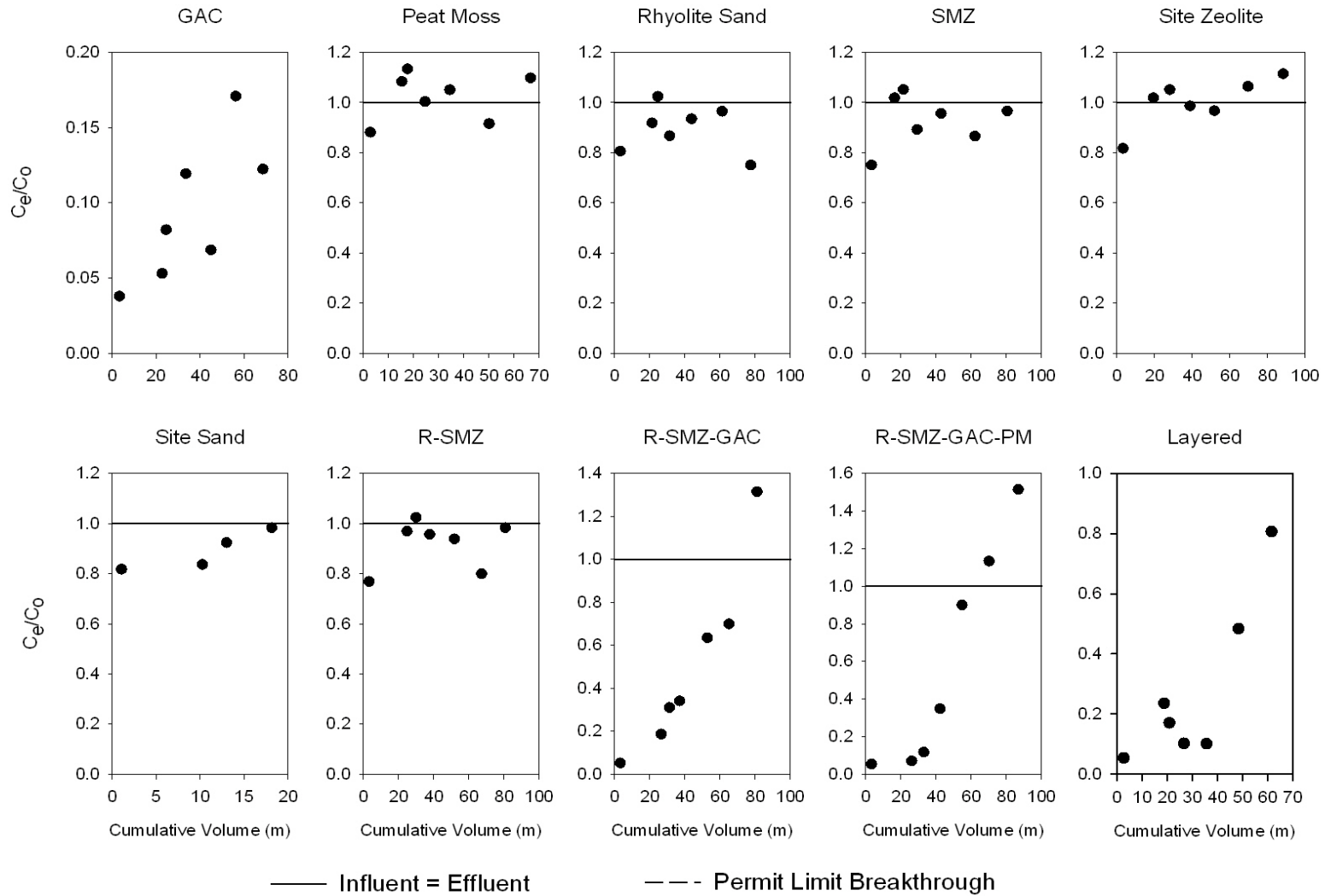
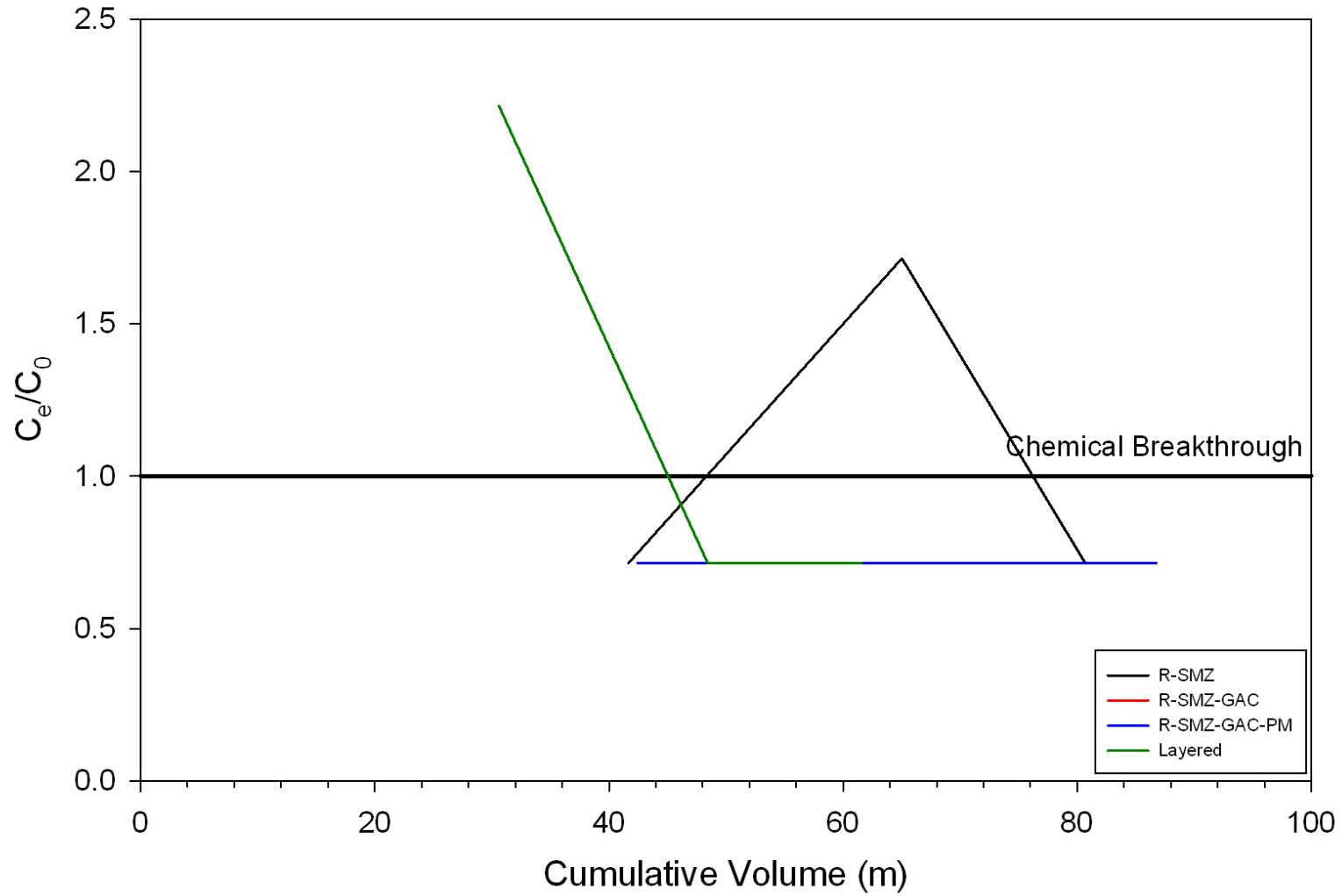


Figure A10-40. Nitrate + Nitrite Normalized Breakthrough Plots

Oil and Grease



OIL AND GREASE

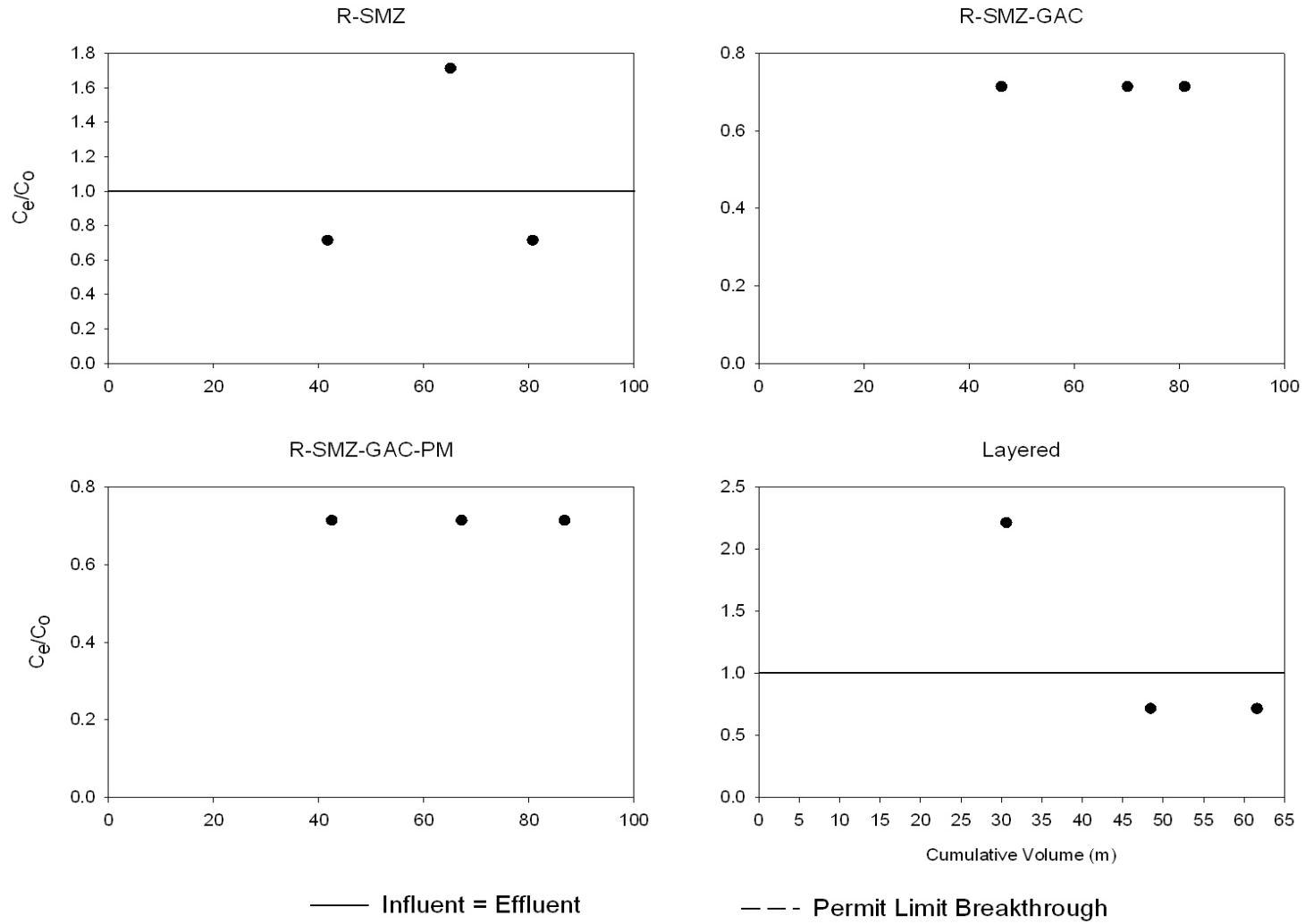
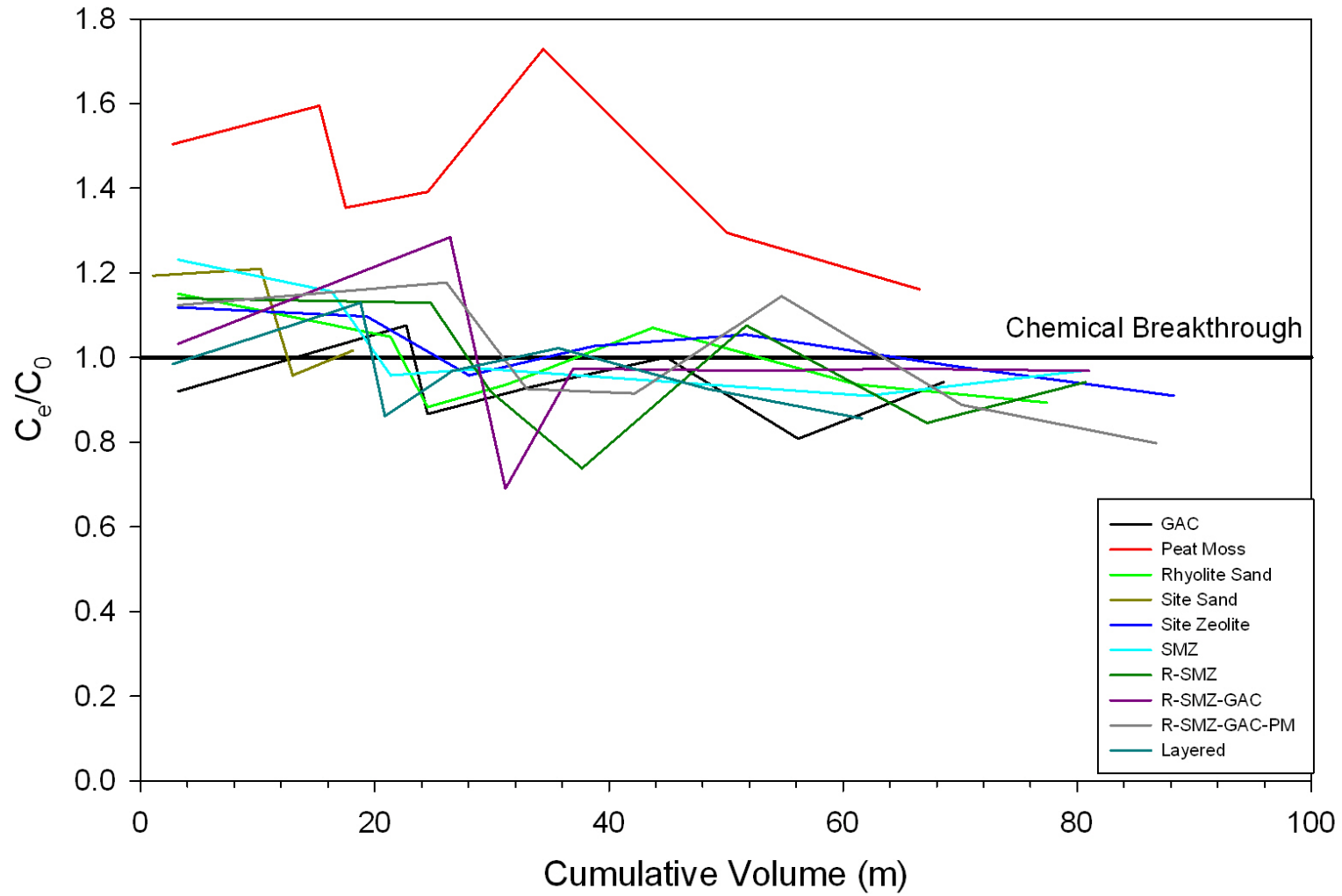


