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TECHNICAL MEMORANDUM

To:	Caryn Kiehl-Simpson and Ed Glaza (Parsons)	**Date:**	October 19, 2011
From:	Dimitri Vlassopoulos, Jessica Goin, and Minna Swanson-Theisen (Anchor QEA)	**Project:**	110139-01.01
Re:	Onondaga Lake Siderite Column Studies Data Report		

This memorandum has been prepared by Anchor QEA for Parsons and Honeywell as a summary of results of column testing conducted to evaluate siderite amendment of a sediment cap for neutralizing hyperalkaline (high pH) porewaters at Onondaga Lake. The text is organized into five sections: 1) Background and Objectives, 2) Materials and Methods, 3) Results and Discussion, and 4) Conclusions.

BACKGROUND AND OBJECTIVES

Previous pre-design work included laboratory batch tests and cap pH modeling to determine performance characteristics and a minimum required siderite mass application rate to meet both long-term and short-term cap pH neutralization effectiveness criteria (SSPA 2009a, 2009b). Batch testing and modeling of porewater pH neutralization by a siderite-amended sediment cap indicated that reactivity and longevity requirements could be met with a relatively low siderite application rate of 1.14 lbs/sq ft. (2 percent by weight in the siderite-amended sand layer).

To ensure the predicted level of reaction would occur under field conditions in the siderite amended sand cap it was considered necessary to evaluate potential pore-scale limitations to reactivity that might affect performance. At low mass amendment rates, less siderite than the bulk average may be encountered along some porewater flow paths, such that pH neutralization under field conditions may be less complete than predicted by the cap pH model. It is presently difficult to evaluate a priori whether pore-scale effects will be important at the recommended 2 percent siderite mass application rate. The simplest and most reliable way to perform this evaluation was through laboratory column testing.

The primary objective of the column testing was to provide information on potential pore scale effects on effectiveness of siderite at low dosages (less than 10%) that would need to be considered in up-scaling from laboratory to field-scale application of siderite amendment to sediment capping at Onondaga Lake.

MATERIALS AND METHODS

Column testing was carried in general accordance with the Phase VI Addendum 2 pH Column Studies Work Plan submitted to NYSDEC (Parsons 2010). The following modifications to procedures outlined in the Work Plan were implemented:

- Column tests were only carried out with a 6-inch siderite-amended layer as opposed to columns with both 3-inch and 6-inch thick amendment layers as originally proposed. This was based on a decision by the design team that a 6-inch thick amendment layer would be employed in the cap. Therefore, five columns were initially assembled: 2% , 5% and 10% siderite-amended sand, one control (no siderite), and one replicate (5% siderite)
- Site porewater collected from TR-05B was used for the column tests.
- The five columns were packed with sand supplied from a local quarry in the Syracuse area (provided to Anchor QEA by Parsons), which was selected as a potential source for cap material. These columns are designated "siderite-quarry sand columns" (Figure 1). Hyperalkaline porewater was pumped through the columns in upflow mode at a flow rate expected to provide complete pH neutralization within the pore volume of the siderite-amended layer (9 mL per day), and pH profiles were periodically monitored across the amendment layer. During these column tests, significant porewater pH reduction was observed in both the control column as well as in the test columns below the amendment layer, indicating that some of the pH neutralization was due to the sand material itself, which complicated interpretation of the data to evaluate siderite performance. The initial column tests were discontinued after approximately 0.5 pore-volumes.
- To confirm that part of the observed pH neutralization in the siderite-quarry sand columns was attributable to siderite, a stop-flow test was conducted. Four of the columns (control, 2%, 5%, and 10% siderite) were completely flushed with high-pH porewater and then closed to flow. Porewater pH profiles were measured periodically and used to compare the rate at which pH was neutralized at different siderite dosages relative to the control column. Monitoring continued for approximately four months, until the pH within the amendment layer in the 2% siderite-amended column was reduced below 8.

- Additional column tests were conducted to address the original objective of evaluating pore-scale effects on siderite performance. Three additional columns were assembled with a high purity silica sand (control, 2%, and 5% siderite). These columns are designated "siderite-Accusand columns" (Figure 2). These columns were operated in upflow mode at a flow rate expected to provide complete pH neutralization within the pore volume of the siderite-amended layer (9 mL per day), and pH profiles were periodically monitored across the amendment layer. The siderite-Accusand column tests were operated until breakthrough of pH greater than 8 was observed in the control column at the first sampling port above the height corresponding to the top of the amendment layer in the siderite-amended columns.
- Column effluent solutions were not monitored.
- Post column-test sampling and characterization of column bed solids was not performed because no evidence of clogging was observed during operation of the columns.
- The mineralogical composition of quarry sand was determined to confirm the presence of aluminosilicate minerals with intrinsic pH-buffering capacity.

Column Assembly

The columns were constructed of cast acrylic pipe 4¾ inches internal diameter (ID) by 18 inches long with threaded holes for sampling ports located at 1-inch intervals between 2 and 16 inches from the column base.

The siderite-quarry sand columns consisted of three 6-inch thick layers – a lower layer of sand, a middle layer containing siderite-amended sand dosed at either 0 (control), 2, 5, or 10 weight percent siderite (dry weight basis), and an upper layer of sand. The siderite was sieved (1-2 mm grain size) and rinsed prior to use. Sampling ports were installed at 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 16 inches above the column base in the siderite-amended columns and at 2, 5, 7, 9, 11, 13, 15, and 16 inches in the control column. The quarry sand as-received contained more than 20 % of silt and clay-sized particles (Table 1). Preliminary tests using a syringe to extract porewater from the packed sand indicated that porewater sampling would not be feasible due to the high clay content. The sand was therefore sieved (No. 18 sieve) to remove particles less than 1 millimeter (mm) in diameter. Prior to use in the columns, the sand was also rinsed to remove fines from the retained particles. Column packing proceeded in lifts of 1 to 2 inches at a time, maintaining 2 to 4 inches of standing water above the top of the packed material at all times.

The siderite-Accusand columns were assembled using a high-purity silica sand (Accusand 20/30, Unimin Co.; comprised of 99.8 percent rounded quartz grains, sorted to a coarse sand size [0.5-0.85 mm]). These columns also consisted of three layers – a lower 4-inch thick layer of sand, followed by a 6-inch thick layer containing siderite-amended sand dosed at either 0 (control), 2, or 5 weight percent siderite (dry weight basis), and an upper 8-inch layer of polypropylene beads. Sampling ports were installed at 1 inch intervals from 2 to 14 inches from the column base.

Characterization of Column Hydraulic and Transport Properties

The saturated hydraulic conductivity of the packed columns was estimated from constant flow head loss measurements. Hydraulic conductivity (K, in cm/s) was calculated from:

$$K = \frac{\Delta h}{\Delta l} \times \frac{Q}{A}$$

where Q is volumetric flow rate (cm^3/s), A is the column cross-sectional area (cm^2), Δh is the measured head loss (cm) and Δl is the distance (cm) across which head loss is measured. Head loss tests were conducted by pumping tap water through each column at a constant flow rate and measuring the difference in water levels of two vertical, narrow tubes attached to the sampling ports at 2 inches and 16 inches along the column and open to the atmosphere at the other end. measuring the height of water in each for a specific flow rate. To assess reproducibility, a minimum of three replicate measurements were made at each flow rate.

A salt tracer test was also carried out for each column to provide baseline estimates of effective porosity and longitudinal dispersion coefficient. Tap water was initially pumped through the column at a constant flow rate (approximately 250 mL/minute) for several minutes, followed by injection of a pulse of a sodium chloride solution at the same flow rate, after which the influent was switched back to tap water. Tracer breakthrough curves were obtained by continuous recording of salt concentrations in column effluent with a calibrated salinity probe. For each test, the linear velocity (v) and dispersion coefficient (D) were estimated by fitting the tracer concentration breakthrough curves to the one-dimensional advection-dispersion equation:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x}$$

Effective porosity (n_e) was then calculated from

$$n_e = \frac{Q}{A \times v}$$

Column Operation

The siderite-quarry sand columns were initially completely flushed with neutral pH tap water. This was followed by slowly pumping sufficient Onondaga Lake hyperalkaline porewater (over a period of approximately 48 hours) to displace the water in the column up to the base of the siderite-amended layer. The influent pump was then set to a constant flow rate of 9.0 mL per day. Porewater in the columns was monitored by periodically extracting samples from the sampling ports using 3-mL disposable syringes and measuring pH and conductivity with calibrated microelectrodes.

The siderite-quarry sand flow-through column tests were initially monitored for 28 days, after which time the flow was stopped. The columns were flushed with hyperalkaline porewater to displace the tap water, and a test was conducted to determine whether pH-buffering by sand versus siderite could be discriminated under stop-flow conditions. Monitoring continued for an additional 121 days under stopped-flow conditions.

The siderite-Accusand columns were monitored over a period of 84 days with an influent flow rate of 9.0 mL per day. The porewater travel time through the siderite-amended layer in these columns was 57±1 days.

RESULTS AND DISCUSSION

Initial Column Characterization

The hydraulic conductivity of each of the packed columns is summarized in Table 2. Hydraulic conductivities for both the quarry sand and Accusand were generally quite high, reflecting the coarse and relatively uniform grain-size of the material. Head-loss measurements were not repeated after the column tests were completed as there were no indications of clogging.

Column effective porosities and dispersivities derived from tracer testing are also summarized in Table 2. Details of model fits to the tracer breakthrough curve are provided in Appendix A.

Influent Porewater Quality

The pH, conductivity, oxidation-reduction potential (ORP), and dissolved oxygen (DO) levels in the influent reservoir were monitored over the course of the study (Table 3). Porewater pH remained relatively stable and close to 12 (11.87±0.22) for the duration of the testing.

Siderite-Quarry Sand Column Tests

The initial column test measurements for pH and conductivity are summarized in Tables 4 and 5, respectively, and porewater pH profiles in each of the columns are presented graphically in Figures 3 to 7. From the first profile taken at day 3, all of the columns showed significant porewater pH reductions within the lower sand layer beneath the amended layer relative to the influent pH. This was even observed in the control column, and indicates that the sand is partially neutralizing the porewater pH.

Porewater pH within the amended layer (from 6 to 12 inches height) was consistently between 7 and 8 in all the siderite-containing columns through day 28. At 28 days, if no neutralization had occurred, the high pH porewater front would have advanced approximately 2 inches into the siderite-amended layer. In the control column, porewater pH was less than 8 at 5 inches (corresponding to 1 inch below the base of the amended layer in the siderite-containing columns) and above at 3, 7 and 14 days. The pH buffering capacity of the sand is limited, however, as evidenced by porewater pH values greater than 8 detected above 6 inches in the control column at day 28.