Figure A10-41. Oil and Grease Normalized Breakthrough Plots

Oxidation-Reduction Potential



OXYGEN REDUCTION POTENTIAL

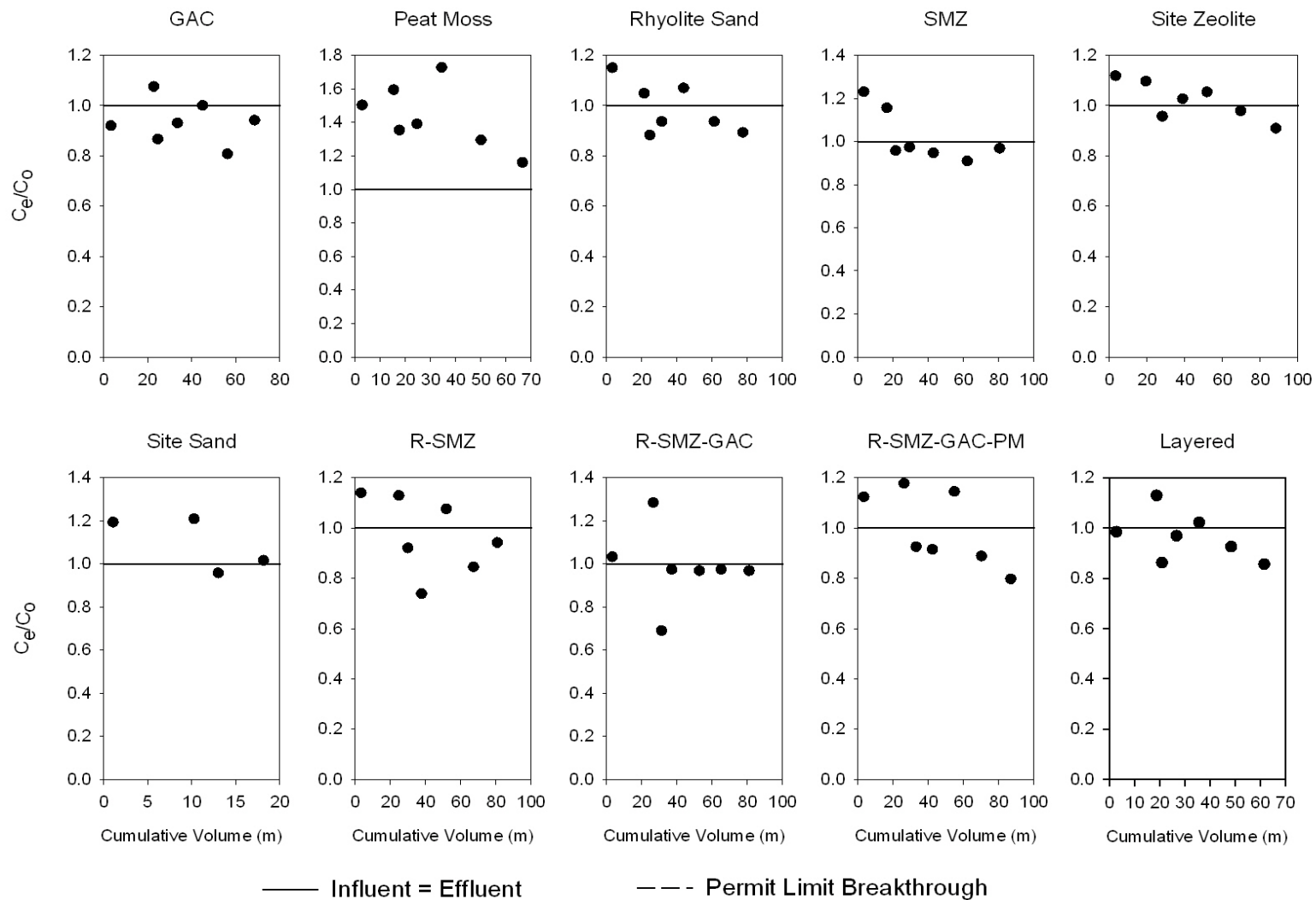
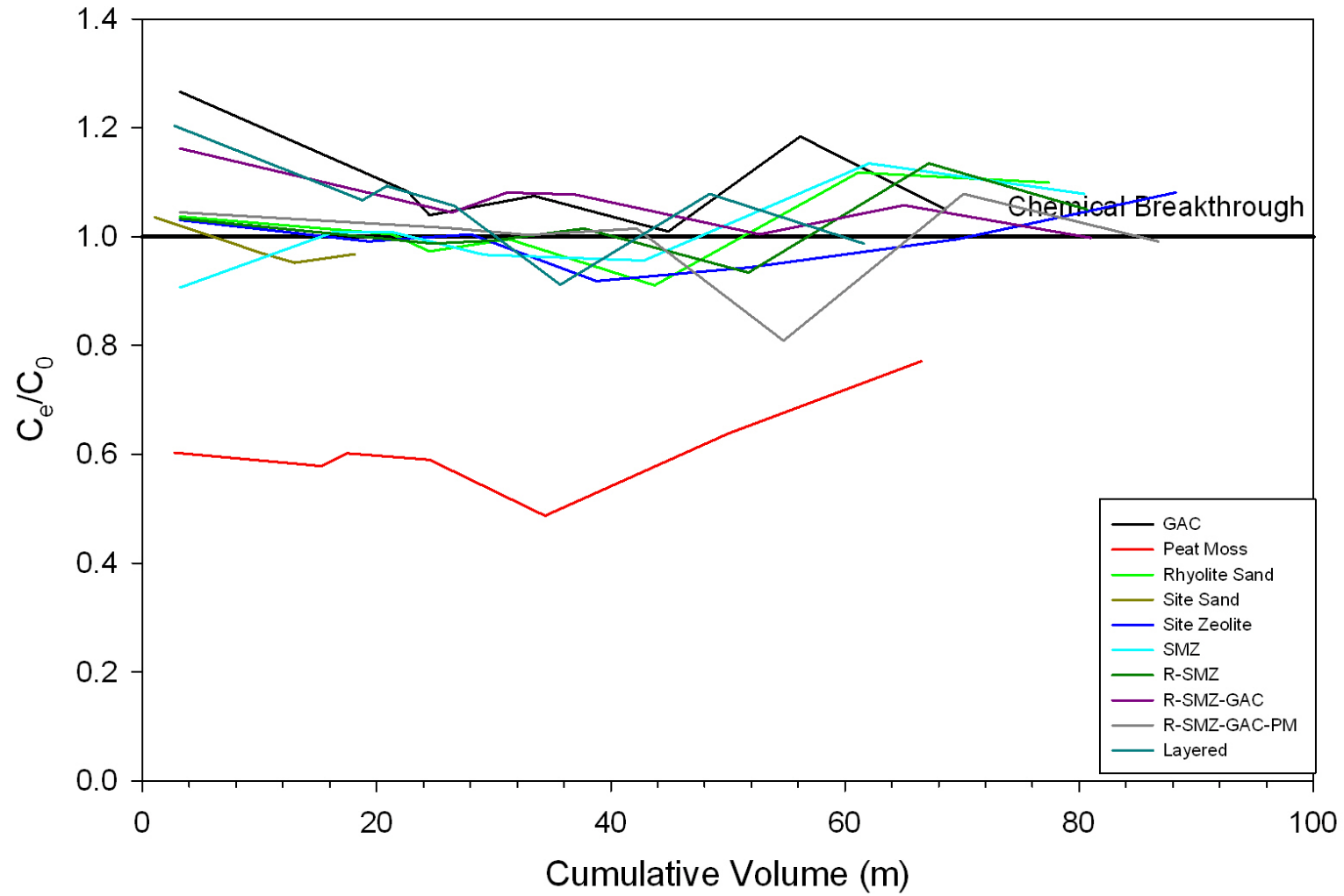


Figure A10-42. Oxidation-Reduction Potential Normalized Breakthrough Plots

pH



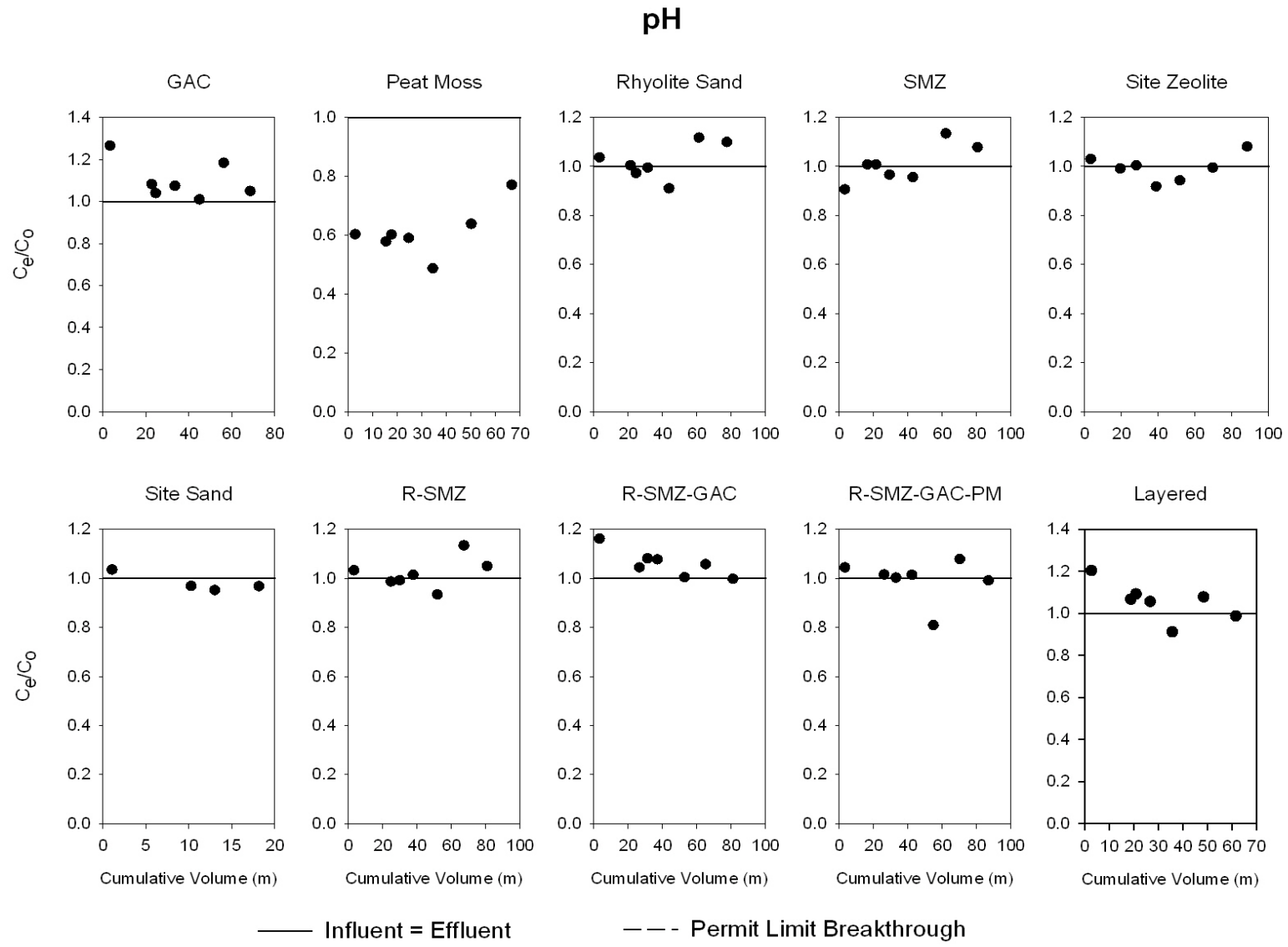
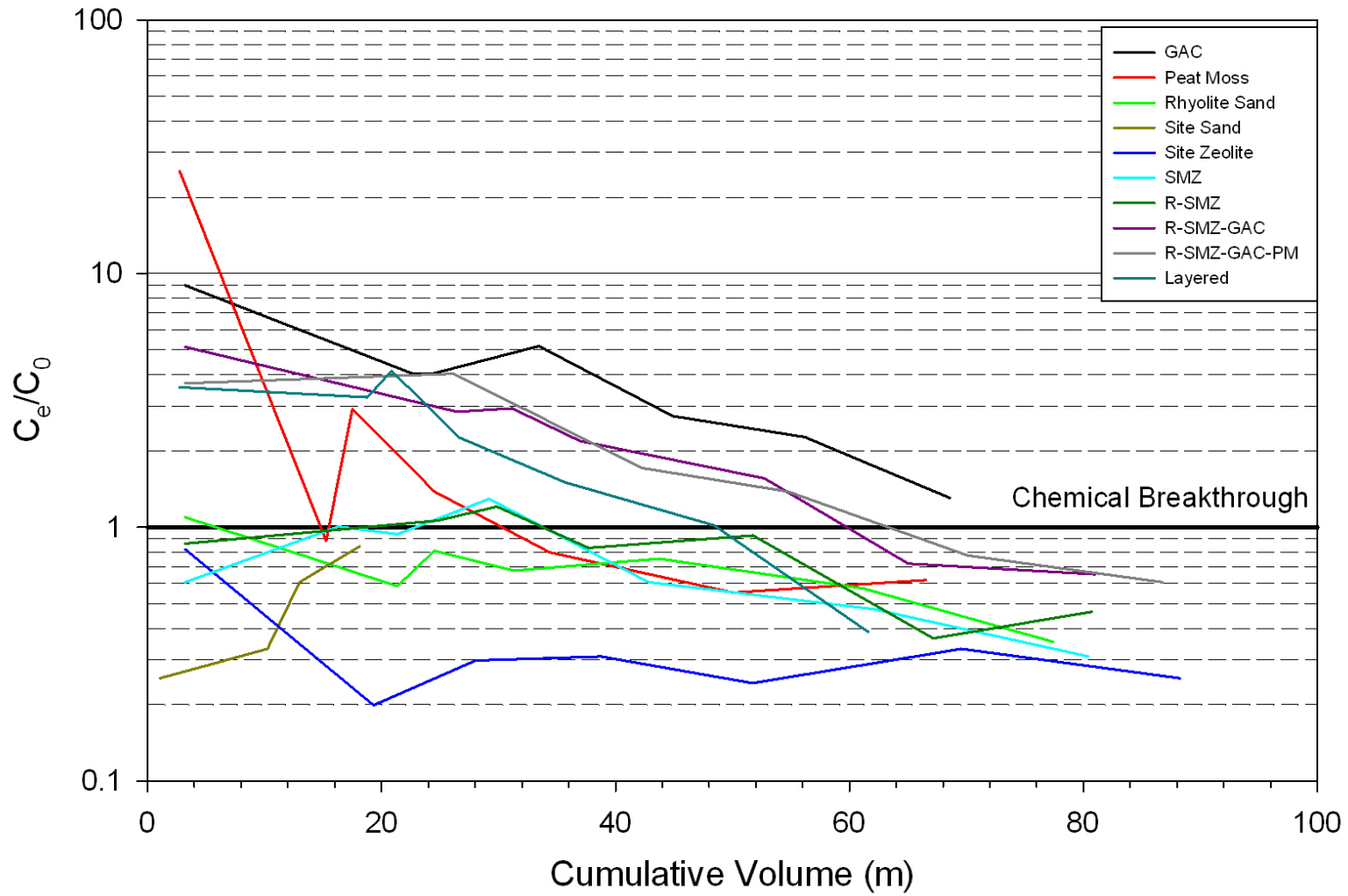


Figure A10-43. pH Normalized Breakthrough Plots

Phosphate



PHOSPHATE

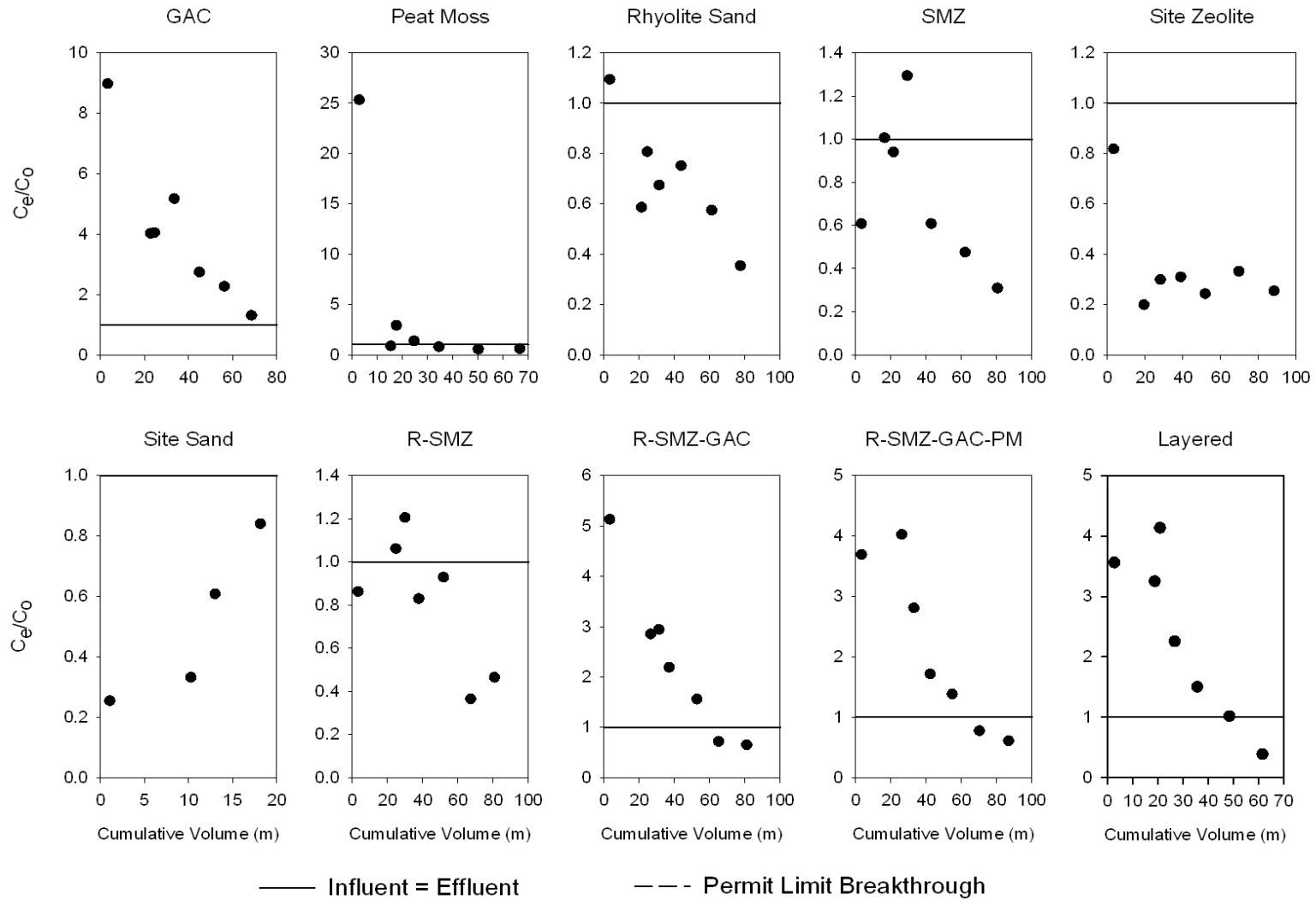
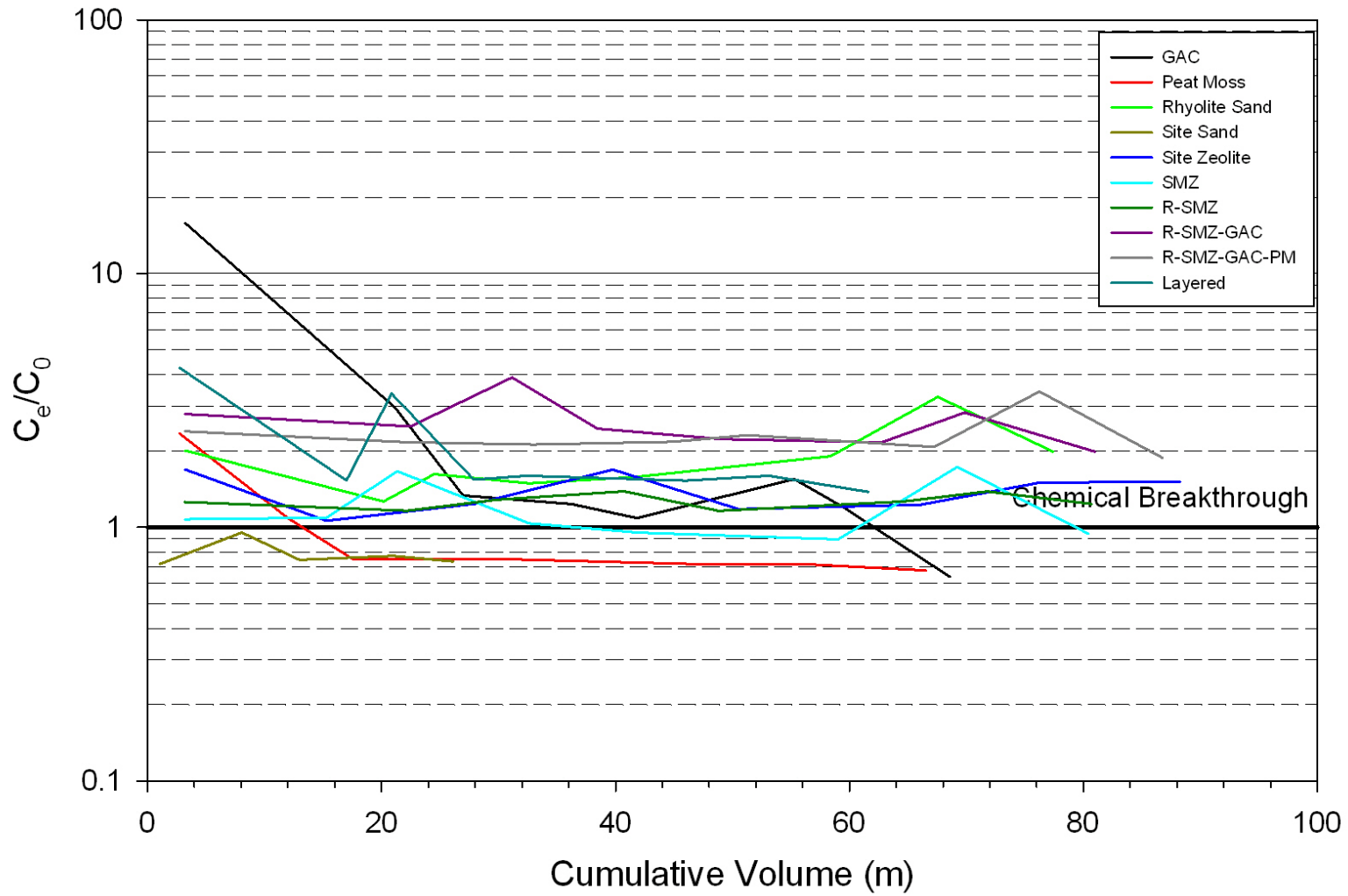


Figure A10-44. Phosphate Normalized Breakthrough Plots

Potassium, Total



POTASSIUM, TOTAL

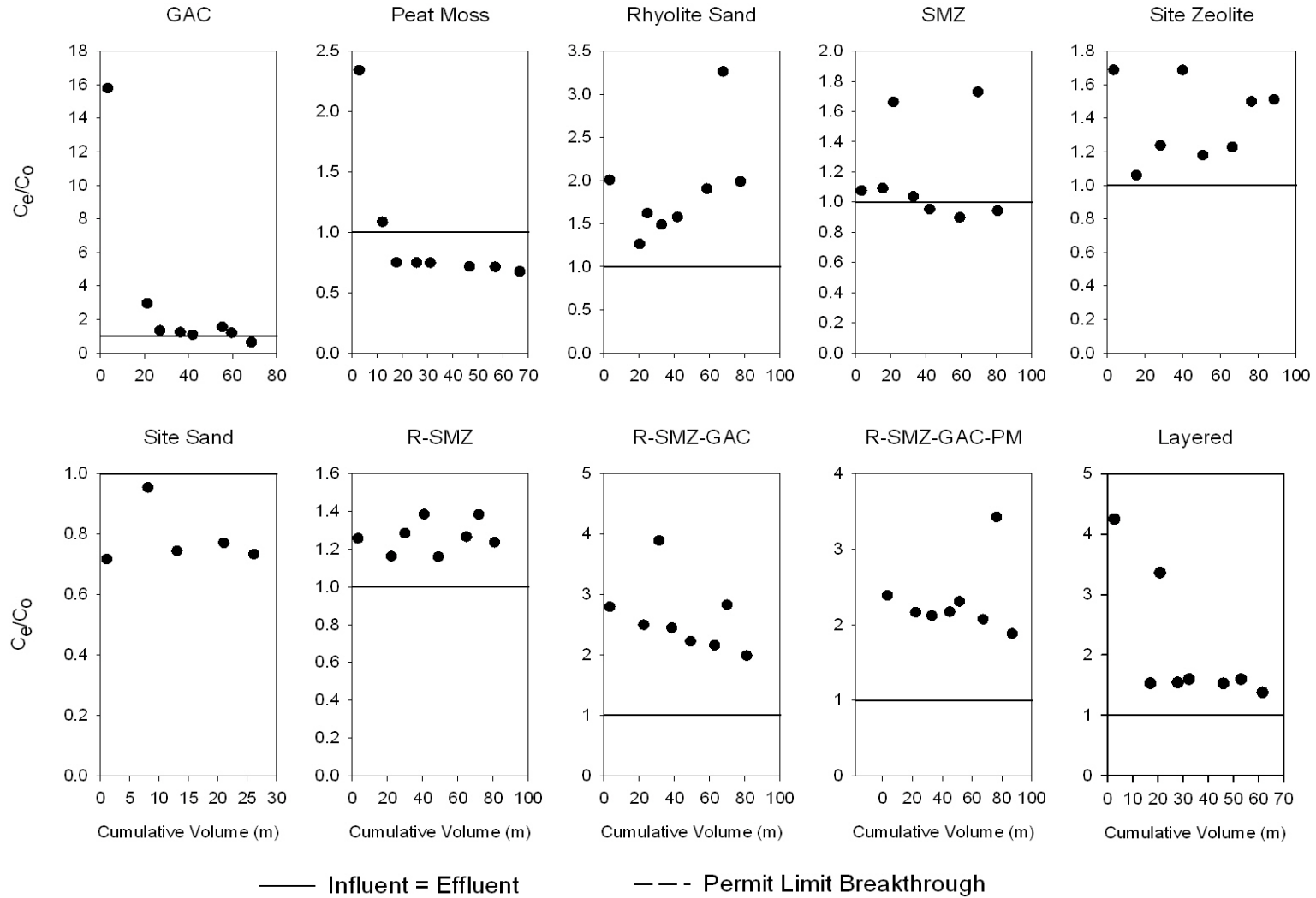
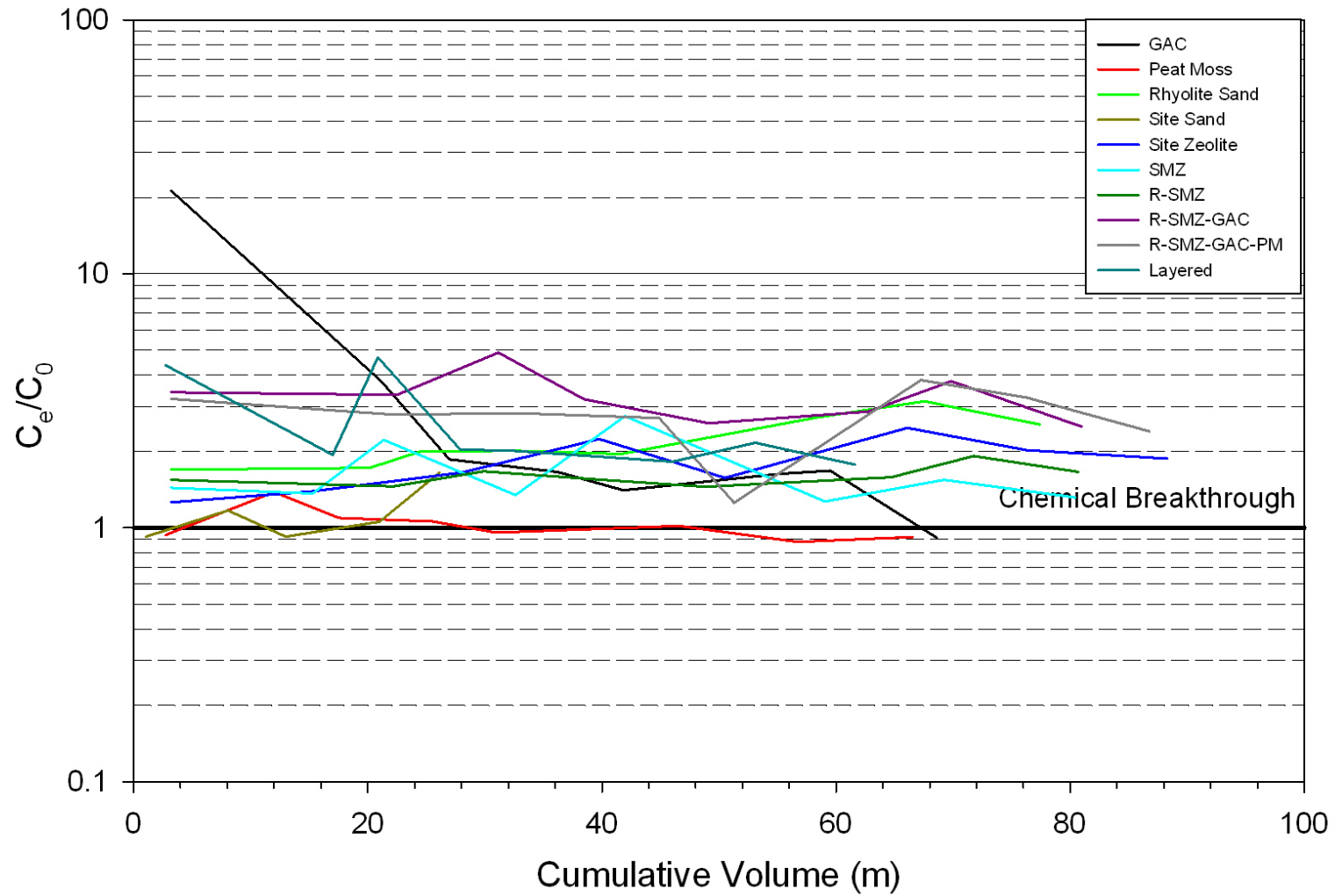


Figure A10-45. Potassium (Total) Normalized Breakthrough Plots

Potassium, Filtered



POTASSIUM, FILTERED

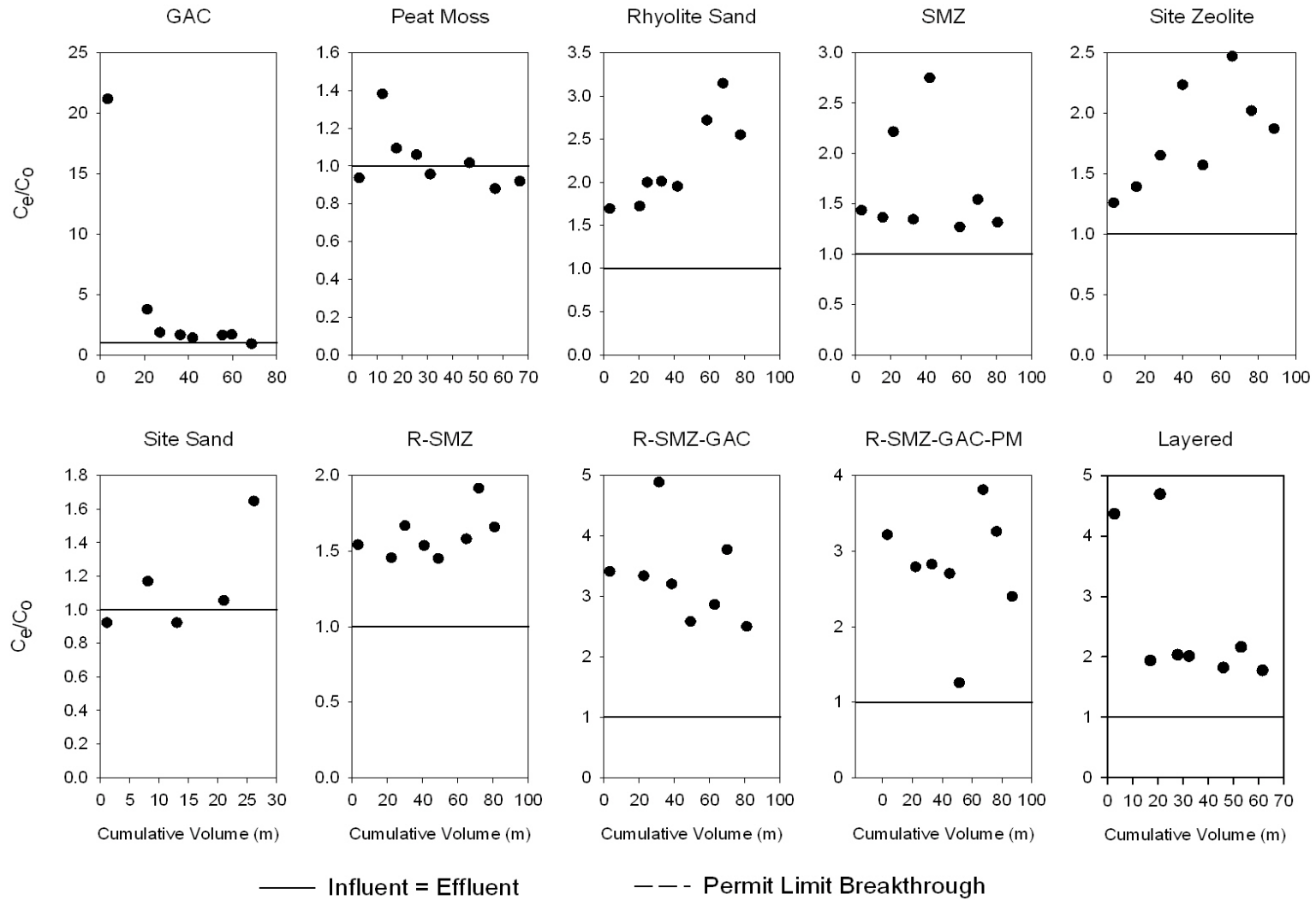
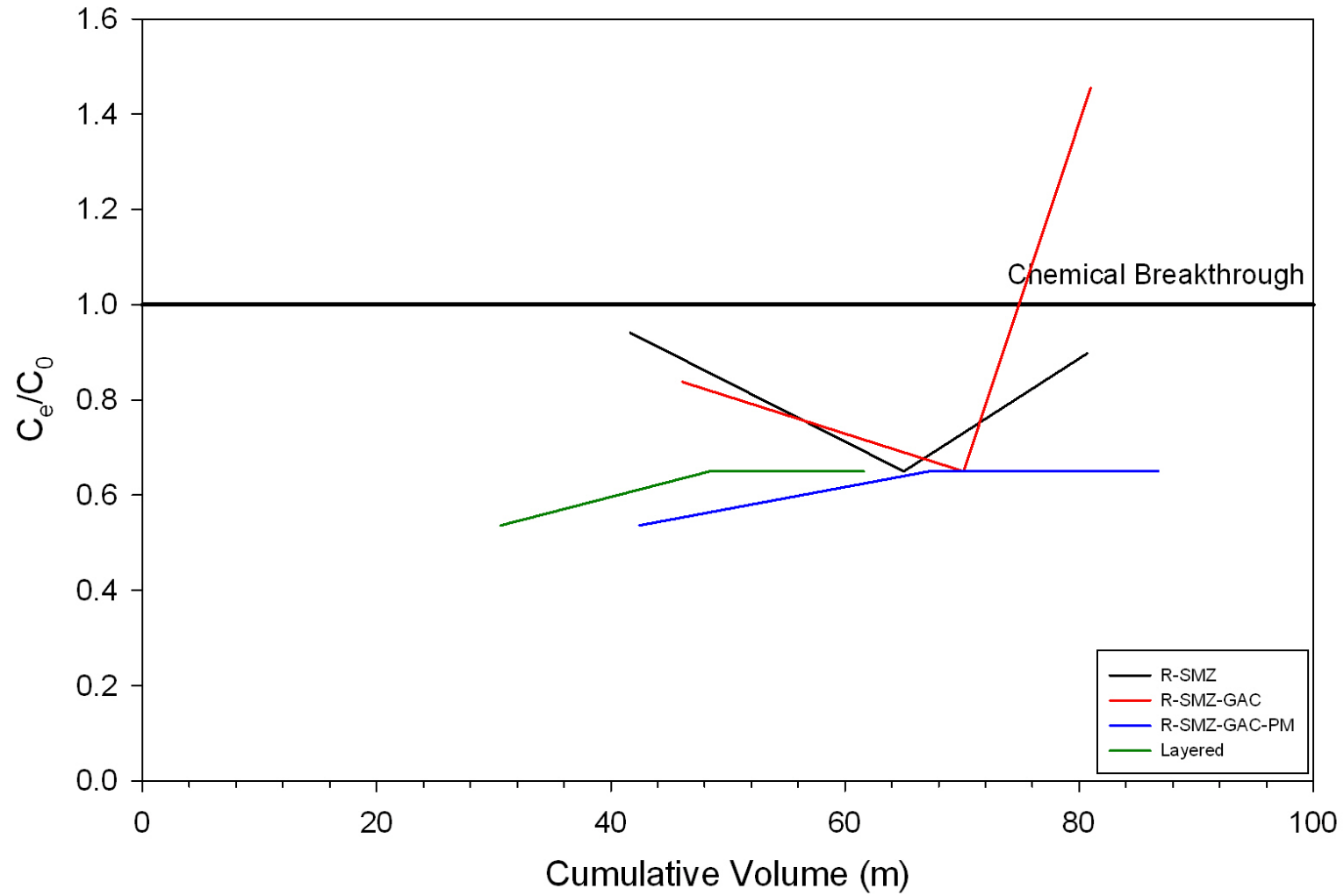