The mineralogy of the quarry sand was analyzed by powder X-ray diffraction (XRD) to determine the nature of the pH-buffering components. The bulk material was separated by into two grain size fractions: coarse (greater than 1 mm) and fine (less than 1 mm) prior to analysis. The coarse fraction is representative of the material used to pack the columns. Results are summarized in Table 6 and the report is provided as Appendix B. In addition to quartz, aluminosilicate minerals, including 17% feldspars (albite and microcline) and 15%

clay minerals (muscovite/illite and chlorite) are abundant in the coarse fraction. Microcline, illite, and quartz form a pH-buffering assemblage which would tend to regulate pH to values between 8 and 10 at equilibrium, depending on silica and potassium concentrations. Due to very slow reaction kinetics with porewater, only partial pH buffering may be achieved, especially under flow conditions.

Recognizing that pH-buffering by the sand complicates the interpretation of the siderite column test data under flow conditions, the test was discontinued after 28 days. The columns were flushed with hyperalkaline porewater, and a test was conducted to determine whether pH-buffering by sand versus siderite could be discriminated under stop-flow conditions. Specific conductivity and pH profiles were monitored over a period of 121 days. The data are presented in Tables 7 and 8, and pH profiles for columns A (control), B (10% siderite), C (5% siderite), and E (2% siderite) are shown in Figures 8 through 11, respectively.

The control column showed a decline in pH over 57 days, after which little change there was little change. At 121 days, the pH remained above 8.0 within the 6-inch interval corresponding to the siderite-amended layer in the other columns (Figure 8). The 10% and 5% siderite-amended columns exhibited a rapid pH decrease within the amended layer during the first 8 days, and then a more gradual but continuing decrease. The 10% siderite column attained pH less than 8.0 throughout the amended within 87 days (Figure 9). The 5% siderite column attained pH less than 8.0 throughout the amended layer, except for the first monitoring point, between 87 and 121 days (Figure 10). The 2% siderite column showed a steady decrease in pH within the amended layer, with pH consistently stabilizing less than 8.0 throughout the amended layer by 121 days (Figure 11).

The stop-flow test data clearly document the effect of siderite in buffering porewater pH to values between 7 and 8. Furthermore, pore-scale effects appear to be negligible in the siderite-quarry sand columns, even at the lowest siderite dose of 2%. From this data alone, however, it is not possible to determine to what extent this is due to the moderating effect of the pH-buffering by the sand.

Siderite-Accusand Column Tests

The siderite-Accusand columns were operated with an influent flow rate of 9.0 mL per day and monitored until porewater pH in the control column was greater than 8.0 within the entire interval corresponding to the position of the siderite-amended layer in the other columns. This period of 84 days of operation corresponds to approximately 1.5 pore volumes of flow through the amended layer. The porewater pH and specific conductivity data are summarized in Tables 9 and 10, respectively, and pH profiles for columns G (control), H (5% siderite), and I (2% siderite) are presented in Figures 12 through 14, respectively.

The porewater pH front advanced through the control column gradually but continuously over the duration of the test (Figure 12). The decrease in the pH in the control column at 84 days in the 4 to 10 inch column height interval is associated primarily with longitudinal dispersion and mixing of the hyperalkaline porewater with the tap water as the tap water is gradually displaced from this interval. Both the 5% (Figure 13) and 2% (Figure 14) siderite columns, in contrast, achieved pH buffering between 7.0 than 8.0 within the first three inches of transport through the siderite-amended layer at 84 days. This confirms that pore-scale effects on siderite reactivity are negligible for doses as low as 2% in a 6-inch thick amended layer.

CONCLUSIONS

Porewater pH neutralization and buffering by siderite was not limited by pore-scale effects, for doses as low as 2 percent by weight distributed within a 6-inch thick siderite-amended sand layer. This conclusion is considered to be robust, as it was demonstrated experimentally by column tests with travel times through the siderite layer that are approximately an order of magnitude faster than expected porewater upwelling rates within the sediment cap at Onondaga Lake. The slower travel times in the cap would provide for additional mitigation of pore-scale effects by diffusion. It is also recognized that aluminosilicate minerals present in the sand used for the cap may provide some additional benefit with regards to pH neutralization, although this is not a specific cap design objective.

REFERENCES

Parsons, 2010. Phase VI Addendum 2 pH Column Studies Work Plan. Prepared for Honeywell.

S.S. Papadopulos & Associates (SSPA), 2009a. ILWD Porewater pH Neutralization Batch Studies. Memorandum dated September 22, 2009. Prepared for Parsons.

SSPA, 2009b. ILWD Porewater pH Neutralization Geochemical Modeling Study. Memorandum dated December 3, 2009. Prepared for Parsons.

ATTACHMENTS

Tables

Figures

Appendix A

Column Tracer Test Results

Appendix B

XRD Report

TABLES

Table 1
Grain Size Analysis of Quarry Sand

Sieve Size (Standard)	Size (mm)	Percent Retained
4	4.75	16.1
10	2	33.9
18	1	10.5
35	0.5	8.7
60	0.25	4.6
120	0.125	2.3
	<0.125	23.9
Sum		100

Table 2
Hydraulic and Transport Properties of Siderite Columns

Column	Media	Siderite Dose	Hydraulic Conductivity	Dispersion Coefficient	Effective Porosity
		weight percent	cm/s (sd)	cm^2/s	-
A	Quarry Sand	0 (control)	170 (60)	0.058	0.438
B		10	240 (70)	0.070	0.440
C		5	190 (50)	0.069	0.460
D		5	270 (60)	0.061	0.469
E		2	280 (70)	0.066	0.435
G	Accusand	0 (control)	330 (40)	0.089	0.303
H		5	290 (50)	0.091	0.295
I		2	250 (40)	0.104	0.299

Table 3
Influent Water Quality Parameters

Date	pH	SC (uS/cm)	ORP (mV)	DO (mg/L)
1/21/11	11.60	13,000	-150	0.8
2/4/11	12.20	11,500	-40	-
2/16/11	12.10	10,900	-68	-
2/22/11	12.10	10,900	-73	0.9
5/19/11	11.86	10,500	-64	1.1
6/16/11	11.86	11,100	-59	1.2
6/23/11	11.81	8,520	-61	1.2
7/13/11	11.78	9,360	-67	1.4
8/10/11	11.70	9,260	-65	1.1

Notes:
SC = specific conductance
uS/cm = microsiemens per centimeter
ORP = oxidation-reduction potential
mV= millivolts
DO = dissolved oxygen
mg/L = milligrams per liter

Table 4
Siderite-Quarry Sand Column Test pH Data

Column	Date	Day	Column Inlet	Column Port (inches above base)													
				2	3	4	5	6	7	8	9	10	11	12	13	15	16
A	1/24/11	3	12.05	9.07	-	-	7.52	-	7.80		8.05	-	7.75	-	6.64	-	7.08
	1/28/11	7	-	9.05	-	-	7.81	-	7.58		7.16	-	7.44	-	7.30	-	6.91
	2/4/11	14	12.20	10.06	-	-	7.76	-	7.55		7.31	-	7.60	-	7.61	-	7.71
	2/18/11	28	-	10.93	-	-	9.80	-	9.36		8.32	-	7.11	-	7.26	-	7.61
B	1/24/11	3	12.05	9.02	8.19	7.96	7.39	7.32	7.36	7.49	7.52	7.77	7.62	7.77	-	-	-
	1/28/11	7	-	8.96	8.32	7.93	7.61	7.61	7.70	7.53	7.43	7.51	7.49	7.56	-	-	-
	2/4/11	14	12.20	9.42	9.23	9.02	7.88	7.87	7.57	7.53	7.44	7.69	7.57	7.45	-	-	-
	2/18/11	28	-	8.92	8.48	7.98	7.66	7.47	7.48	7.53	7.26	7.39	7.40	7.59	-	-	-
C	1/24/11	3	12.05	9.17	8.73	8.32	8.00	7.46	7.45	7.53	7.73	7.77	7.81	7.77	-	-	-
	1/28/11	7	-	8.95	8.85	8.18	7.68	7.40	7.36	7.45	7.49	7.42	7.50	7.46	-	-	-
	2/4/11	14	12.20	9.51	9.33	9.42	9.30	8.38	7.56	7.66	7.74	7.84	7.84	7.99	-	-	-
	2/18/11	28	-	8.93	8.65	8.22	8.00	7.71	7.38	7.34	7.48	7.55	7.66	7.83	-	-	-
D	1/24/11	3	12.05	9.42	8.49	8.21	7.53	7.29	7.30	7.46	7.69	7.64	7.51	7.48	-	-	-
	1/28/11	7	-	8.97	8.40	7.89	7.54	7.43	7.48	7.53	7.47	7.54	7.38	7.54	-	-	-
	2/4/11	14	12.20	9.62	9.39	8.85	8.58	7.40	7.37	7.46	7.43	7.24	7.25	7.37	-	-	-
	2/18/11	28	-	9.70	9.14	8.75	8.58	8.02	7.91	7.89	7.90	7.96	7.85	7.79	-	-	-
E	1/24/11	3	12.05	9.19	8.45	7.82	7.32	7.22	7.27	7.46	7.65	7.88	7.41	7.64	-	-	-
	1/28/11	7	-	8.86	8.08	7.97	7.49	7.29	7.30	7.47	7.42	7.46	7.44	7.46	-	-	-
	2/4/11	14	12.20	10.26	9.90	9.49	8.84	7.95	7.68	7.66	7.67	7.47	7.55	7.62	-	-	-
	2/18/11	28	-	9.63	8.92	8.29	7.87	7.77	7.76	7.82	7.90	7.71	7.69	-	-	-	-

Notes:
Flow rate: 9.0 mL per day

Table 5
Siderite-Quarry Sand Column Test Specific Conductivity Data

Column	Date	Day	Column Inlet	Column Port (inches above base)													
				2	3	4	5	6	7	8	9	10	11	12	13	15	16
A	1/28/11	7	13,000	9,720	-	-	8,340	-	414	-	505	-	245	-	259	253	259
	2/18/11	28	10,900	7,340	-	-	7,320	-	8,310	-	5,830	-	1,700	-	132	103	82.0
B	1/28/11	7	13,000	9,950	9,850	9,470	8,700	6,490	2,960	2,070	946	611	593	522	-	-	433
	2/18/11	28	10,900	8,010	7,620	7,070	6,190	5,090	3,640	2,780	1,880	1,130	786	604	-	-	-
C	1/28/11	7	13,000	10,200	10,100	9,970	9,700	9,120	8,120	5,670	3,000	1,210	615	447	-	-	840
	2/18/11	28	10,900	8,880	8,530	8,210	7,410	6,400	5,560	4,170	2,920	1,940	1,380	872	-	-	-
D	1/28/11	7	13,000	10,000	10,000	9,880	9,450	8,600	6,910	4,310	2,350	877	572	440	-	-	440
	2/18/11	28	10,900	8,920	8,700	8,770	8,680	8,620	7,680	6,310	5,120	3,470	2,470	1,240	-	-	341
E	1/28/11	7	13,000	10,050	9,930	9,830	9,490	8,840	7,430	4,920	2,530	922	503	363	-	-	354
	2/18/11	28	10,900	9,420	9,320	9,470	9,700	8,690	7,860	6,690	5,250	3,720	2,350	-	-	-	346