Figure A10-46. Potassium (Filtered) Normalized Breakthrough Plots

Radium-226 + Radium-228



RADIUM-226 + RADIUM-228

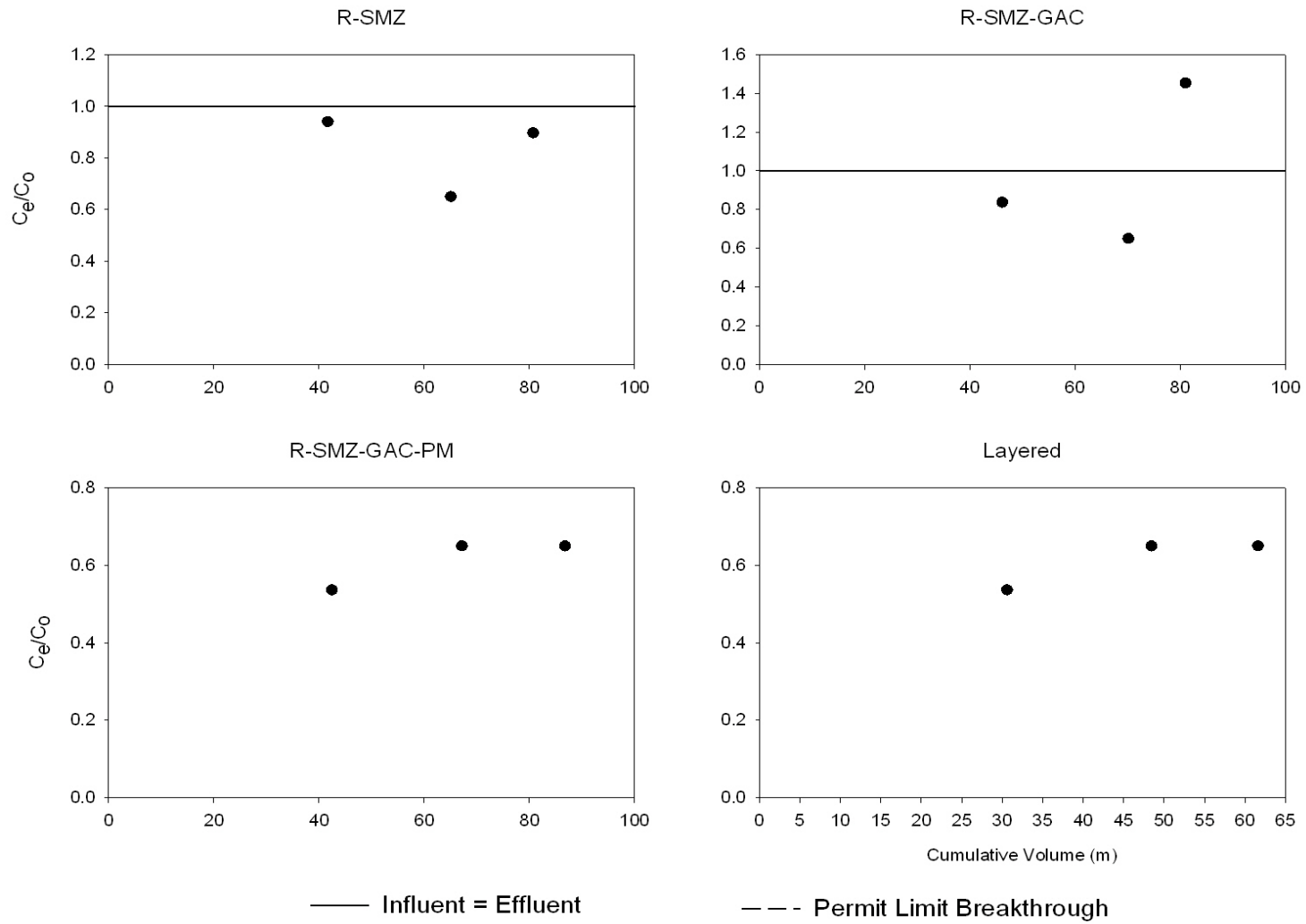
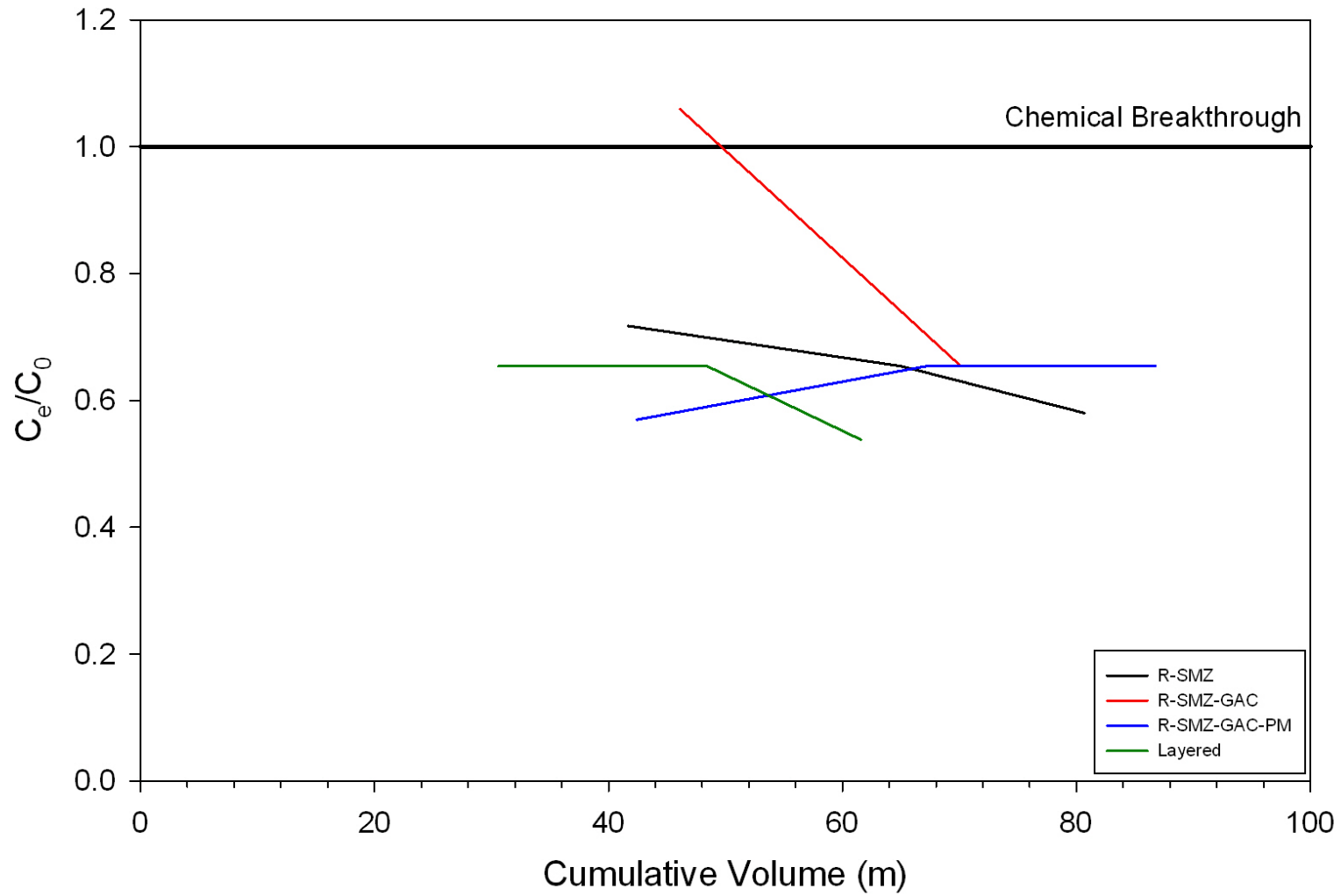


Figure A10-47. Radium 226 + Radium 228 Normalized Breakthrough Plots

Radium-226



RADIUM-226

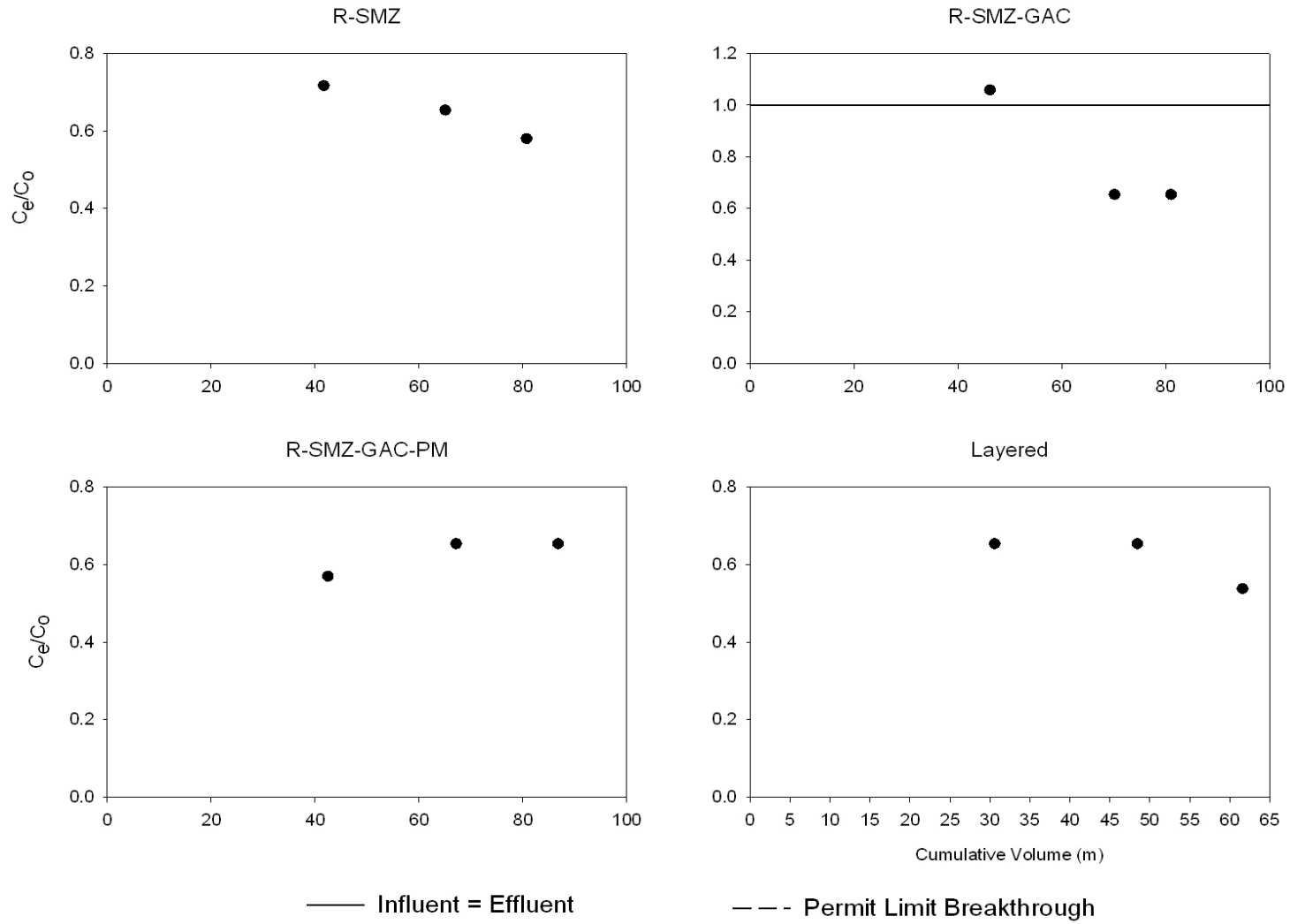
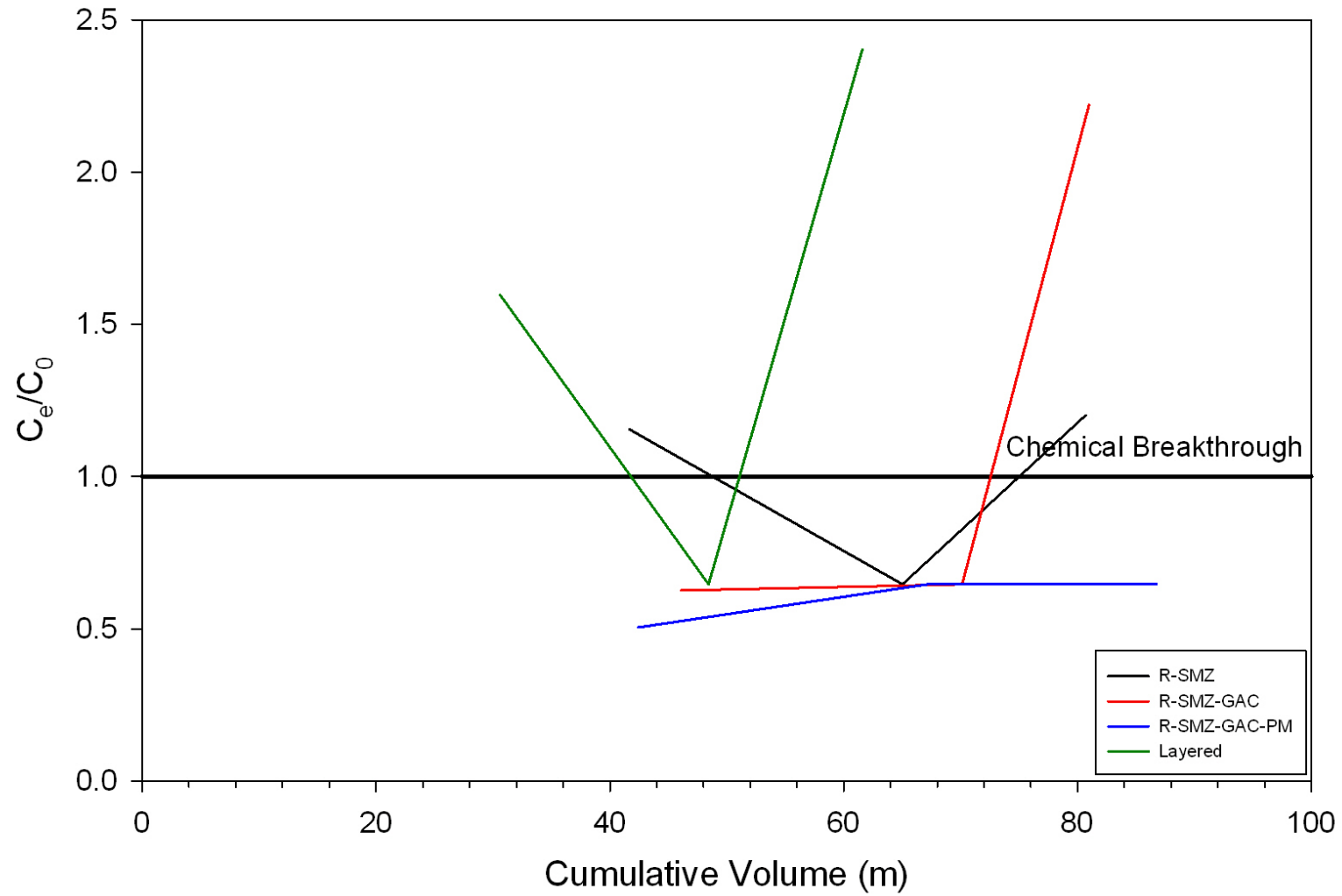


Figure A10-48. Radium 226 Normalized Breakthrough Plots

Radium-228



RADIUM-228

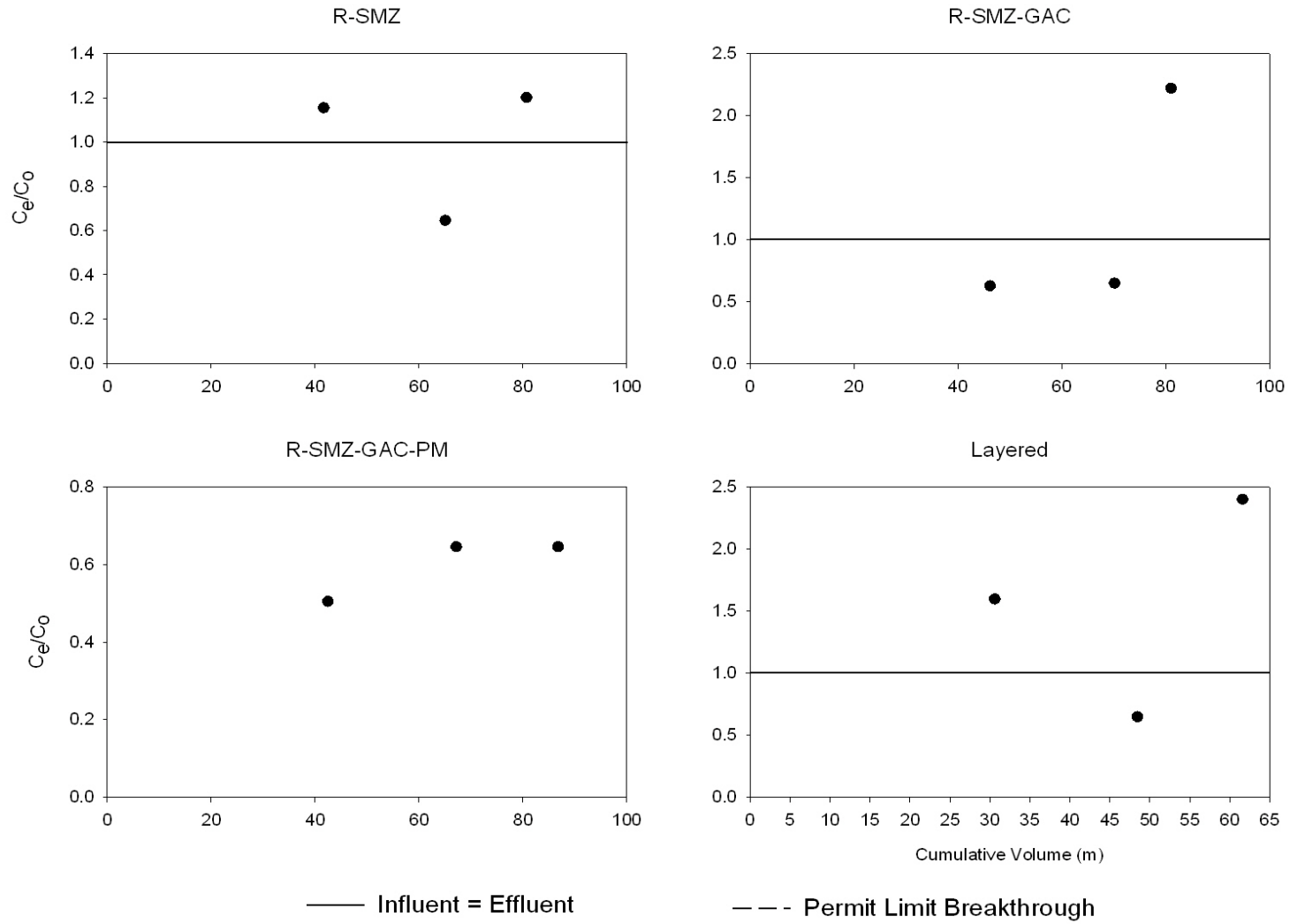
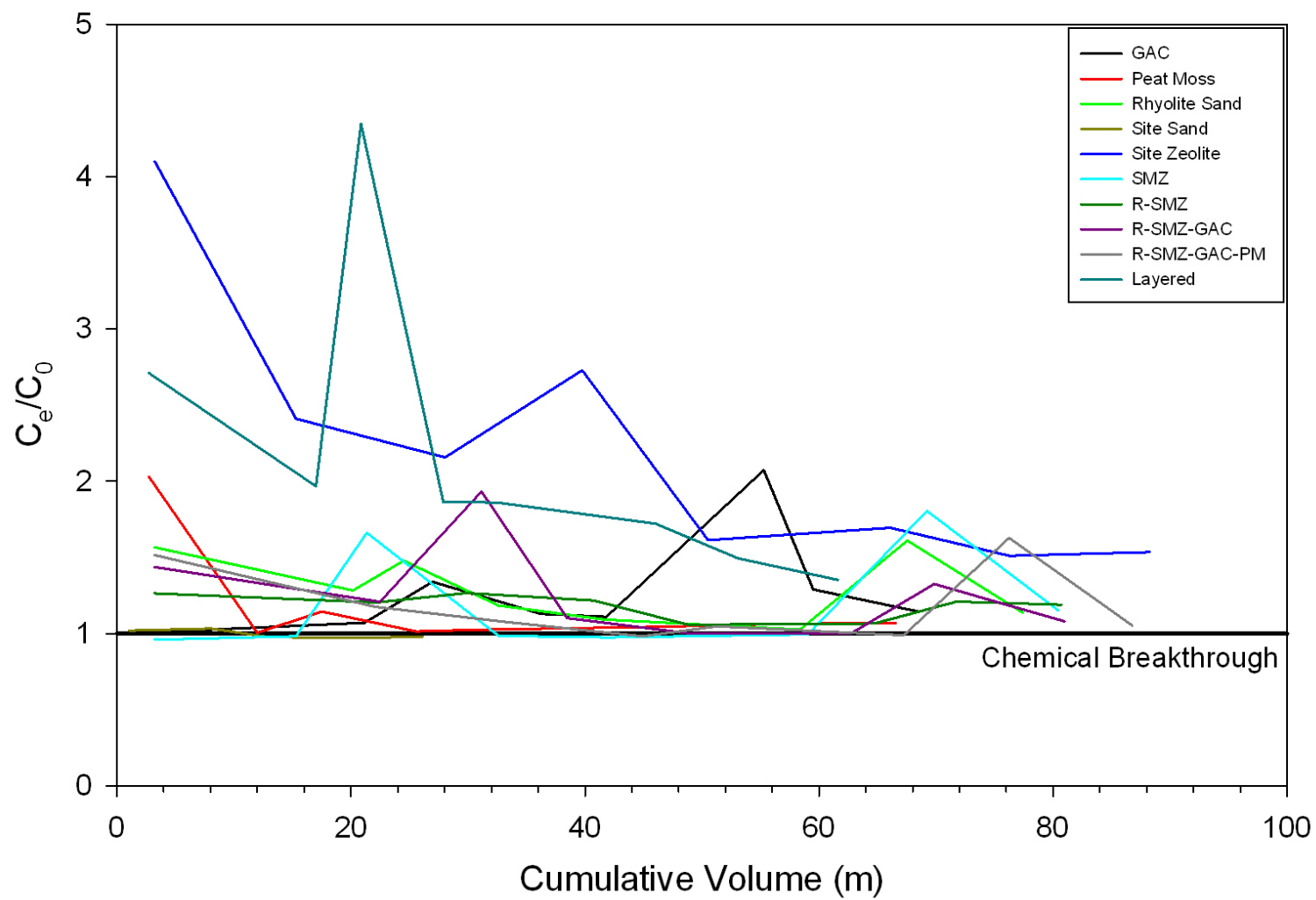


Figure A10-49. Radium 228 Normalized Breakthrough Plots

Sodium, Total



SODIUM, TOTAL

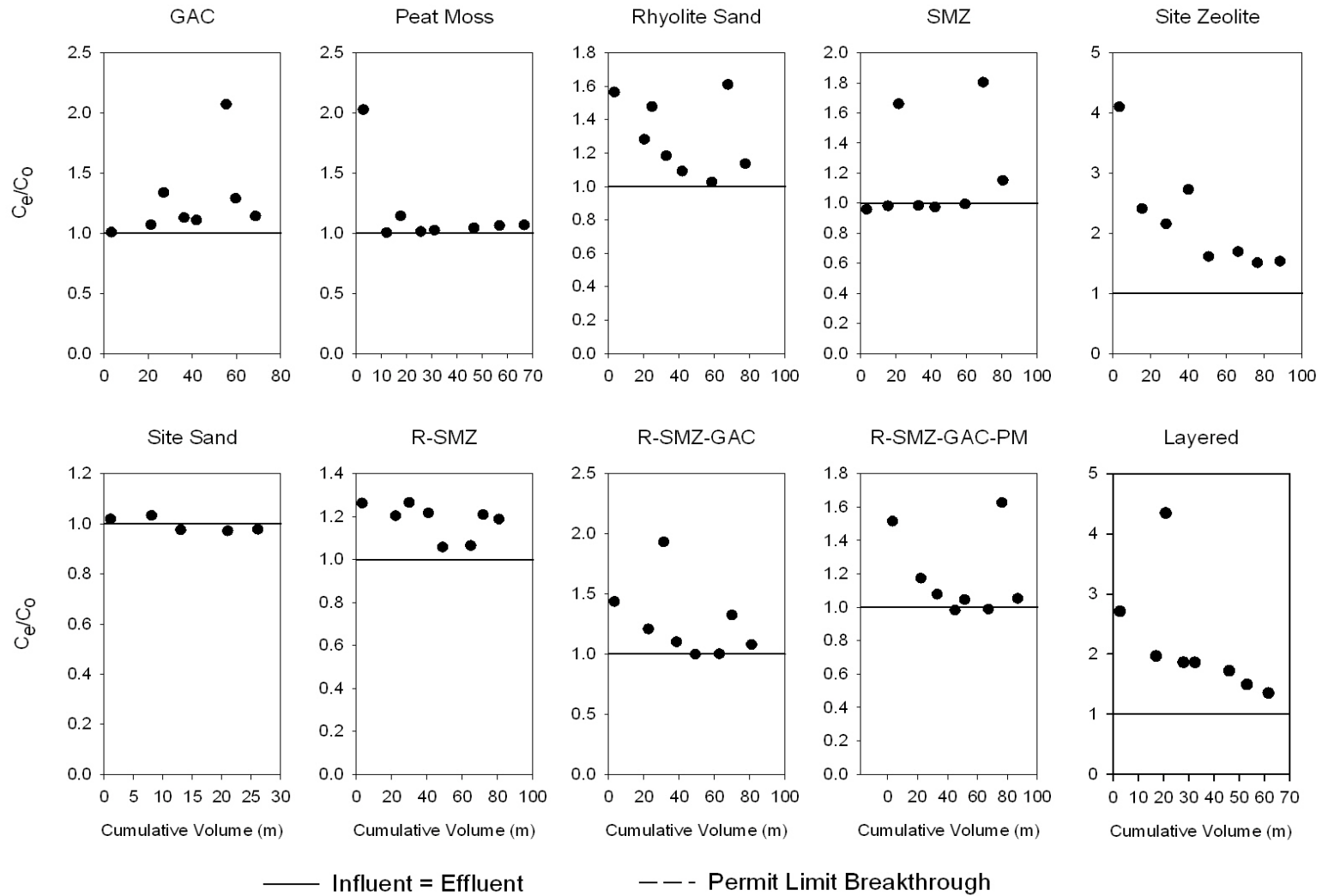


Figure A10-50. Sodium (Total) Normalized Breakthrough Plots

SODIUM, FILTERED

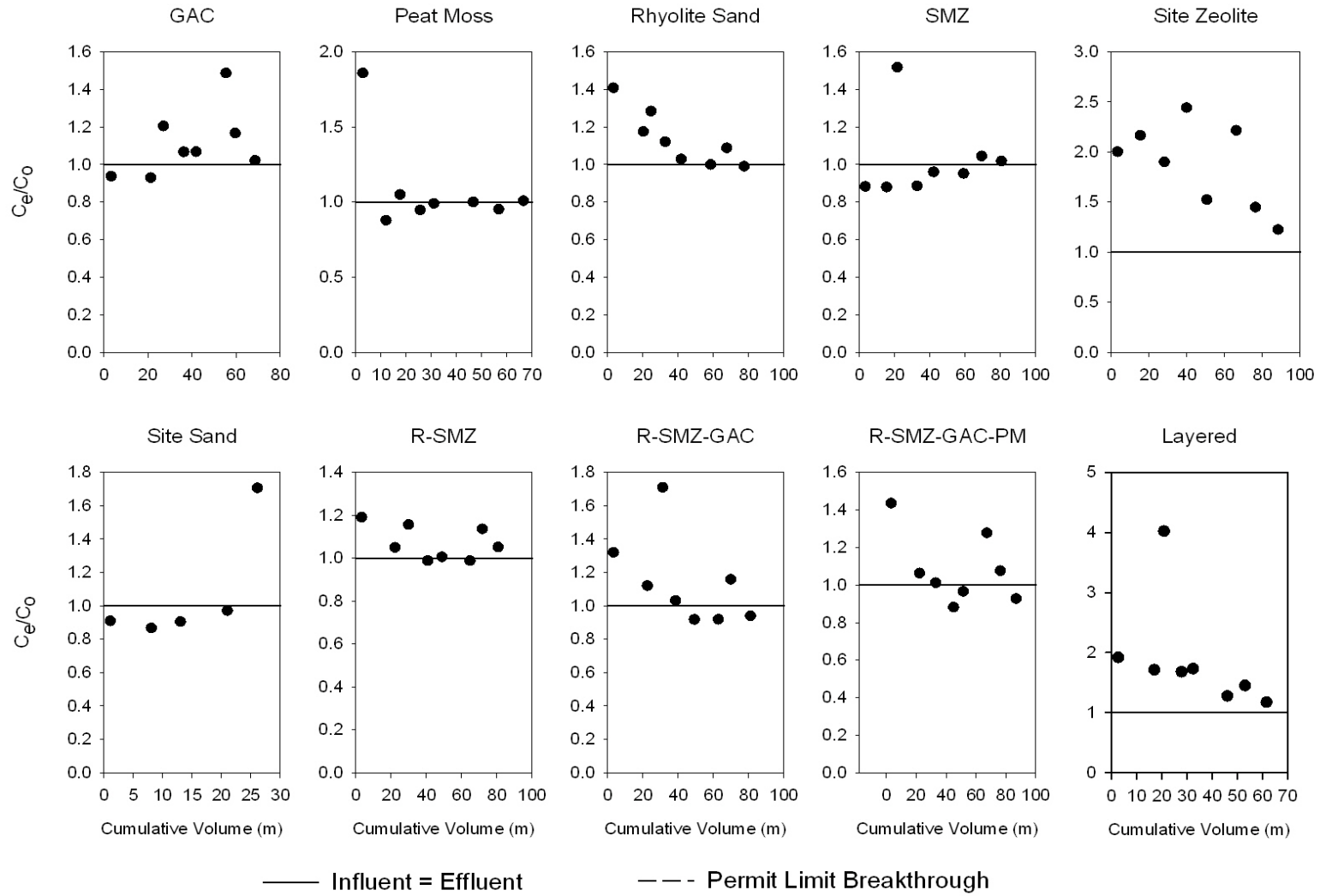


Figure A10-51. Sodium (Filtered) Normalized Breakthrough Plots

SULFATE

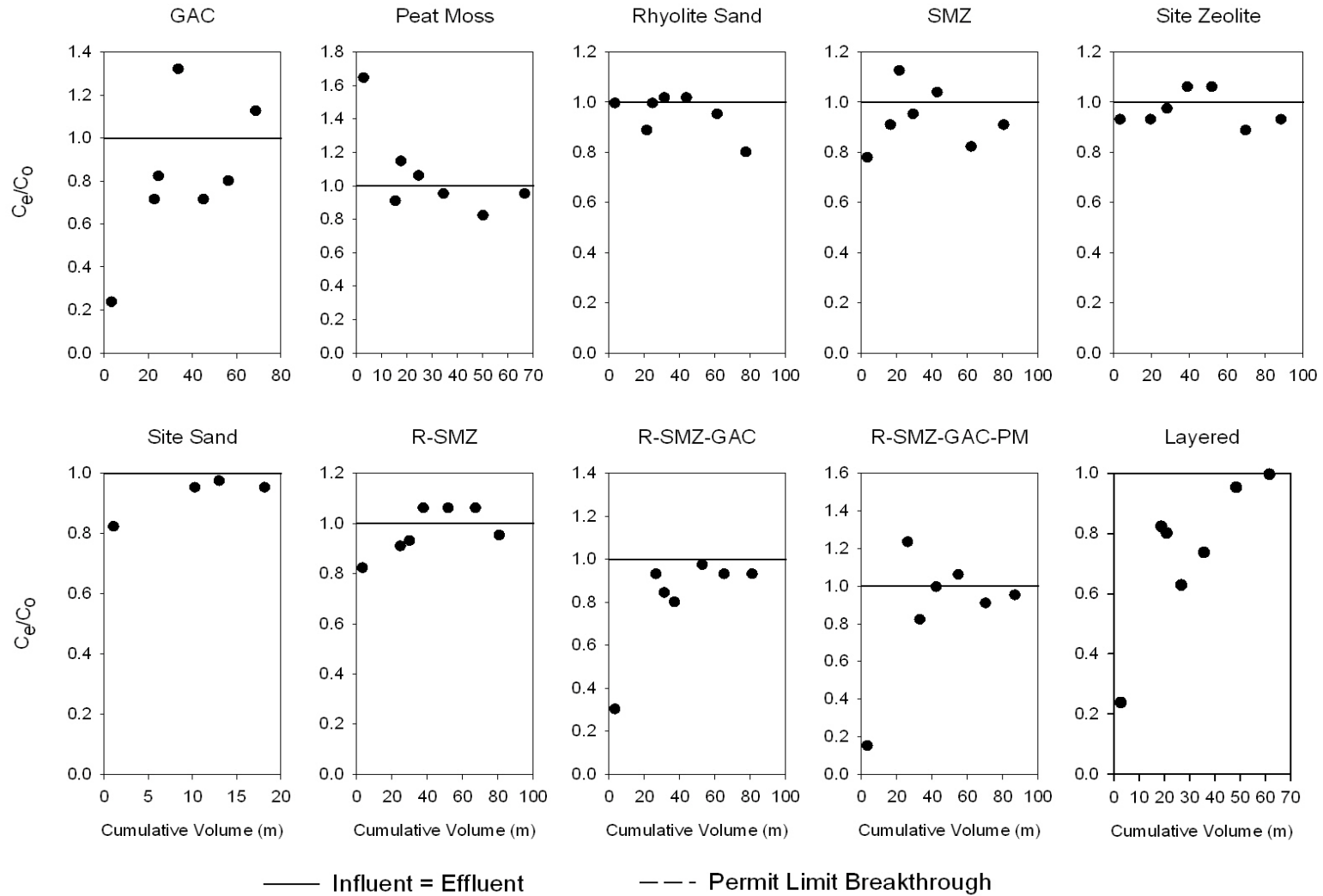
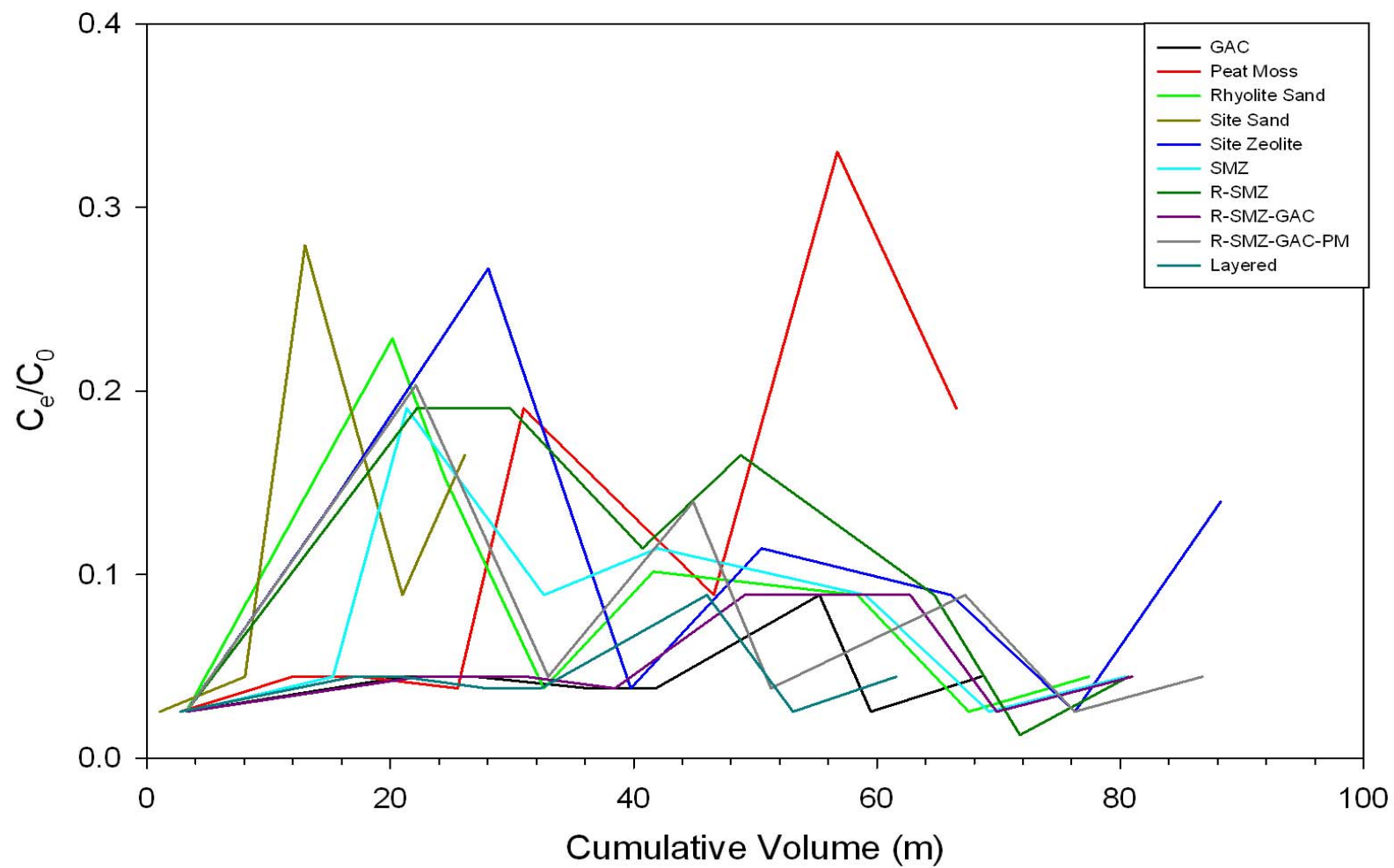