Notes:
Flow rate: 9.0 mL per day
Unit of measure for specific conductance: microsiemens per centimeter (uS/cm)

Table 6
Mineralogy of Quarry Sand

Mineral	Abundance	
	coarse fraction (>1 mm)	fine fraction (<1 mm)
Quartz	68%	69%
Albite	14%	15%
Microcline/Orthoclase	3%	8%
Muscovite/Illite	7%	4%
Chlorite	8%	3%
Amphibole	-	1%

Table 7
Siderite-Quarry Sand Column Stop-Flow Test pH Data

Column	Date	Day	Column Inlet	Column Port (inches above base)													
				2	3	4	5	6	7	8	9	10	11	12	13	15	16
A	2/23/11	2	12.10	10.76	-	-	10.22	-	10.06	-	9.67	-	9.19	-	9.27	9.07	9.16
	3/2/11	8	-	10.15	-	-	9.58	-	9.31	-	9.00	-	8.68	-	8.43	8.21	8.43
	3/9/11	15	-	10.18	-	-	9.64	-	9.28	-	9.03	-	8.60	-	8.27	8.32	8.33
	3/23/11	29	-	9.88	-	-	9.37	-	8.86	-	8.55	-	8.27	-	8.17	8.00	7.98
	4/20/11	57	-	9.61	-	-	8.99	-	8.64	-	8.39	-	8.26	-	8.22	8.02	8.10
	5/20/11	87	-	9.60	-	-	9.01	-	8.66	-	8.33	-	8.01	-	7.96	7.78	7.63
	6/23/11	121	11.81	9.41	-	-	8.92	-	8.55	-	8.33	-	8.08	-	8.08	-	8.02
B	2/23/11	2	12.10	10.61	10.49	10.18	9.87	9.66	9.55	9.42	9.43	9.30	9.20	9.23	-	-	8.94
	3/2/11	8	-	10.24	10.02	9.73	9.38	8.93	8.87	8.84	8.68	8.68	8.57	8.55	-	-	8.36
	3/9/11	15	-	9.99	9.70	9.40	9.09	8.85	8.64	8.55	8.51	8.47	8.37	8.36	-	-	8.14
	3/23/11	29	-	9.70	9.50	9.20	9.01	8.70	8.50	8.48	8.35	8.21	8.23	8.27	-	-	8.28
	4/20/11	57	-	9.46	9.32	9.00	8.71	8.34	8.16	8.00	8.09	7.99	7.91	7.92	-	-	7.92
	5/20/11	87	-	9.20	9.04	8.76	8.48	8.17	7.96	7.87	7.72	7.77	7.72	7.65	-	-	7.53
	6/23/11	121	11.81	9.05	8.96	8.61	8.38	8.04	7.79	7.77	7.72	7.73	7.77	7.80	-	-	7.89
C	2/23/11	2	12.10	10.89	10.66	10.43	10.09	9.70	9.70	9.57	9.50	9.41	9.36	9.52	-	-	9.16
	3/2/11	8	-	10.31	10.04	9.67	9.43	9.19	9.02	8.85	8.71	8.60	8.53	8.43	-	-	8.41
	3/9/11	15	-	10.02	9.90	9.60	9.26	9.05	8.82	8.62	8.47	8.38	8.31	8.08	-	-	8.09
	3/23/11	29	-	9.88	9.77	9.51	9.28	8.99	8.68	8.50	8.33	8.33	8.16	8.04	-	-	8.01
	4/20/11	57	-	9.84	9.57	9.34	8.94	8.60	8.36	7.87	7.82	7.75	7.72	7.70	-	-	7.61
	5/20/11	87	-	9.59	9.24	9.24	8.96	8.63	8.33	8.01	7.69	7.77	7.66	7.78	-	-	7.70
	6/23/11	121	11.81	9.64	9.36	9.13	8.86	8.67	8.38	8.09	7.82	7.75	7.70	7.65	-	-	7.33
E	2/23/11	2	12.10	10.13	10.01	9.90	9.65	9.61	9.59	9.53	9.36	9.37	9.30	9.12	-	-	8.88
	3/2/11	8	-	9.95	9.66	9.51	9.39	9.44	9.30	9.31	9.13	8.93	8.97	8.81	-	-	8.43
	3/9/11	15	-	9.80	9.50	9.32	9.22	9.15	9.12	9.18	9.04	8.82	8.74	8.52	-	-	8.25
	3/23/11	29	-	9.73	9.46	9.09	9.00	8.92	8.88	8.82	8.57	8.29	8.30	8.33	-	-	8.32
	4/20/11	57	-	9.52	9.27	9.03	8.84	8.75	8.58	8.48	8.28	8.08	8.05	8.02	-	-	7.82
	5/20/11	87	-	9.25	8.96	8.88	8.75	8.55	8.30	8.28	8.12	7.99	8.02	7.95	-	-	7.90
	6/23/11	121	11.81	9.08	8.95	8.74	8.50	8.08	7.90	7.91	7.83	7.78	7.84	7.82	-	-	7.63

Table 8
Siderite-Quarry Sand Column Stop-Flow Test Specific Conductivity Data

Column	Date	Day	Column Inlet	Column Port (inches above base)													
				2	3	4	5	6	7	8	9	10	11	12	13	15	16
A	2/23/11	2	8,700	8,960	-	-	9,090	-	8,910	-	8,570	-	7,470	-	8,220	7,060	8,080
	3/2/11	8	-	8,830	-	-	8,730	-	8,590	-	8,460	-	8,300	-	8,310	8,630	7,830
	3/9/11	15	-	8,950	-	-	8,860	-	8,740	-	8,710	-	8,490	-	8,550	8,460	8,280
	3/23/11	29	-	8,390	-	-	8,390	-	8,260	-	8,060	-	7,990	-	7,990	7,740	7,660
	4/20/11	57	-	9,060	-	-	9,020	-	7,980	-	8,660	-	8,700	-	8,620	8,540	8,780
	6/23/11	121	-	9,270	-	-	9,080	-	8,940	-	8,900	-	8,760	-	8,530		7,890
B	2/23/11	2	8,710	8,580	8,660	8,220	8,190	7,670	7,420	8,200	8,050	7,260	6,770	8,690	-	-	7,980
	3/2/11	8	-	9,040	8,730	8,750	8,750	8,760	8,760	8,720	8,670	8,460	8,450	8,450	-	-	8,260
	3/9/11	15	-	8,830	8,940	8,920	8,970	8,880	8,830	8,920	8,780	8,810	8,780	8,830	-	-	8,510
	3/23/11	29	-	8,640	8,840	8,930	8,890	8,760	8,840	8,550	8,800	8,510	8,550	8,640	-	-	8,430
	4/20/11	57	-	8,900	8,820	8,820	8,780	8,820	8,900	8,980	8,940	8,900	9,020	8,860	-	-	8,180
	6/23/11	121	-	9,270	9,060	9,100	8,980	8,740	8,730	8,600	8,530	8,390	8,310	8,230	-	-	7,620
C	2/23/11	2	8,740	9,160	9,000	8,930	8,760	8,280	8,400	8,460	8,500	8,190	8,510	8,710	-	-	8,290
	3/2/11	8	-	8,730	8,810	8,800	8,810	8,690	8,700	8,660	8,550	8,400	8,470	8,390	-	-	8,180
	3/9/11	15	-	9,210	9,140	8,980	8,980	8,880	8,900	8,960	8,950	8,890	8,860	8,710	-	-	8,480
	3/23/11	29	-	9,090	9,180	8,890	8,840	8,930	9,050	8,890	8,800	8,720	8,640	8,510	-	-	8,140
	4/20/11	57	-	9,100	9,100	9,060	9,100	9,140	9,140	9,140	9,140	9,020	9,140	8,700	-	-	8,700
	6/23/11	121	-	9,200	9,160	9,040	9,180	9,040	9,220	8,920	8,850	8,790	8,840	8,480	-	-	8,120
E	2/23/11	2	8,930	9,010	8,900	8,820	8,810	8,820	8,710	8,700	8,200	8,430	8,350	7,700	-	-	7,850
	3/2/11	8	-	8,830	9,030	8,830	8,760	8,810	8,740	8,770	8,690	8,730	8,690	8,530	-	-	8,350
	3/9/11	15	-	8,880	8,940	8,920	9,030	9,000	8,980	9,020	8,970	8,810	8,820	8,820	-	-	8,560
	3/23/11	29	-	8,930	8,890	8,970	8,890	8,890	8,840	8,800	8,840	8,840	8,760	8,720	-	-	8,300
	4/20/11	57	-	9,340	9,100	9,060	9,060	9,020	9,020	9,220	9,100	9,260	9,340	8,940	-	-	7,860
	6/23/11	121	-	9,170	9,090	9,030	8,990	8,980	8,940	8,850	8,900	8,960	8,930	8,880	-	-	8,060

Note:
Unit of measure for specific conductance: microsiemens per centimeter (uS/cm)

Table 9
Siderite-Accusand Column Test pH Data

Column	Date	Day	Column Inlet	Column Port (inches above base)											
				2	3	4	5	6	7	8	9	10	11	12	14
G	5/19/11	1	11.86	11.6	11.6	10	7.2	7.2	6.15	-	-	-	-	-	-
	6/16/11	28	11.86	10.99	11.11	10.52	10.1	9.48	9.16	8.36	6.5	6.07	5.9	6.39	6.37
	7/13/11	56	11.78	10.95	10.79	10.54	10.09	9.55	9.31	9.18	8.55	7.92	6.86	6.64	6.3
	8/10/11	84	11.70	11.39	11.27	11.04	10.65	10.04	9.7	9.38	8.89	8.78	8.29	8.14	7.34
H	5/19/11	1	11.86	11.9	11.6	10.1	6.9	7.3	6.15	-	-	-	-	-	-
	6/16/11	28	11.86	10.95	10.55	9.56	8.67	7.8	6.67	6.35	6.13	6.23	5.98	5.97	5.92
	7/13/11	56	11.78	10.15	9.67	9.03	8.44	7.96	7.39	7.19	7.07	6.89	6.78	6.33	6.54
	8/10/11	84	11.70	10.67	10.18	9.49	8.79	8.44	7.95	7.78	7.39	7.02	6.93	6.9	7.12
I	5/19/11	1	11.86	11.8	11.2	9.5	7.1	7.1	6.15	-	-	-	-	-	-
	6/16/11	28	11.86	10.57	9.94	8.98	8.23	6.86	6.42	6.35	6.17	6.05	5.83	5.99	6.17
	7/13/11	56	11.78	10.27	9.71	8.75	8.48	7.72	7.11	6.99	6.77	6.46	6.36	6.39	7.04
	8/10/11	84	11.70	10.01	9.95	9.32	8.87	8.32	7.78	7.31	7.03	7.01	6.72	6.76	6.77

Note:
Flow rate: 9.0 mL per day

Table 10
Siderite-Accusand Column Test Specific Conductivity Data

Column	Date	Day	Column Inlet	Column Port (inches above base)											
				2	3	4	5	6	7	8	9	10	11	12	14
G	6/16/11	28	9,820	8,736	8,950	7,568	5,326	3,384	1,970	1,416	264	232	140	104	68.0
	7/13/11	56	9,360	9,263	9,032	7,980	6,691	4,744	3,565	2,907	1,202	818	352	220	200
	8/10/11	84	9,300	9,800	9,800	9,100	8,700	7,400	5,600	4,700	2,700	2,100	1,500	1,300	900
H	6/16/11	28	9,820	8,495	7,985	7,475	6,603	5,687	4,355	3,225	1,926	763	582	313	168
	7/13/11	56	9,360	7,875	7,338	6,483	5,649	4,794	3,763	2,874	1,953	1,235	801	434	264
	8/10/11	84	9,300	8,700	8,300	7,500	6,600	6,000	5,000	4,100	3,200	2,300	1,900	1,300	700
I	6/16/11	28	9,820	7,354	6,203	4,201	3,094	1,821	1,213	758	204	148	104	100	60
	7/13/11	56	9,360	7,223	6,307	4,837	4,360	4,481	2,348	1,657	988	423	670	368	168
	8/10/11	84	9,300	8,100	7,700	6,800	6,100	5,300	4,600	3,800	2,800	1,600	1,300	1,000	400

Notes:
Flow rate: 9.0 mL per day
Unit of measure for specific conductance: microsiemens per centimeter (uS/cm)
SC profiles were not collected at Day 1 due to malfunction of the conductivity microelectrode.

FIGURES

Figure 1
SIderite-Quarry Sand Columns
Onondaga Lake Siderite Column Study
Data Report

Figure 2
Siderite-Accusand Columns (Day 84)
Onondaga Lake Siderite Column Study
Data Report

ANCHOR QEA

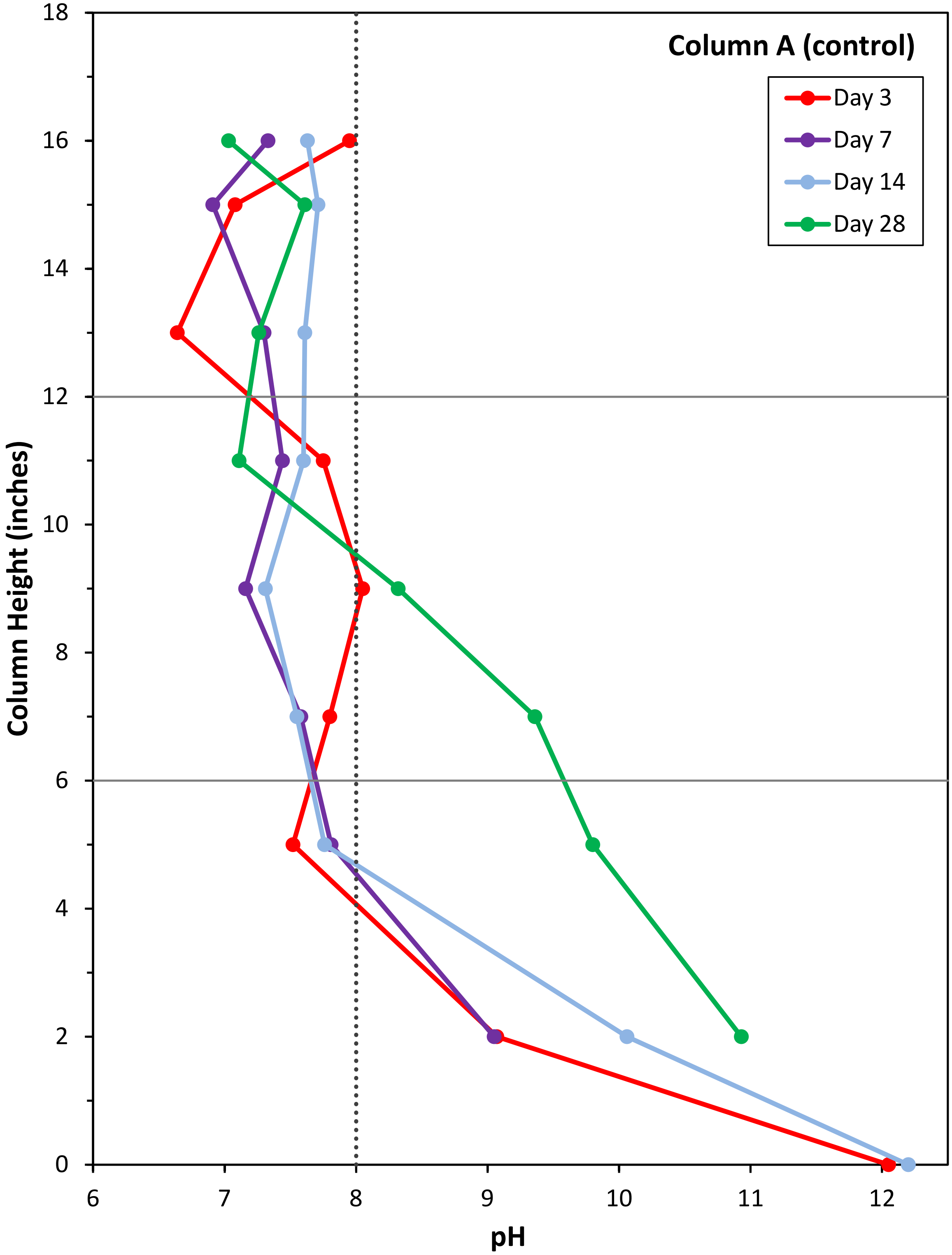

Figure 3
Column A (Quarry Sand Control) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

ANCHOR QEA

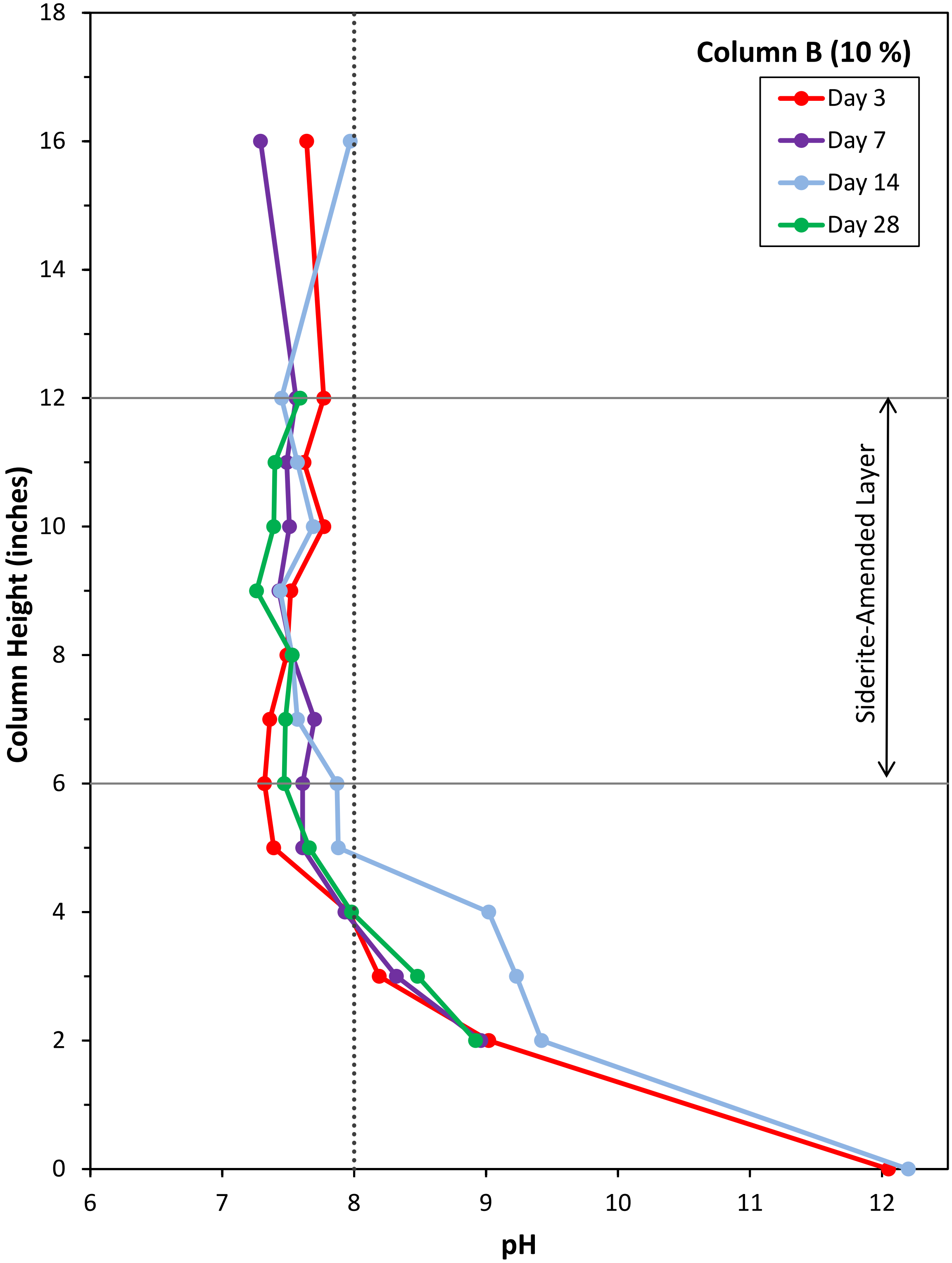

Figure 4
Column B (10% Siderite-Quarry Sand) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