Figure A10-52. Sulfate Normalized Breakthrough Plots

Thallium, Total



THALLIUM, TOTAL

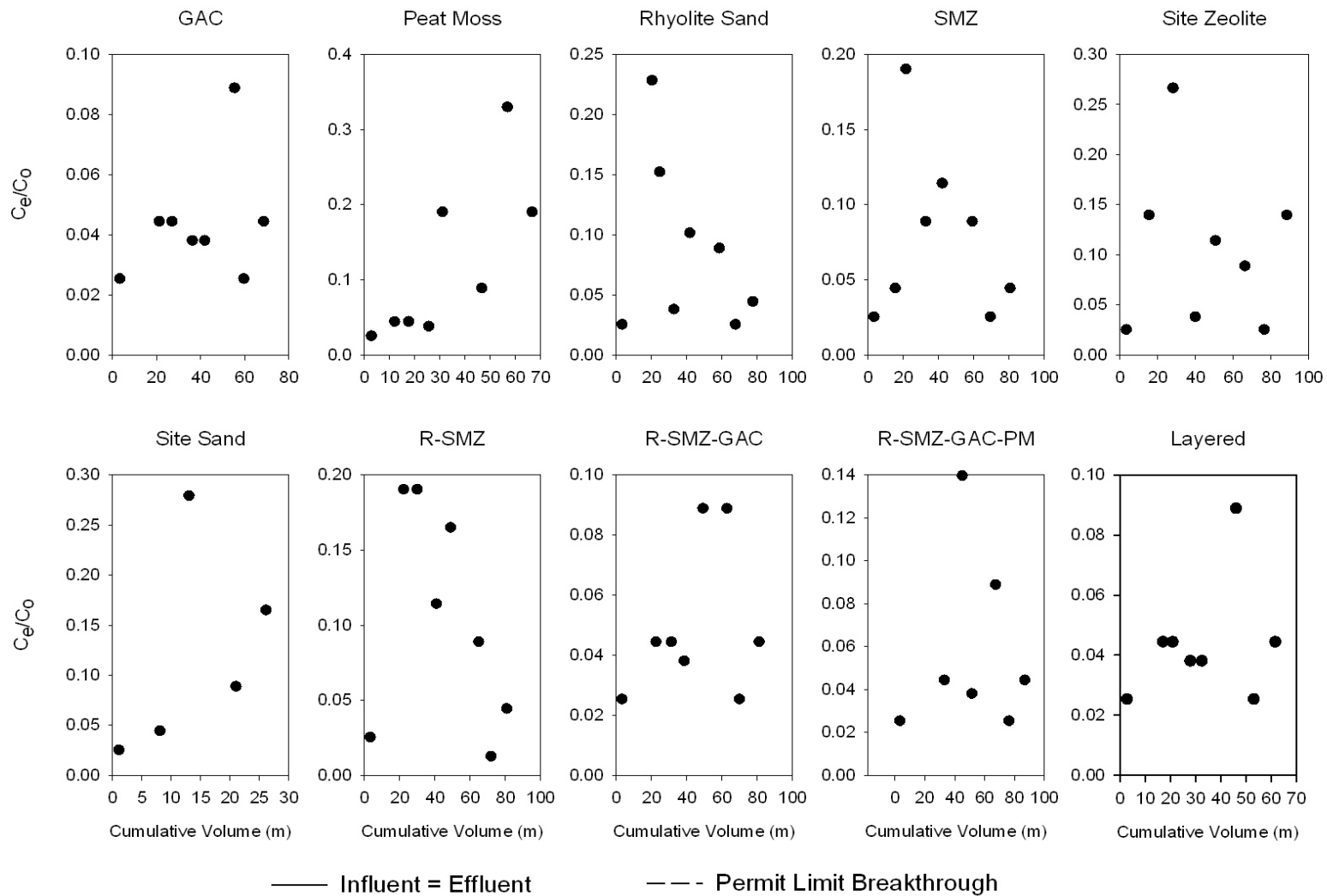


Figure A10-53. Thallium (Total) Normalized Breakthrough Plots

THALLIUM, FILTERED

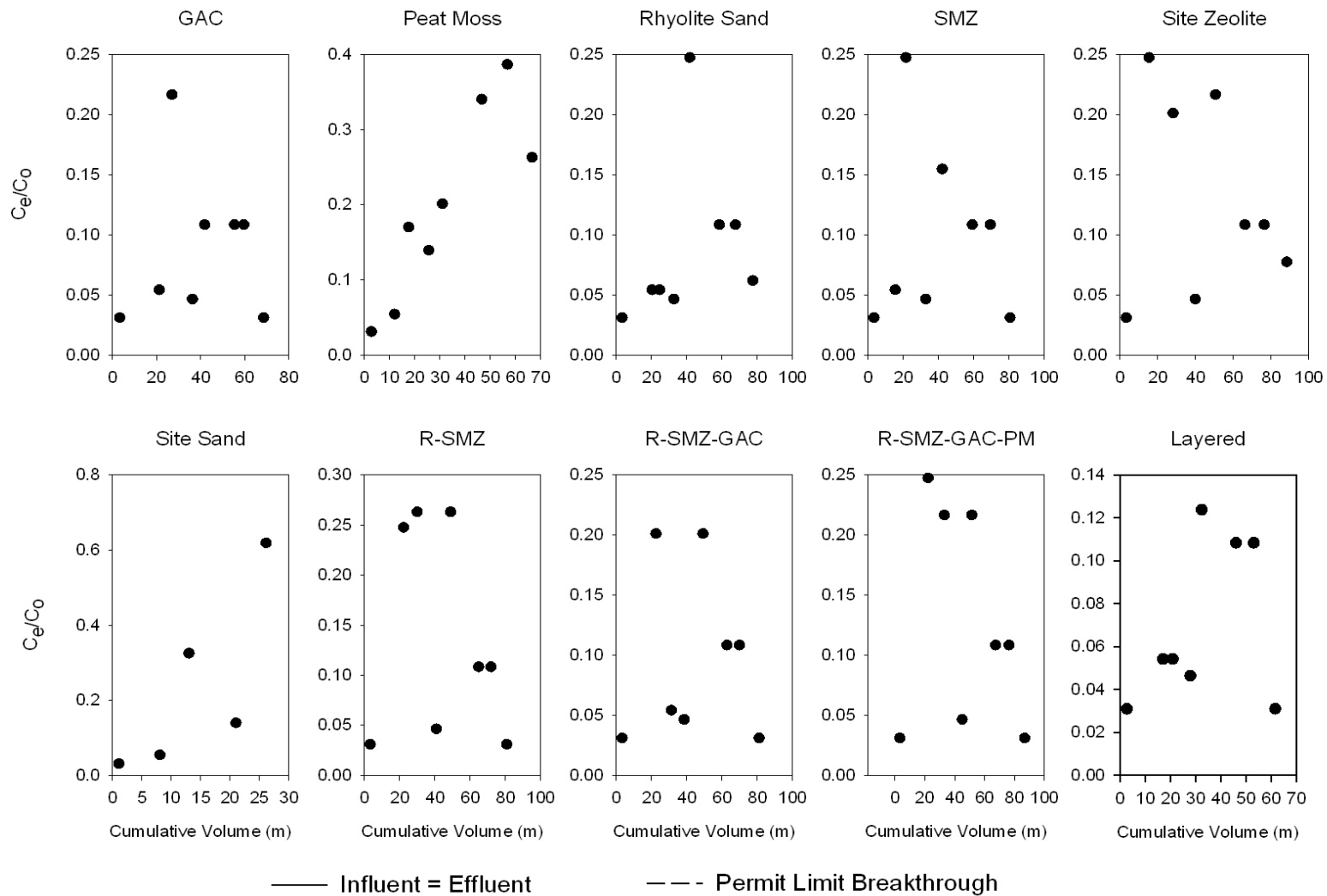
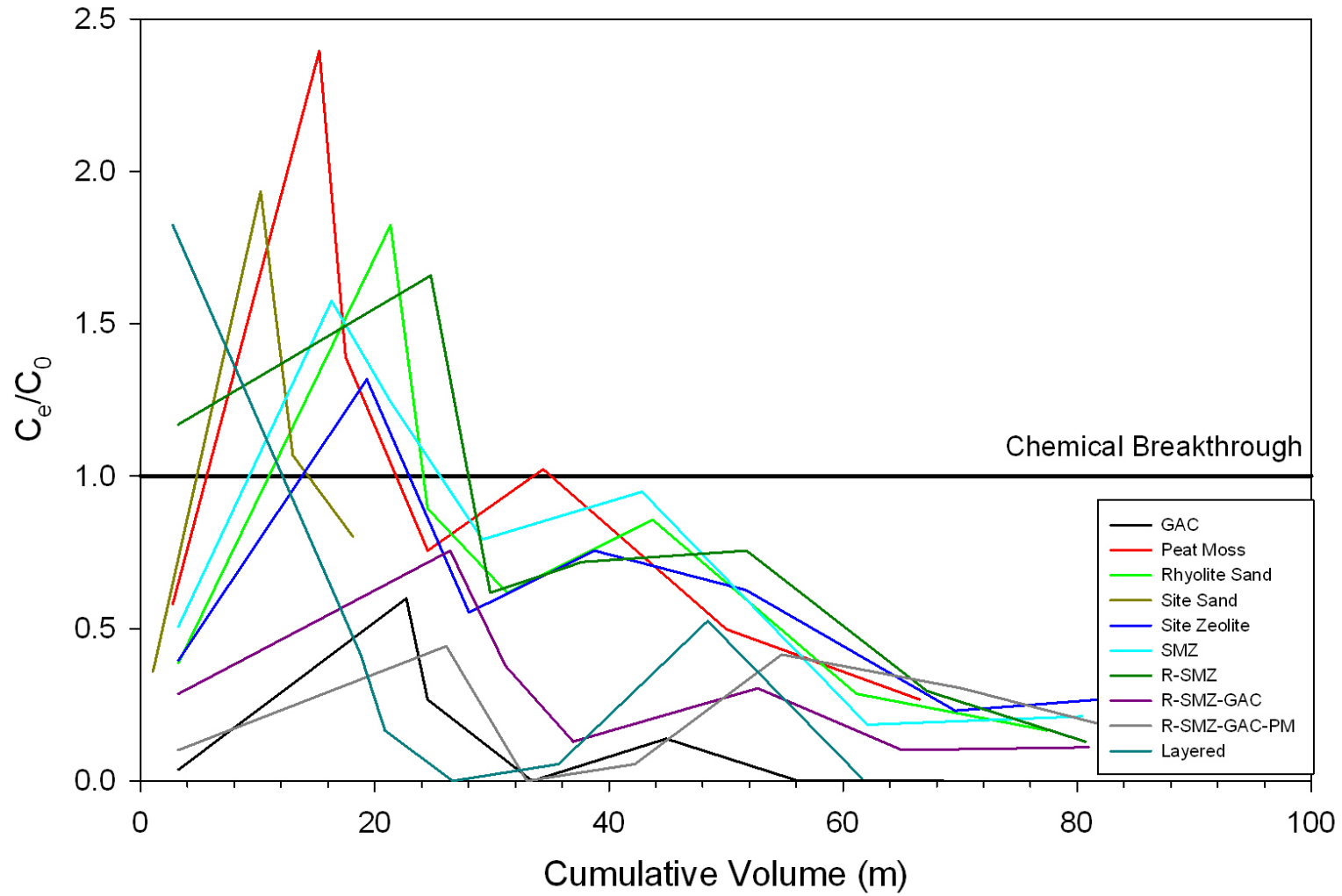


Figure A10-54. Thallium (Filtered) Normalized Breakthrough Plots

Total Nitrogen



TOTAL NITROGEN

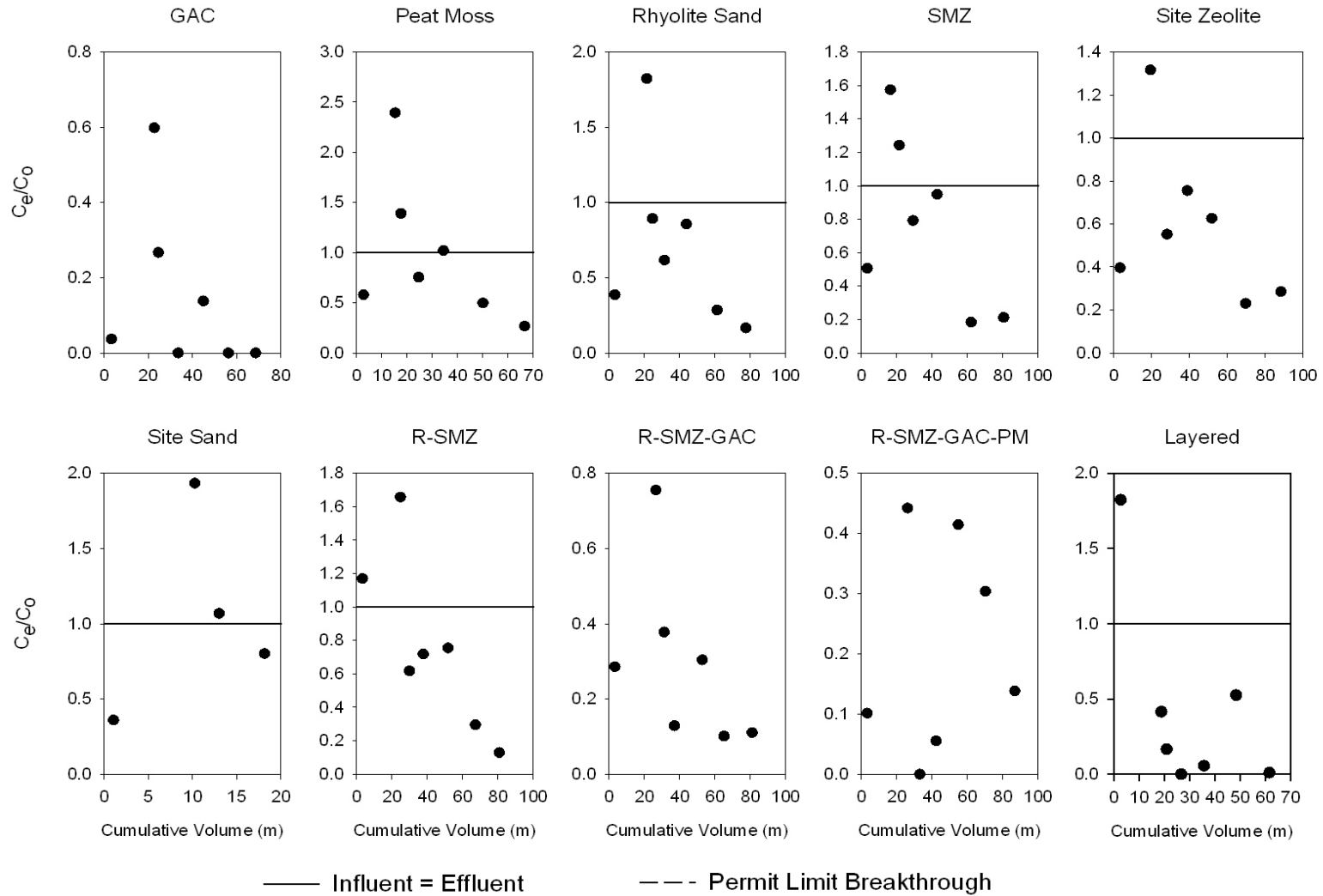


Figure A10-55. Total Nitrogen Normalized Breakthrough Plots

TOTAL PHOSPHORUS

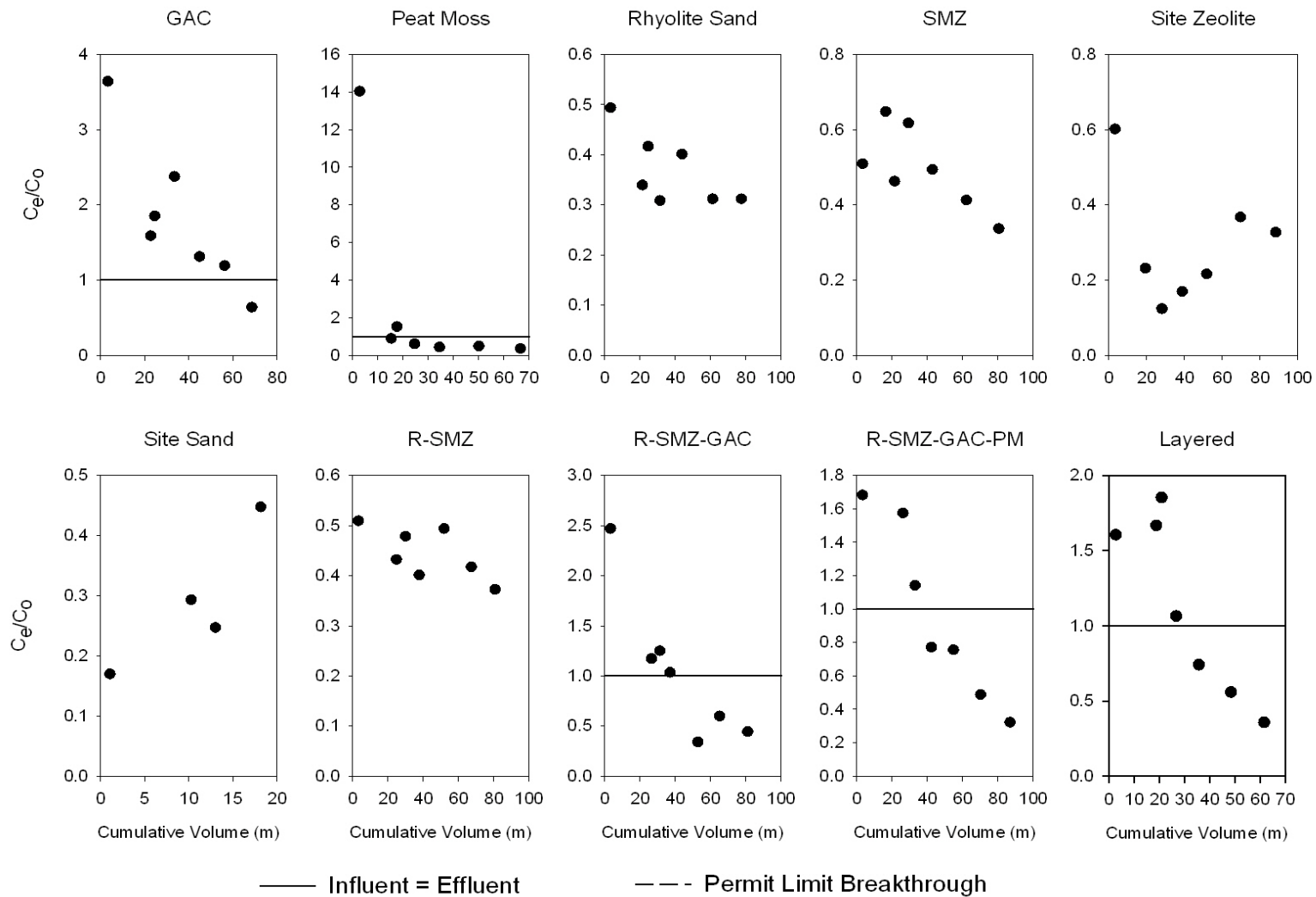
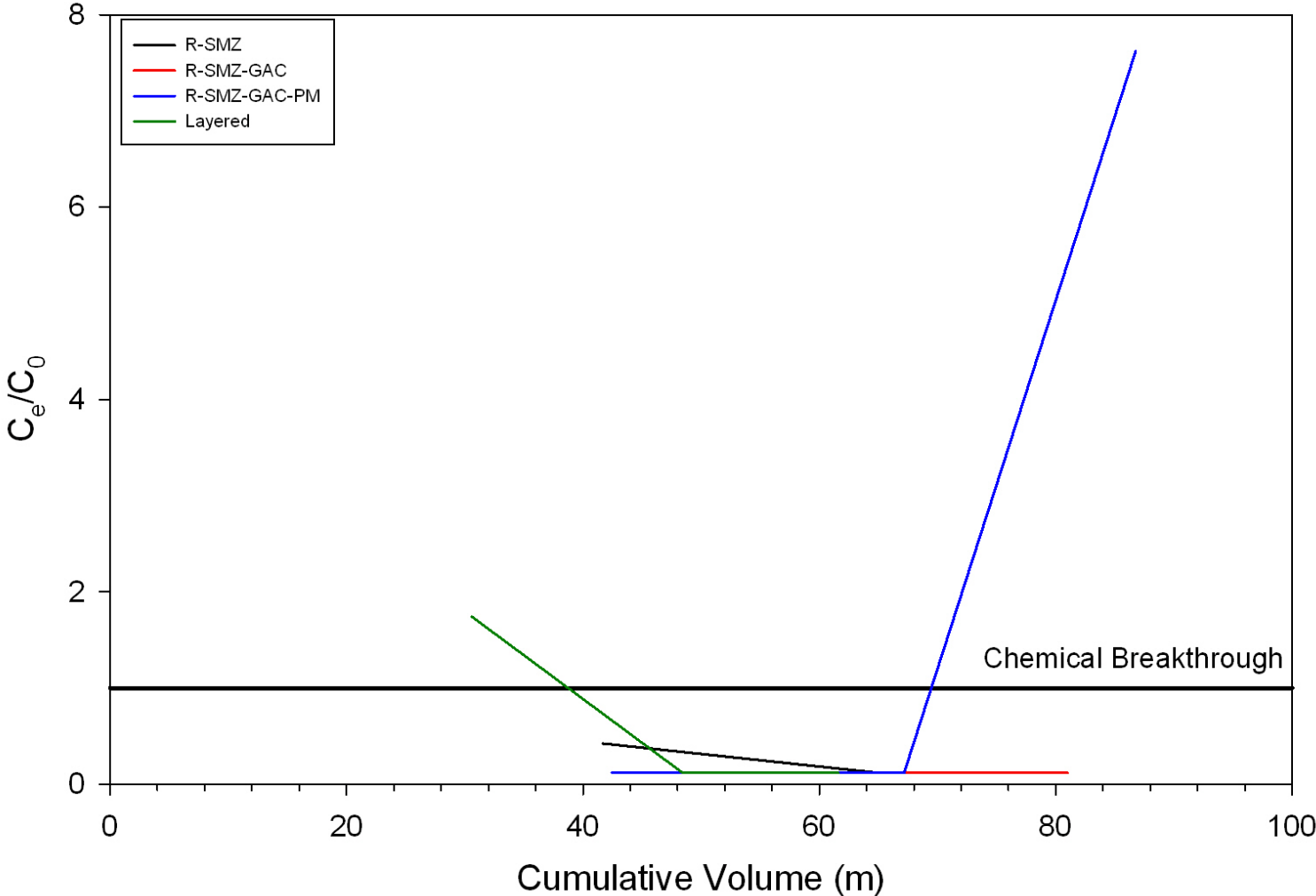