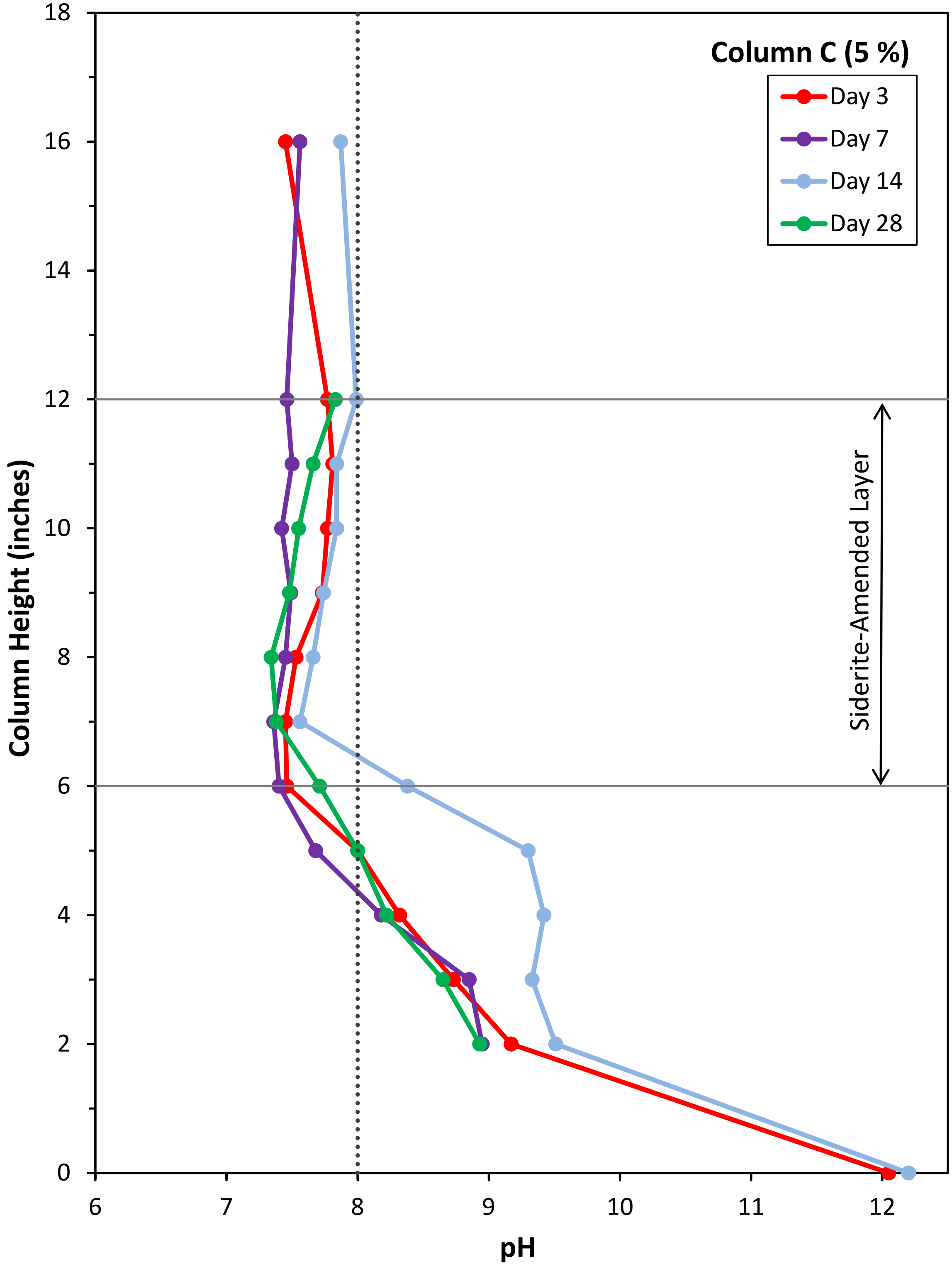

Figure 5
Column C (5% Siderite-Quarry Sand) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

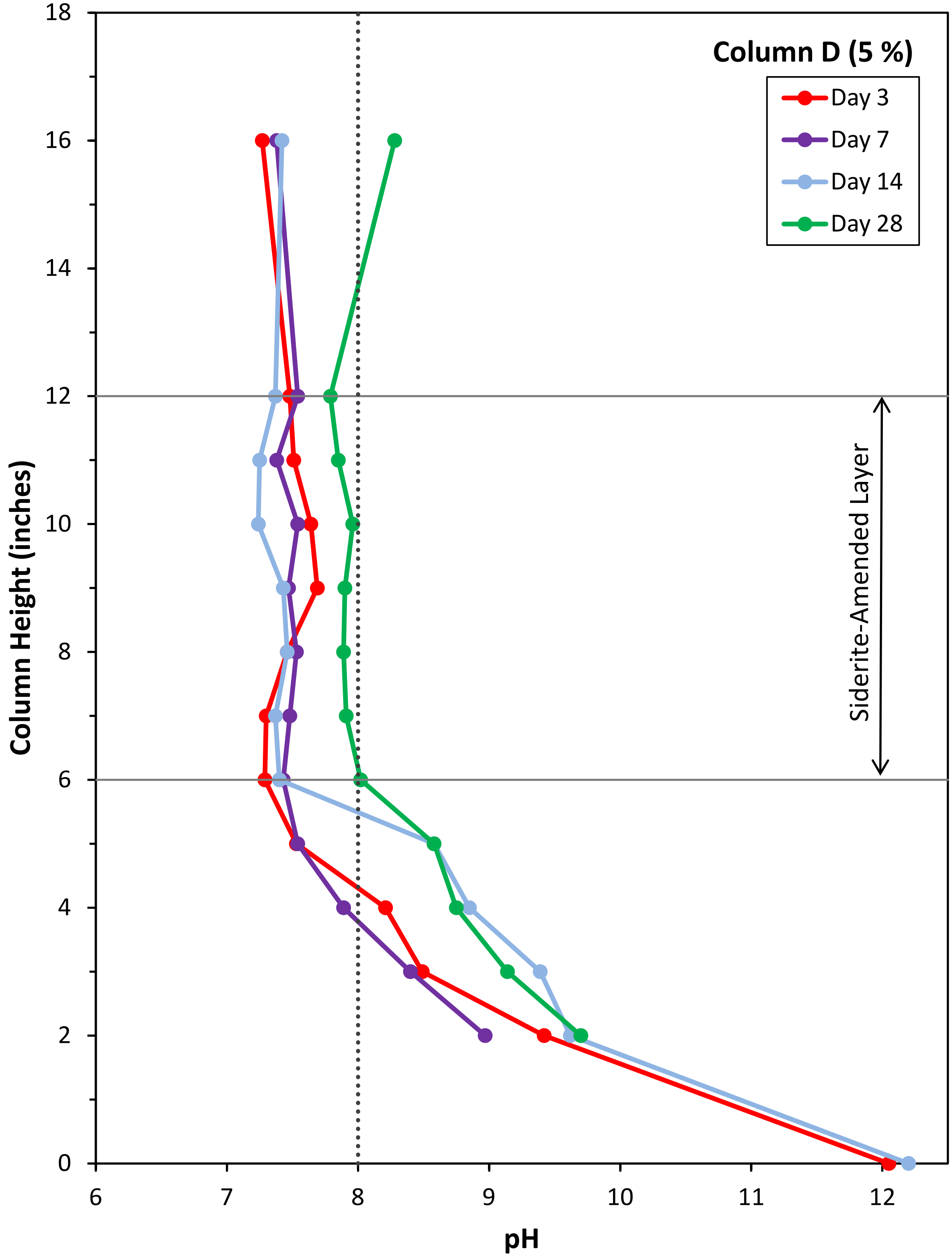

Figure 6
Column D (5% Siderite-Quarry Sand) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

ANCHOR QEA

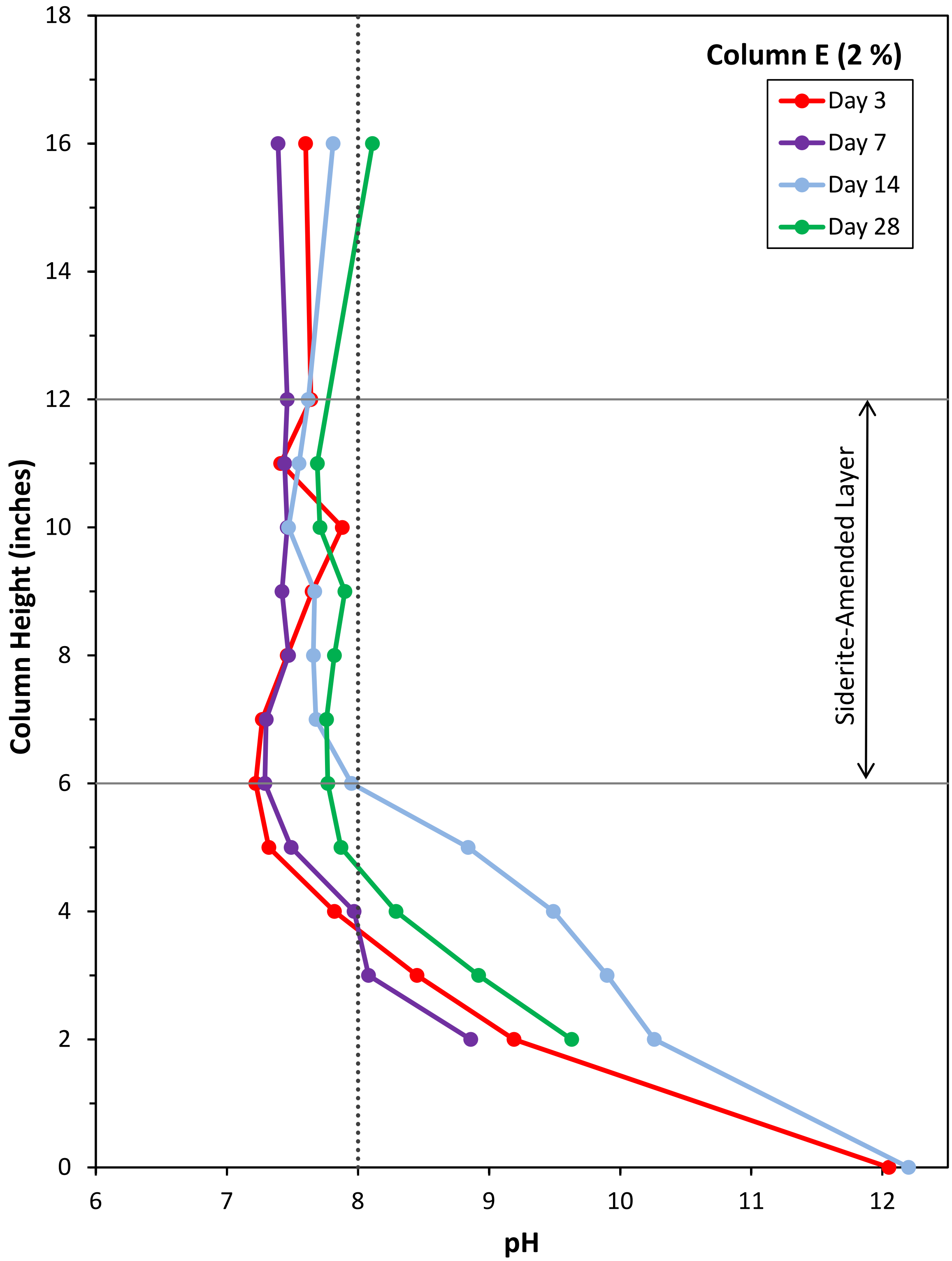

Figure 7
Column E (2% Siderite-Quarry Sand) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