Figure A10-56. Total Phosphorus Normalized Breakthrough Plots

Uranium



URANIUM

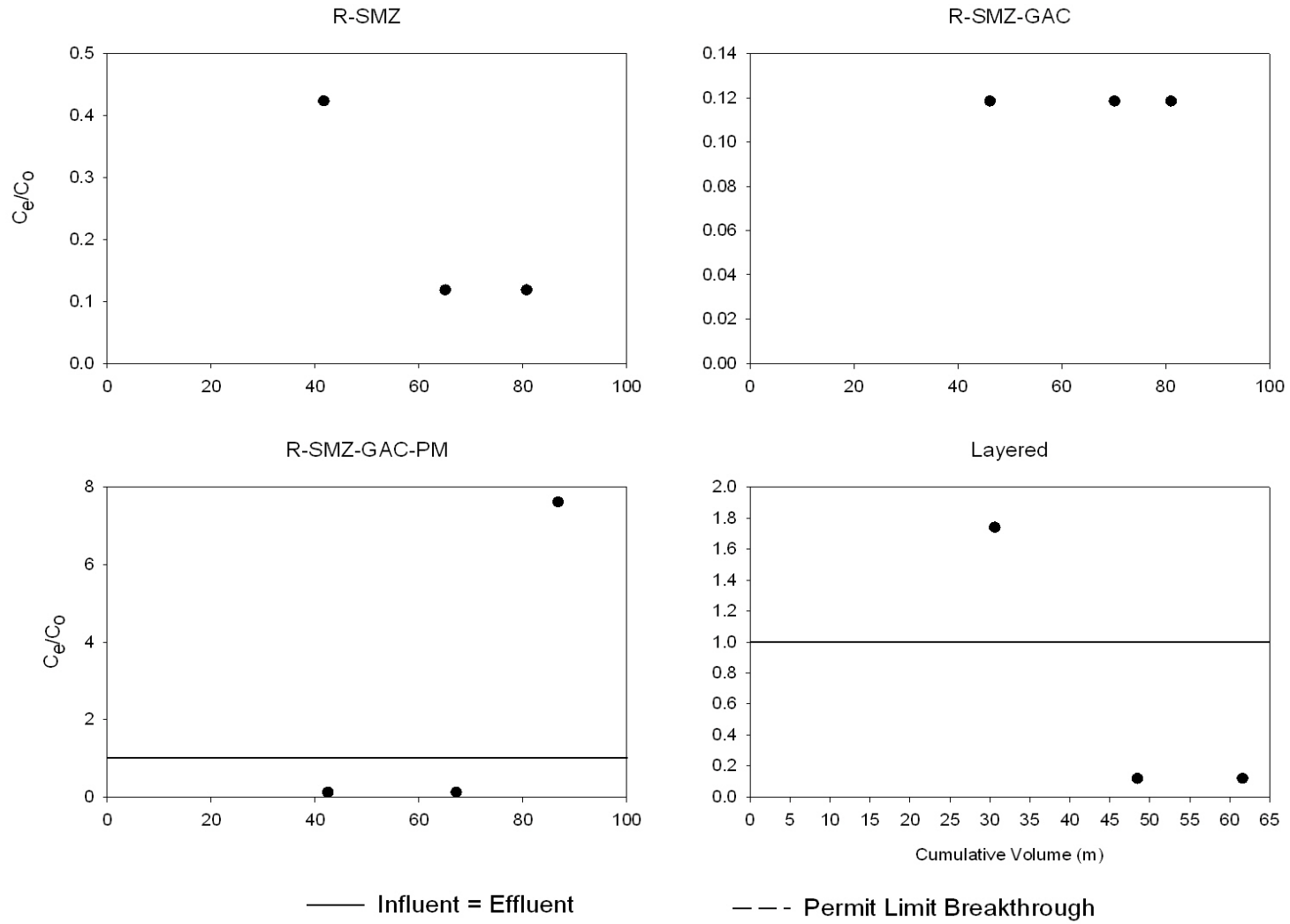
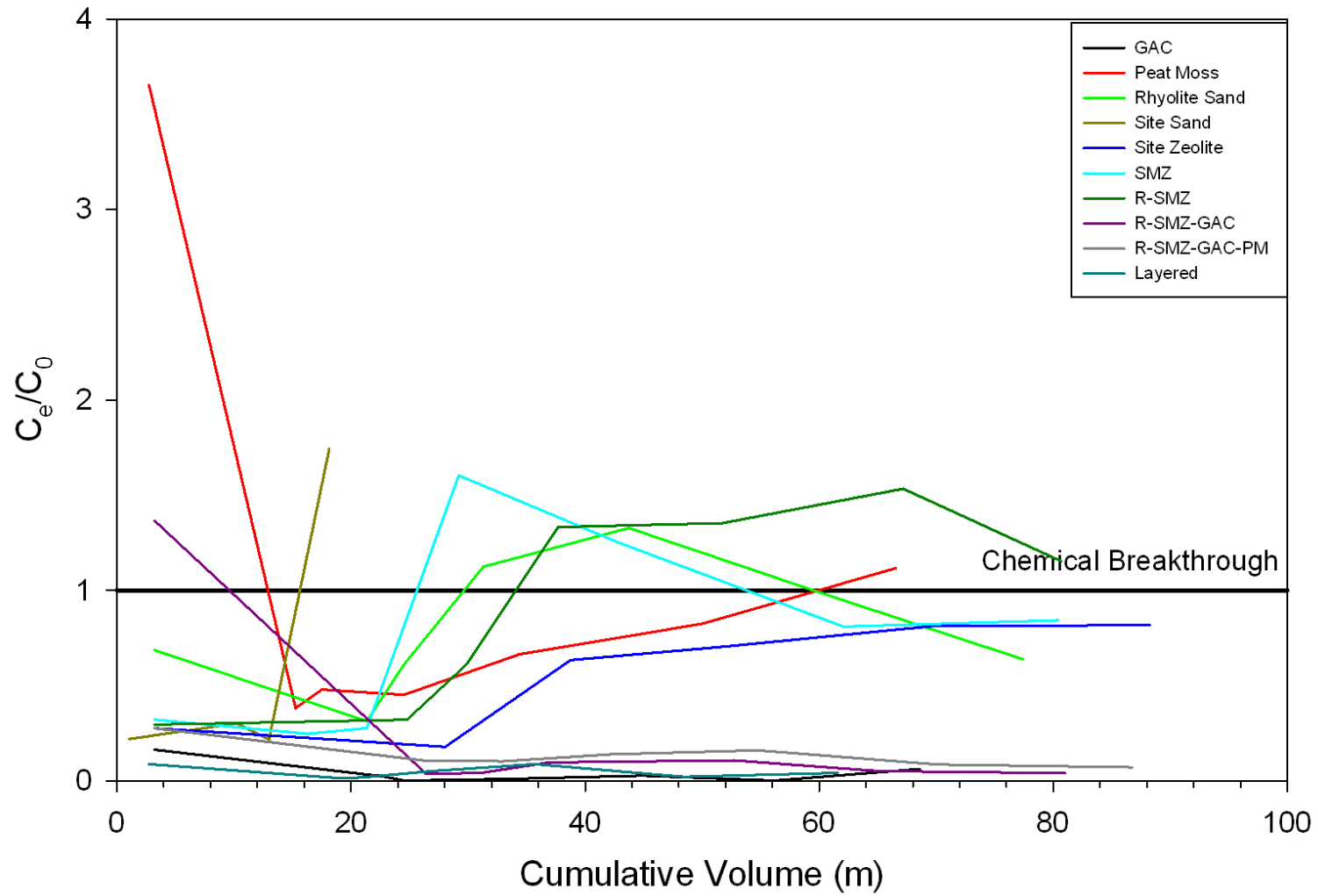


Figure A10-57. Uranium (Total) Normalized Breakthrough Plots

UV-254



UV-254

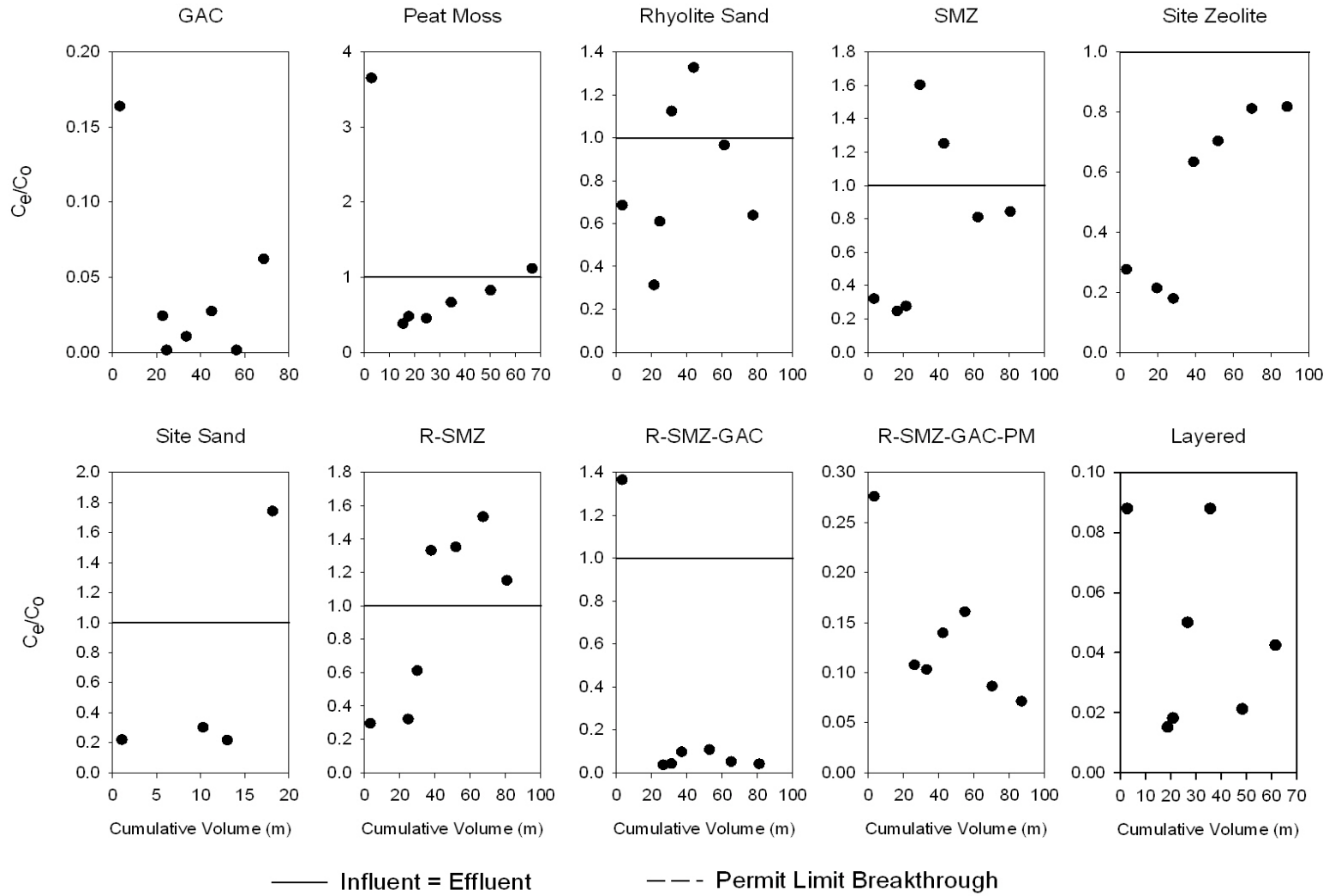
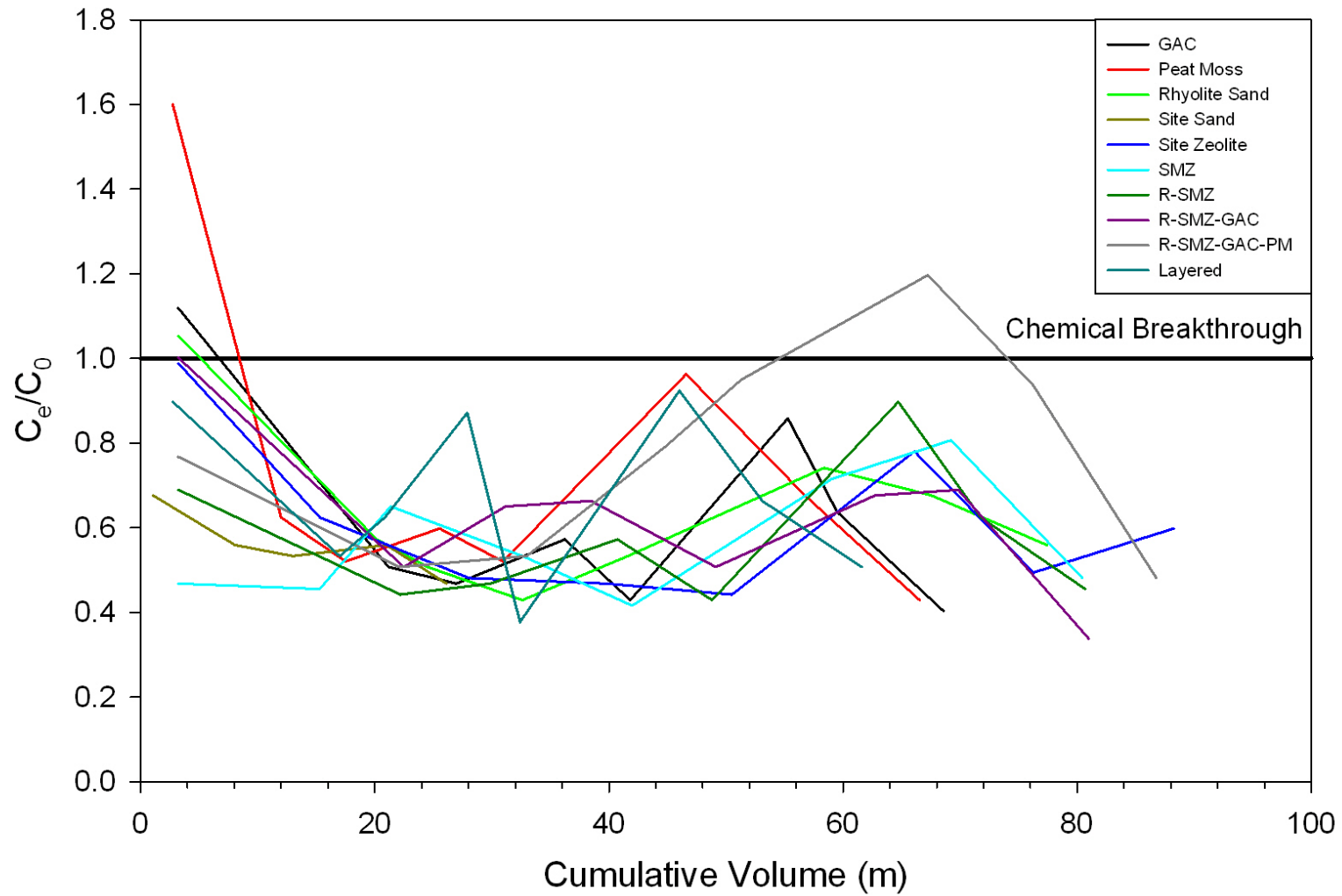