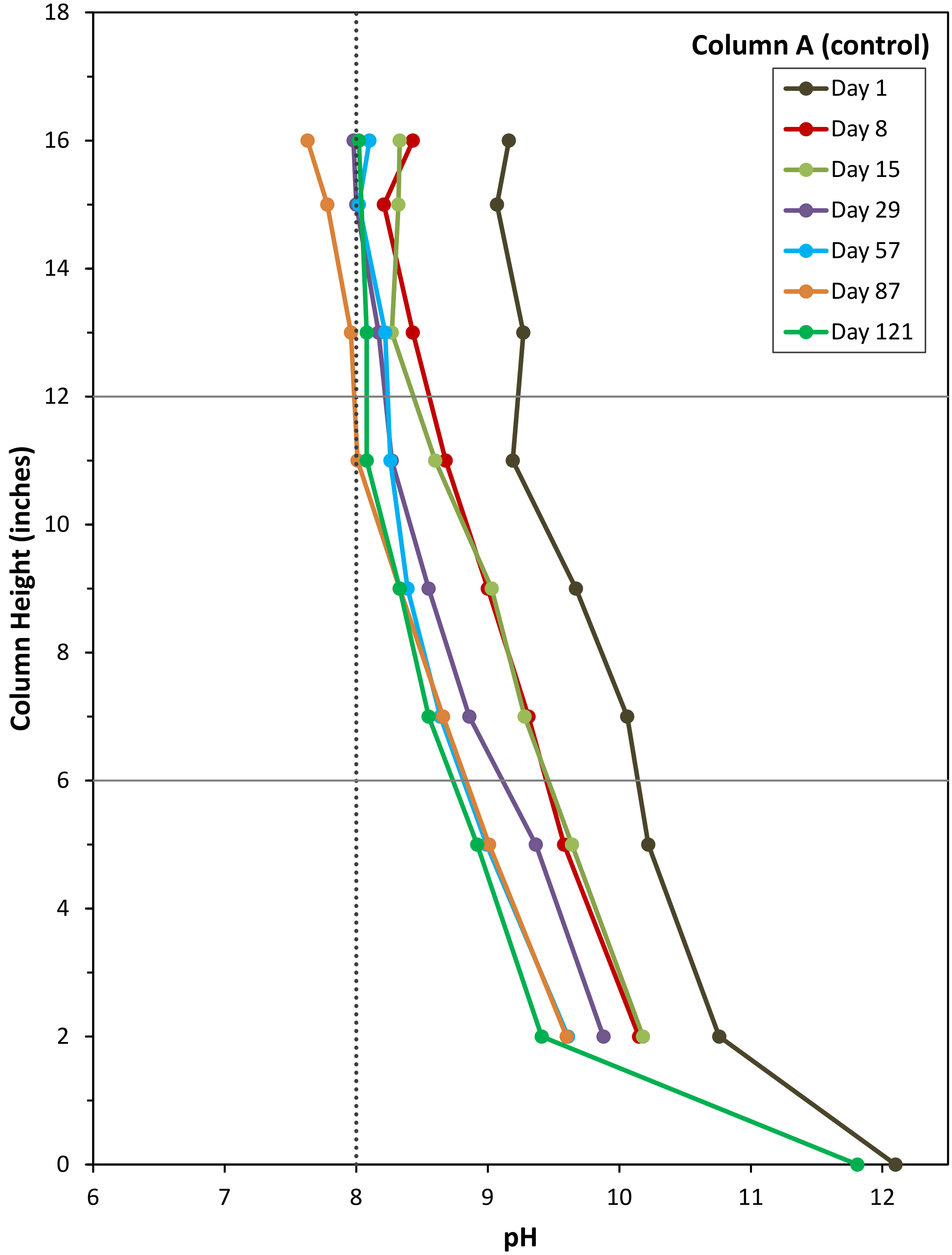

Figure 8
Column A (Quarry Sand Control) pH Profiles During Stop-Flow Test
Onondaga Lake Siderite Column Study
Data Report

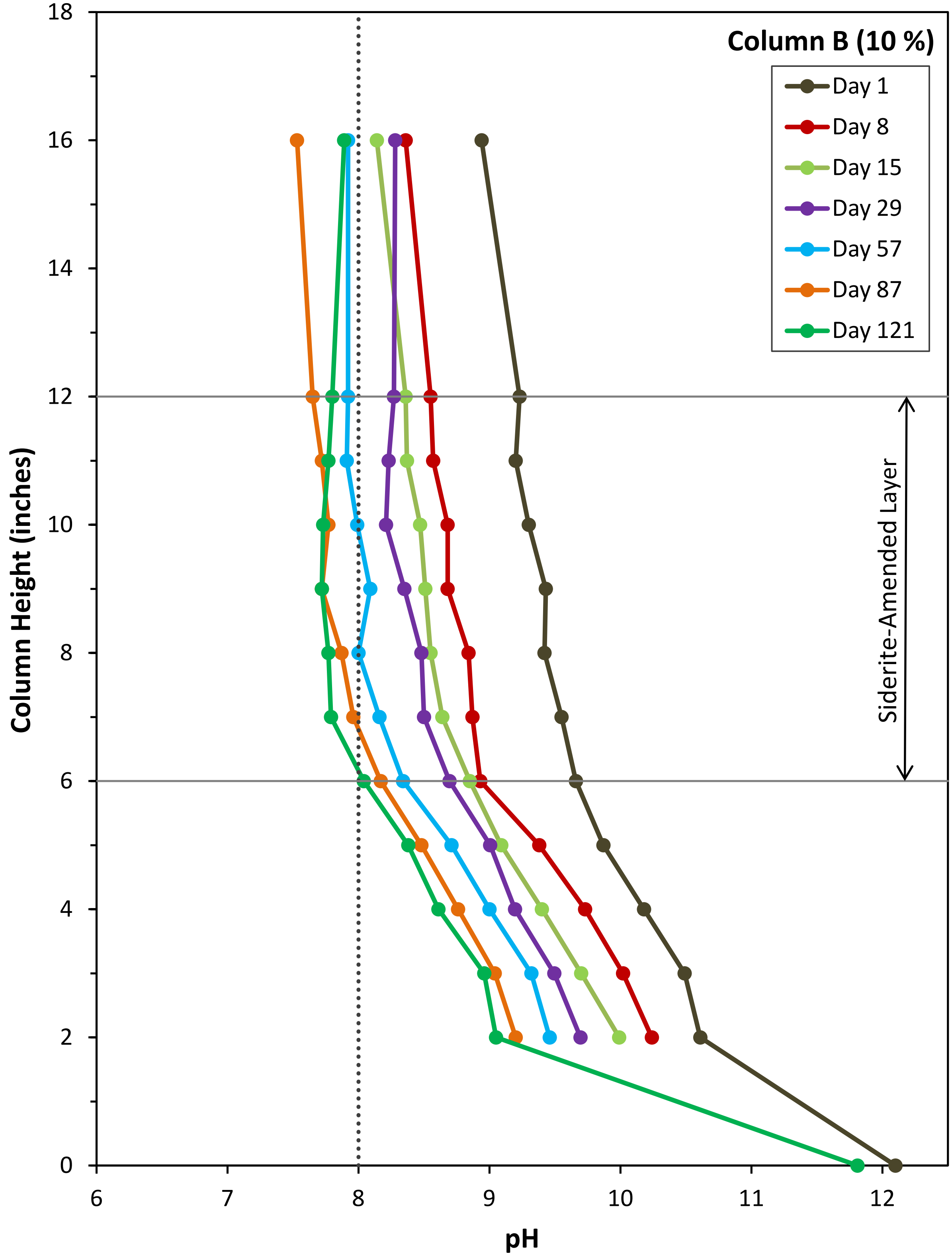

Figure 9

Column B (10% Siderite-Quarry Sand) pH Profiles During Stop-Flow Test
Onondaga Lake Siderite Column Study
Data Report

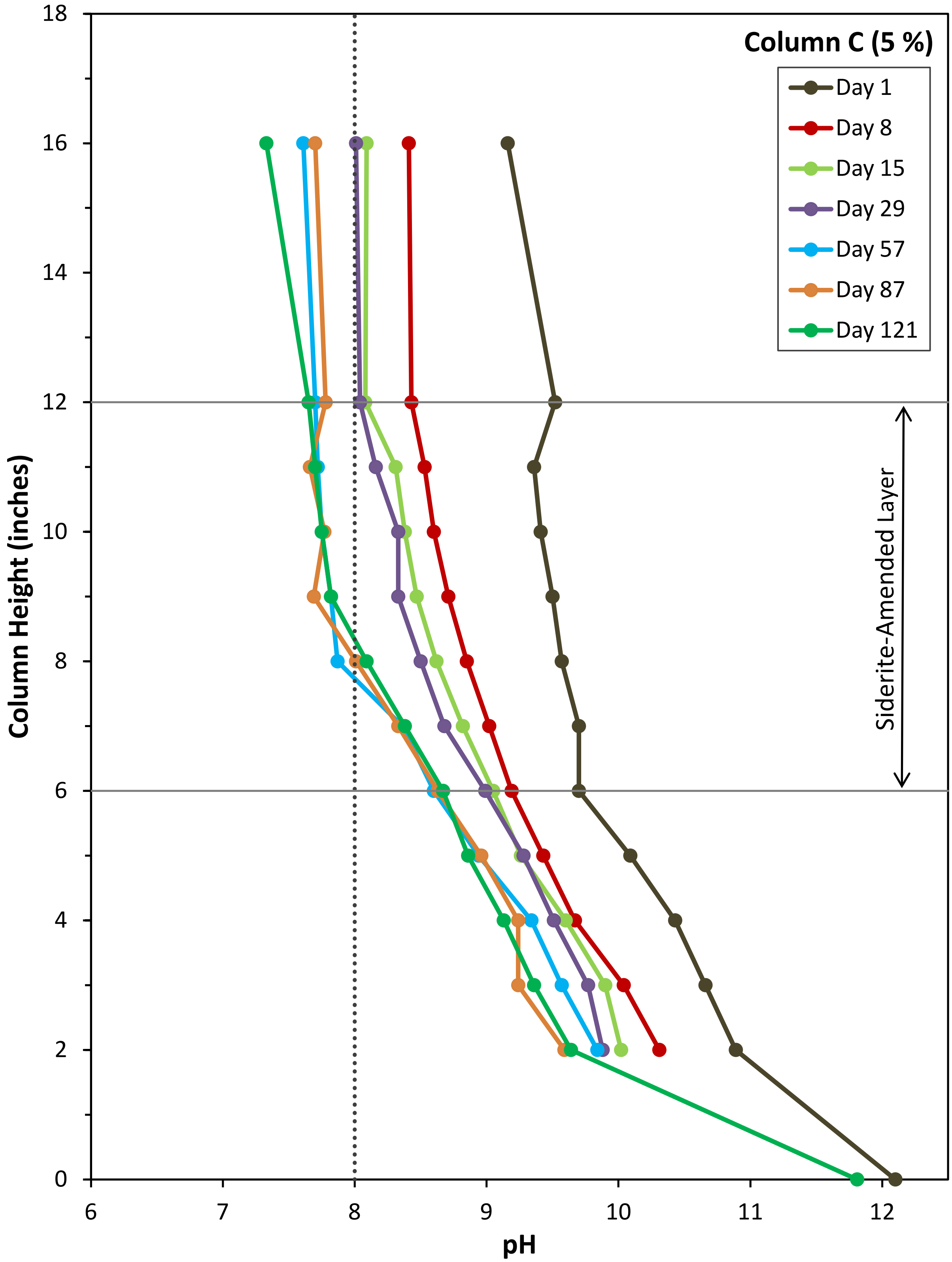

Figure 10
Column C (5% Siderite-Quarry Sand) pH Profiles During Stop-Flow Test
Onondaga Lake Siderite Column Study
Data Report