Figure A10-58. UV-254 Normalized Breakthrough Plots

Zinc, Total



ZINC, TOTAL

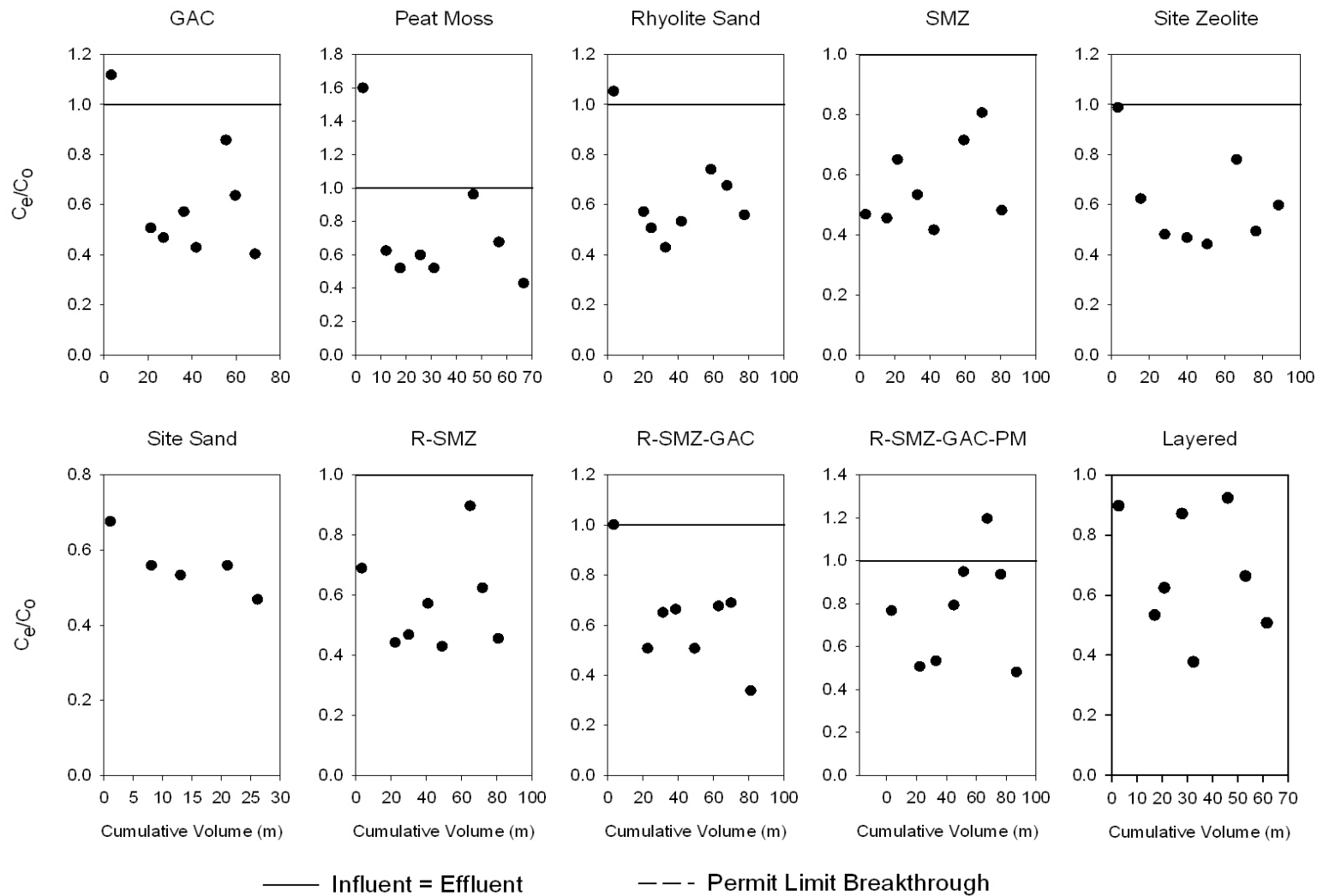


Figure A10-59. Zinc (Total) Normalized Breakthrough Plots

ZINC, FILTERED

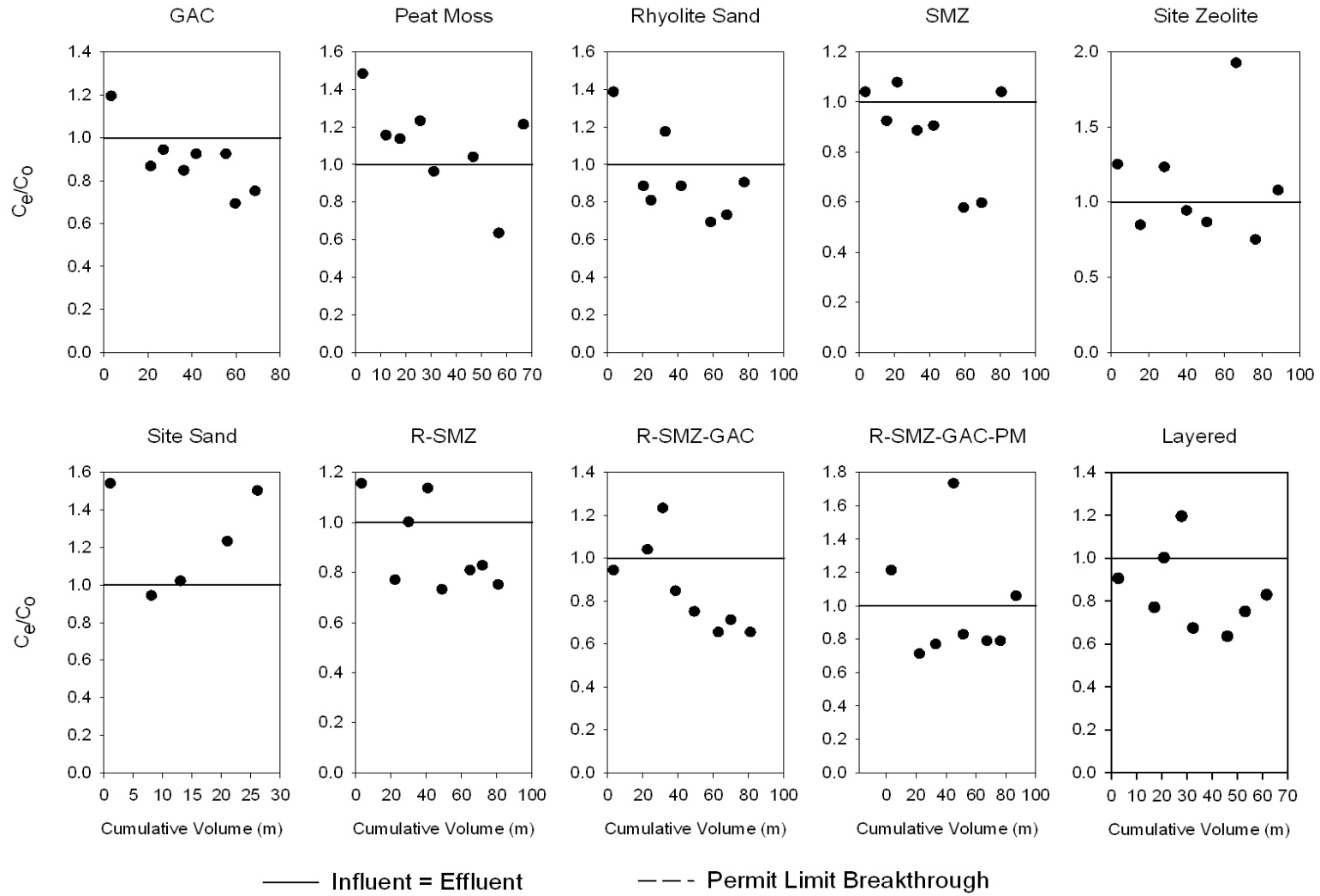


Figure A10-60. Zinc (Filtered) Normalized Breakthrough Plots

Table A10-1. Site Sand: Comparison of Capacities by Testing Method (Long-Term Breakthrough Column Tests vs. Traditional Batch Capacity Tests)

Pollutant	Long-Term Column Breakthrough Testing (mg pollutant/g media)	Batch Testing (mg pollutant/g media)
Arsenic	0.000503	0.220
Aluminum	0.000392	0.00448
Boron	0.000884	0.127
Calcium	0.0610	0.312
Cadmium	0.000590	0.0131
Copper	0.000183	0.001
Iron	0.000516	2.5E-05
Lead	0	0.263
Nickel	0	0.0017
Magnesium	0.000369	0.0175
Manganese	0	0.00174
Zinc	0	0.0120
Potassium	0.000172	-0.0319
Sodium	0.0276	0.0786
Chromium	4.64E-05	0.00185
Thallium	0.00114	0.0132
Antimony	0.000578	0.0200
Nitrite	1.08E-05	
Nitrate	0.0118	0.597
Ammonia	0.00256	0.122
TP	0.00738	0.0898
COD	0.812	2.95
Fluoride	0.00877	2.44
Sulfate	0.0544	0
Phosphate	0.00713	0.0647
TN	0.00650	
Chloride	0	
Hardness	0.0133	

Table A10-2. Rhyolite Sand: Comparison of Capacities by Testing Method (Long-Term Breakthrough Column Tests vs. Traditional Batch Capacity Tests)

Pollutant	Long-Term Column Breakthrough Testing (mg pollutant/g media)	Batch Testing (mg pollutant/g media)
Arsenic	0.00173	0.414
Aluminum	0.000361	0.0169
Boron	-0.00113	0.156
Calcium	0.347	0.233
Cadmium	0.00392	0.0152
Copper	0.000440	0.00154
Iron	-0.000658	0.00673
Lead	0	0.178
Nickel	0	7.33E-05
Magnesium	0.00328	0.00934
Manganese	0	0.00414
Zinc	0	0.00969
Potassium	-0.000219	0.00145
Sodium	-0.0352	-0.249
Chromium	9.89E-05	0.00255
Thallium	0.00913	0.214
Antimony	0.00135	0.0149
Nitrite	-1.378E-05	
Nitrate	0.0264	0.149
Ammonia	0.421	0.0957
TP	0.0641	0.199
COD	8.60	5.48
Fluoride	0.0438	1.35
Sulfate	0.0336	0.491
Phosphate	-0.00909	0.00996
TN	0.542	
Chloride	0	
Hardness	0.158	

Table A10-3. Site Zeolite: Comparison of Capacities by Testing Method (Long-Term Breakthrough Column Tests vs. Traditional Batch Capacity Tests)

Pollutant	Long-Term Column Breakthrough Testing (mg pollutant/g media)	Batch Testing (mg pollutant/g media)
Arsenic	0.00476	5.74
Aluminum	-0.000513	0.0889
Boron	0.000148	0.0551
Calcium	0.761	-1.81
Cadmium	0.00624	0.106
Copper	0.00304	0.00847
Iron	-0.00104	0.0137
Lead	0.321	1.25
Nickel	0.000326	0.0199
Magnesium	0.00400	0.0457
Manganese	0	0.0259
Zinc	0	0.0616
Potassium	-0.000345	0.0300
Sodium	-0.0554	-3.95
Chromium	-7.40E-05	0.0114
Thallium	0.0144	0.350
Antimony	0.00273	0.0865
Nitrite	0.000597	
Nitrate	-0.0119	2.72
Ammonia	0.754	0.397
TP	0.121	2.45
COD	15.6	111
Fluoride	0.0905	6.92
Sulfate	0.124	14.8
Phosphate	0.160	0.0500
TN	0.0580	
Chloride	0	
Hardness	2.94	

Table A10-4. Surface Modified Zeolite: Comparison of Capacities by Testing Method (Long-Term Breakthrough Column Tests, Varying-Depth Column Tests, Traditional Batch Capacity Tests)

Pollutant Capacity (mg pollutant/g media)	Long-Term Column Breakthrough Testing	Short-Term Column - 14" Column	Short-Term Column - 26" Column	Short-Term Column - 38" Column	Batch Testing	Average Capacity	COV
Arsenic	0.00185	-0.00037	-0.00081	-0.00069	5.81	1.16	2.24
Aluminum	1.30E-06	0.0126	0.00577	0.00404	0.0842	0.0213	1.66
Boron	-0.00143	0.00603	0.00300	0.00137	0.156	0.0330	2.09
Calcium	0.185	0.239	0.0241	-0.0188	0.663	0.219	1.24
Cadmium	0.00464	0.00653	0.00252	0.00137	0.0919	0.0214	1.84
Copper	-0.000297	0.0182	0.0113	0.00783	0.00799	0.00899	0.742
Iron	-0.000836	0.00555	0.00244	0.00147	0.0105	0.00383	1.15
Lead	0	0	0	0	0.985	0.197	2.24
Nickel	0	0.00690	0.00386	0.00251	0.00990	0.00465	0.832
Magnesium	0.00449	0.00614	0.00277	0.00160	0.0360	0.010192	1.42
Manganese	0	1.27E-05	5.63E-05	3.69E-05	0.0384	0.00769	2.23
Zinc	0	0.00595	0.00284	0.00240	0.0604	0.0143	1.81
Potassium	-0.000278	-0.00028	-0.00028	-0.00028	0.0299	0.00576	2.35
Sodium	0.0395	-0.0457	-0.0456	-0.0457	0.188	0.0181	5.62
Chromium	4.38E-05	-7.7E-05	9.22E-05	3.37E-05	0.0160	0.00321	2.22
Thallium	0.0108	0.00734	0.00278	0.00126	0.301	0.0647	2.04
Antimony	0.000891	0.00372	0.00107	-3.5E-05	0.111	0.0234	2.10
Nitrite	0.000363	0.000713	0.000211	0.000137		0.000356	0.719
Nitrate	0.0112	0.00016	-0.0110	-0.01249	2.72	0.542	2.25
Ammonia	0.570	0.301	0.144	0.0921	0.155	0.252	0.767
TP	0.0589	-0.0122	-0.0122	-0.0122	2.55	0.514	2.21
COD	8.49	9.22	2.37	1.68	61.9	16.7	1.52
Fluoride	0.0292	-0.00613	0.000781	-0.00982	0.846	0.172	2.19
Sulfate	0.227	-0.0139	-0.0797	-0.0763	-4.95	-0.979	-2.27
Phosphate	-0.00845	-0.0118	-0.0118	-0.0118	0.0300	-0.00277	-6.62
TN	0.0363	0.474	0.276	0.0667		0.213	0.956
Chloride	0	0.00953	0.0103	0.00693		0.00668	0.700
Hardness	0.0246	1.40	0.374	0.287		0.522	1.16

Table A10-5. Granular Activated Carbon: Comparison of Capacities by Testing Method (Long-Term Breakthrough Column Tests, Varying-Depth Column Tests, Traditional Batch Capacity Tests)

Pollutant Capacity (mg pollutant/g media)	Long-Term Column Breakthrough Testing	Short-Term Column - 14" Column	Short-Term Column - 26" Column	Short-Term Column - 38" Column	Batch Testing	Average Capacity	COV
Arsenic	0.00629	-0.00189	-0.00224	-0.00286	2.50	0.500	2.24
Aluminum	0.0125	0.0279	-0.00223	-0.00223	0.143	0.0357	1.71
Boron	0.0368	0.576	0.491	0.976	0.851	0.586	0.623
Calcium	1.19	0.826	1.06	3.67	1.65	1.68	0.685
Cadmium	0.00735	0.0176	0.00786	0.0166	0.253	0.0606	1.78
Copper	0.0127	0.0829	0.0455	0.0837	0.0538	0.0557	0.530
Iron	0.0172	0.0202	0.0100	0.0181	0.0961	0.0323	1.11
Lead	0.00395	0	0	0.0513	0.576	0.126	2.00
Nickel	0.00102	0.0233	0.0132	0.023	0.00175	0.0125	0.875
Magnesium	0.00739	0.0174	0.00849	0.0163	0.116	0.0331	1.41
Manganese	0	0.000324	0.000176	0	0.0513	0.0104	2.21
Zinc	0	0.0238	0.0116	0.0202	0.237	0.0585	1.71
Potassium	-0.00056	-0.00098	-0.00098	-0.00098	-6.92	-1.38	-2.23
Sodium	0.0337	-0.157	-0.157	-0.157	0.0714	-0.0732	-1.58
Chromium	0.00441	0.00201	0.000972	0.00159	0.0172	0.00524	1.30
Thallium	0.0171	0.0209	0.00895	0.0200	0.337	0.0808	1.77
Antimony	0.00826	0.00158	-0.00072	0.00242	0.108	0.0240	1.97
Nitrite	0.000676	0.00199	0.00753	0.00925		0.00486	0.858
Nitrate	1.92	1.46	1.04	2.156	1.72	1.66	0.261
Ammonia	0.866	0.248	0.187	0.475	0.139	0.383	0.781
TP	-0.0241	-0.042	-0.0419	-0.042	0.886	0.147	2.81
COD	20.42	26.3	12.7	25.0	46.8	26.2	0.482
Fluoride	0.0678	0.0286	-0.0130	0.0798	5.17	1.07	2.15
Sulfate	2.20	3.26	3.57	8.18	0.249	3.49	0.837
Phosphate	-0.0233	-0.0406	-0.0405	-0.0406	-0.205	-0.0699	-1.08
TN	3.25	3.16	1.58	3.27		2.81	0.293
Chloride	0.0369	0.0261	0.280	0.410		0.188	1.00
Hardness	1.31	9.16	6.89	19.2		9.15	0.818

Table A10-6. Peat Moss: Comparison of Capacities by Testing Method (Long-Term Breakthrough Column Tests, Varying-Depth Column Tests, Traditional Batch Capacity Tests)

Pollutant Capacity (mg pollutant/g media)	Long-Term Column Breakthrough Testing	Short-Term Column - 14" Column	Short-Term Column - 26" Column	Short-Term Column - 38" Column	Batch Testing	Average Capacity	COV
Arsenic	-0.00492	-0.00381	-0.0039	-0.00423	0.479	0.0924	2.34
Aluminum	-0.00383	-0.00392	-0.00295	-0.00035	-0.102	-0.0227	-1.96
Boron	0.0300	0.0311	0.0107	0.0105	0.422	0.101	1.78
Calcium	21.4	14.3	8.58	5.41	10.7	12.1	0.507
Cadmium	0.0253	0.0339	0.0146	0.00721	2.26	0.468	2.14
Copper	0.0268	0.153	0.0756	0.0505	0.120	0.0850	0.601
Iron	-0.00504	0.00557	-0.00511	-0.00515	0.00025	-0.0019	-2.52
Lead	0.0278	0	0	0	2.49	0.504	2.21
Nickel	0	0.0150	0.00454	0.00516	0.105	0.0259	1.72
Magnesium	0.0235	0.0331	0.0151	0.00822	1.42	0.300	2.09
Manganese	0	0.000613	2.89E-05	0.000198	0.00125	0.000418	1.26
Zinc	0	0.0257	0.0181	0.0120	0.763	0.164	2.05
Potassium	0.00567	-0.00172	-0.0017	-0.00171	0.115	0.0232	2.28
Sodium	-0.270	-0.276	-0.274	-0.276	0.272	-0.165	-1.48
Chromium	0.0117	0.00260	0.00126	0.000429	-0.0524	-0.00728	-3.52
Thallium	0.0502	0.0207	0.0102	0.00565	0.736	0.165	1.94
Antimony	0.0495	0.0322	0.0152	0.00832	0.112	0.0435	0.957
Nitrite	-0.00011	0.0287	0.0185	0.00972		0.0142	0.866
Nitrate	-0.0771	-0.0616	-0.103	-0.0406	3.49	0.642	2.48
Ammonia	0.169	0.125	-0.0112	0.00210	0.0998	0.0768	1.02
TP	-0.0721	0.0940	-0.0732	-0.0200	-0.0998	-0.0342	-2.26
COD	-7.94	34.8	15.8	-7.32	-26.7	1.72	13.9
Fluoride	0.969	1.13	0.484	0.321	1.55	0.890	0.557
Sulfate	-0.532	0.645	-0.250	-0.523	0.125	-0.107	-4.66
Phosphate	-0.0697	0.0482	-0.0707	-0.0711	0.0998	-0.0127	-6.40
TN	0.159	0.0270	0.0677	0.0855		0.0847	0.649
Chloride	0	0.134	0	0.335		0.117	1.35
Hardness	47.4	45.8	22.5	15.5		32.8	0.494