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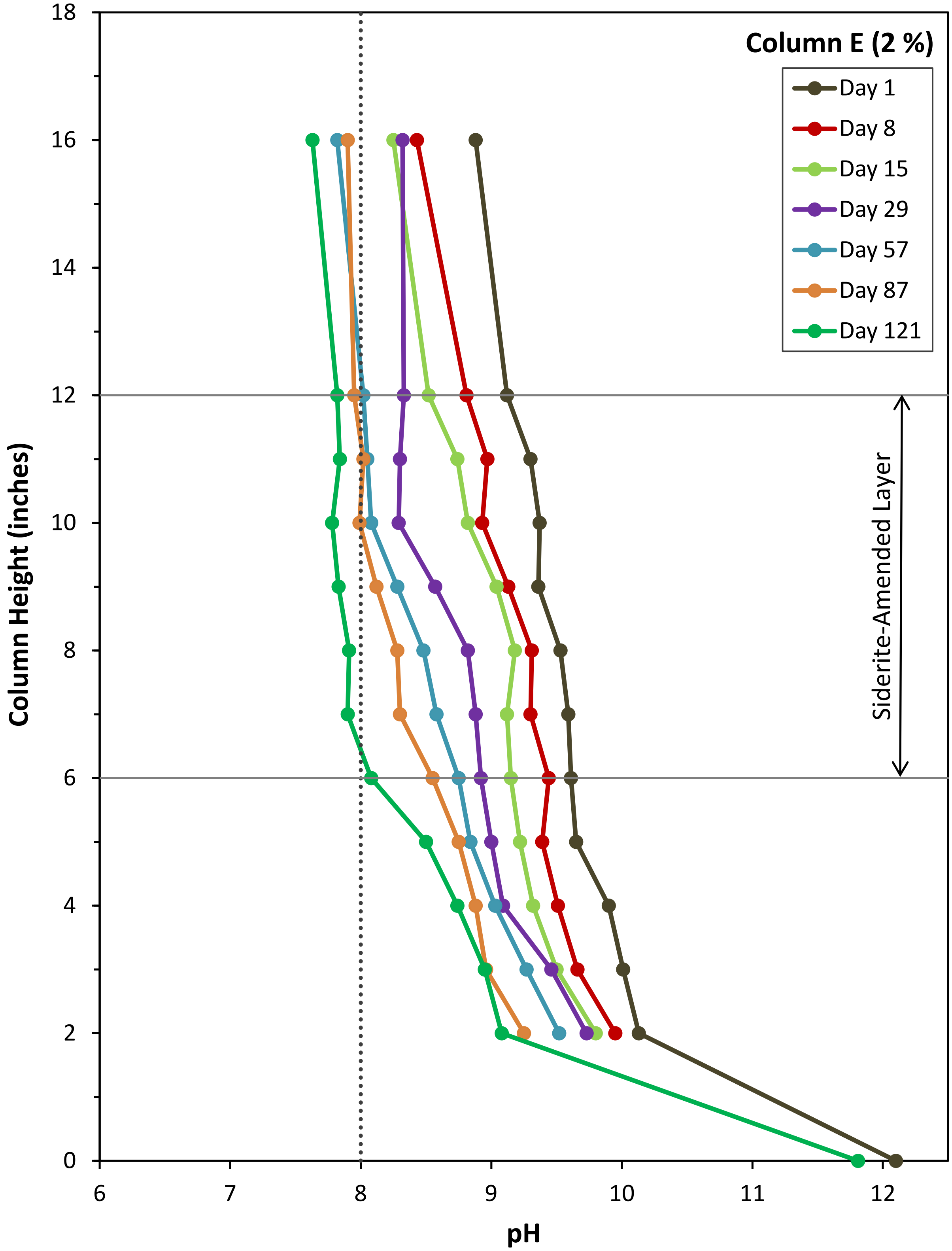

Figure 11
Column E (2% Siderite-Quarry Sand) pH Profiles During Stop-Flow Test
Onondaga Lake Siderite Column Study
Data Report

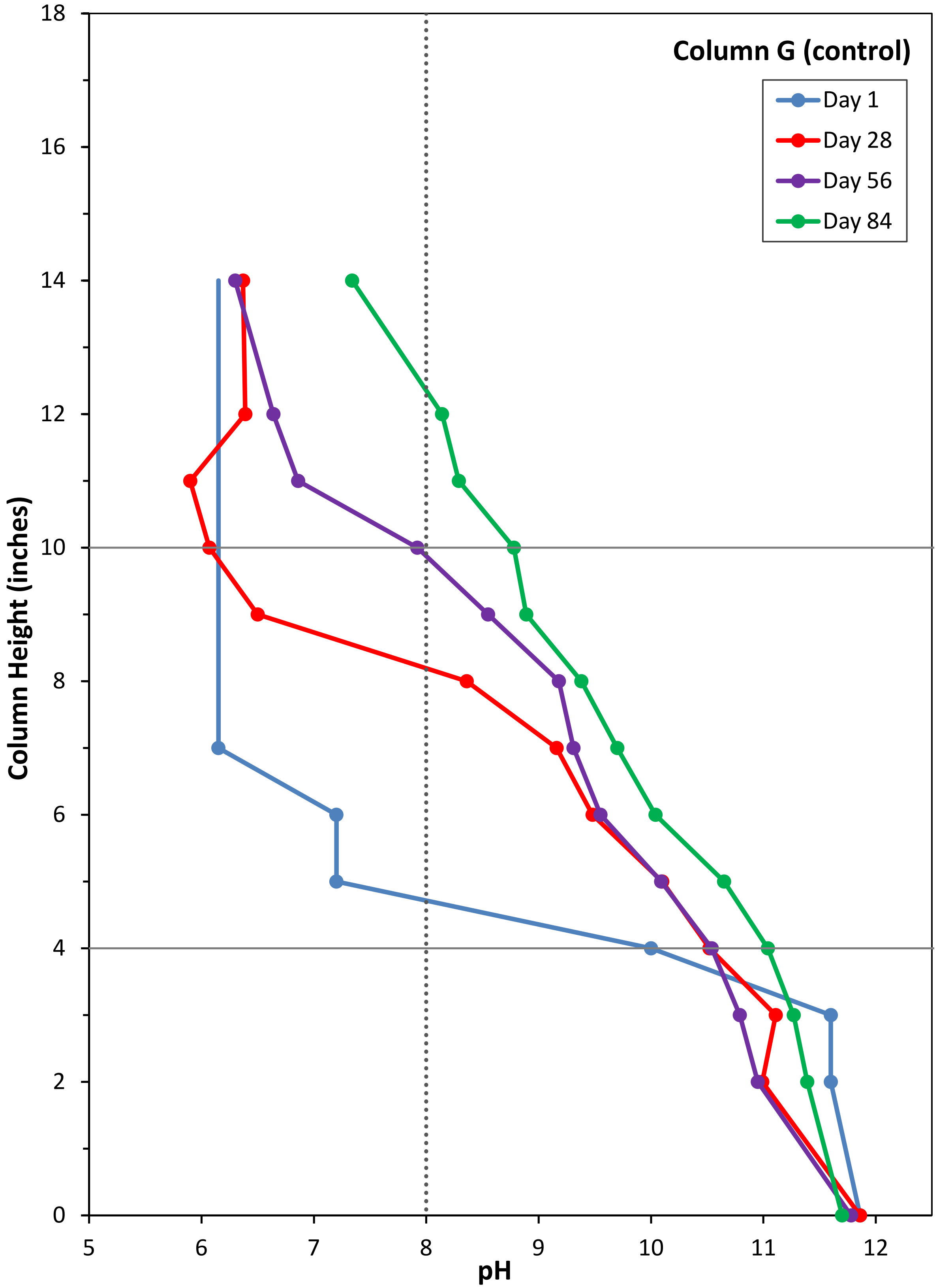

Figure 12
Column G (Accusand Control) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

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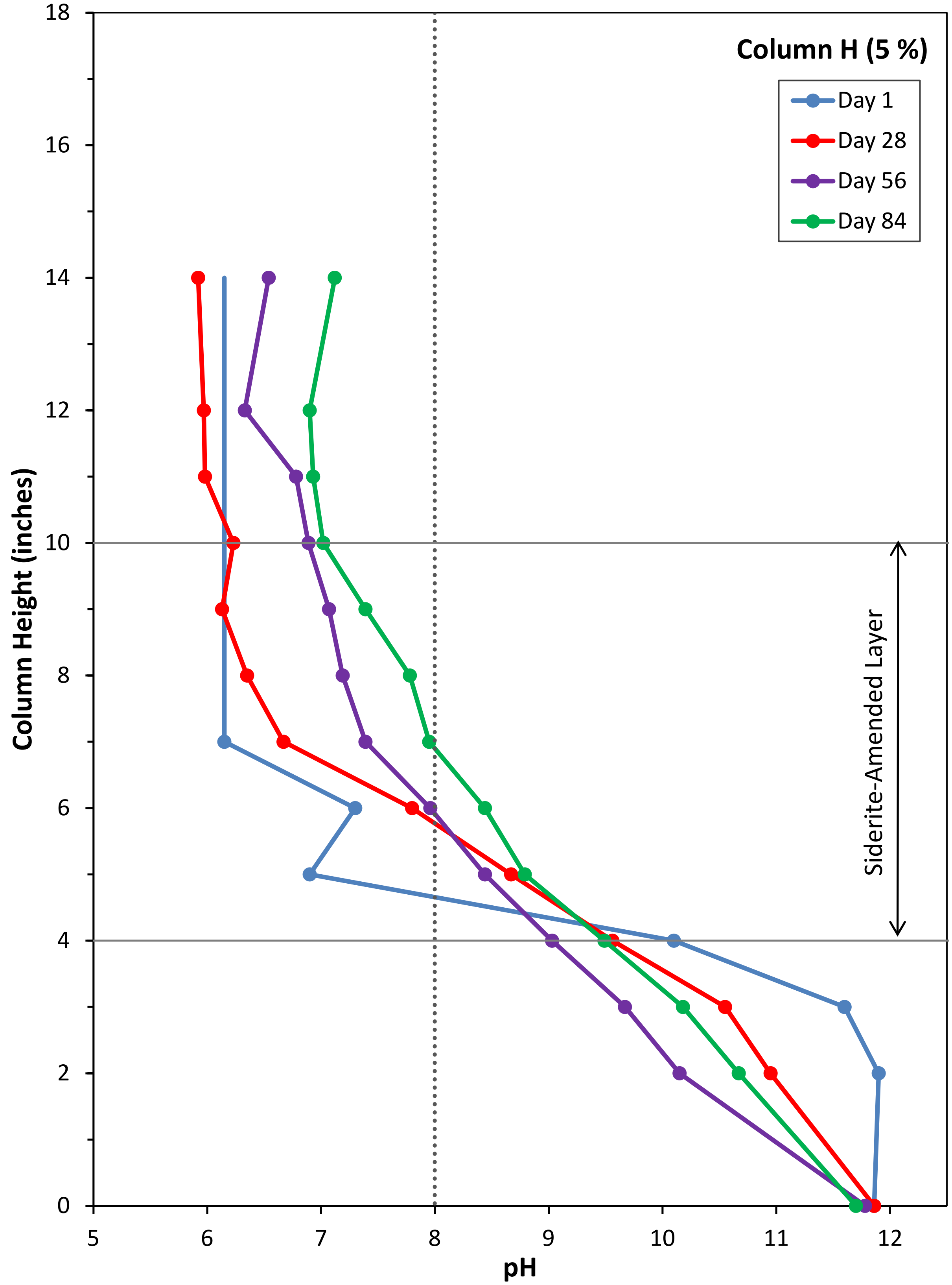

Figure 13
Column H (5% Siderite-Accusand) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

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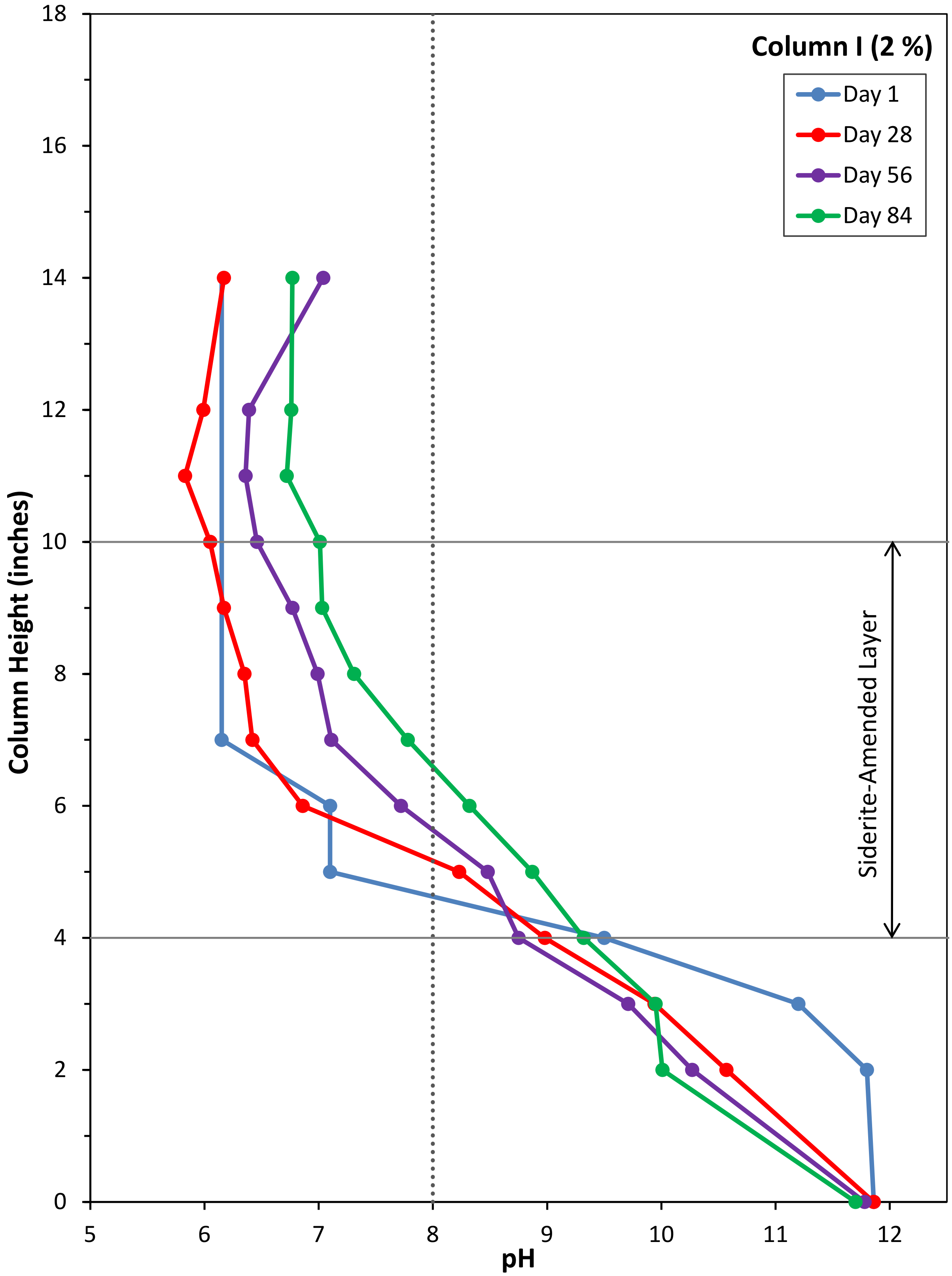


Figure 14
Column I (2% Siderite-Accusand) pH Profiles
Onondaga Lake Siderite Column Study
Data Report

ANCHOR QEA

APPENDIX A – COLUMN TRACER TESTS

Hydraulic and solute transport characteristics of the columns were determined initially prior to porewater introduction into the columns in order to establish effective porosity and dispersion coefficients. Tracer tests were not performed after completion of column tests as no evidence of column clogging was observed.

The tracer tests were performed by first pumping neutral tap water through the columns, followed by a finite pulse injection of sodium chloride (NaCl) solution, then switching back to tap water until the salt pulse was flushed out. The injection rate (Q) was 235 cm^3/min for the siderite-quarry sand columns and 270 cm^3/min for the siderite-Accusand columns. The columns have an empty bed volume of 5,227 cm^3 and a cross-sectional area (A) of 114.3 cm^2.

Sodium chloride concentrations were continuously monitored in column effluent during the tracer tests. The concentration breakthrough curves were fit to an advection-dispersion finite-pulse model to determine the linear velocity and dispersion coefficient, by iteratively solving the 1D advection-dispersion equation for a non-reactive solute:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x}$$

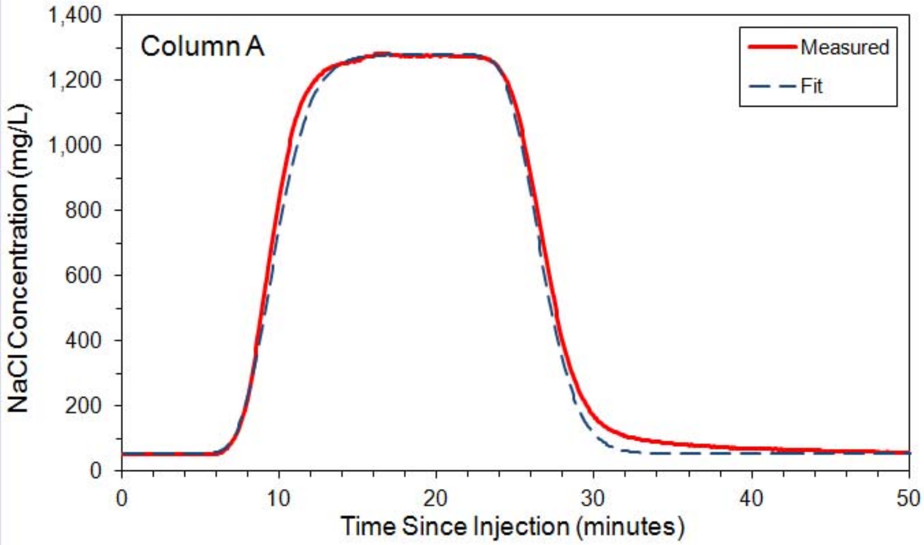
where C is the solute concentration, D is the dispersion coefficient (cm^2/s), and v is the linear velocity (cm/s).

Effective porosity was calculated using the linear velocity and specific discharge:

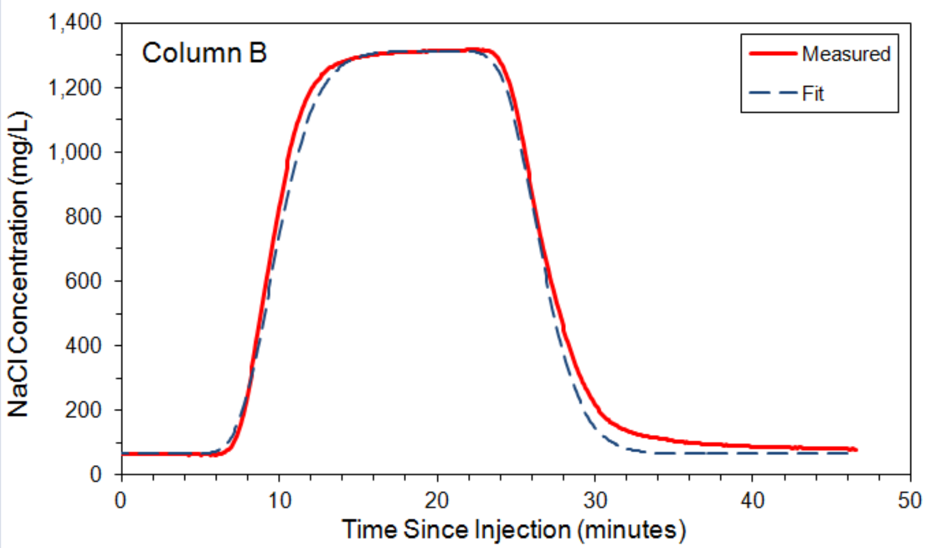
$$n_e = \frac{q}{v}$$

where n_e is the effective porosity and q is the specific discharge (Q/A, in cm/s).

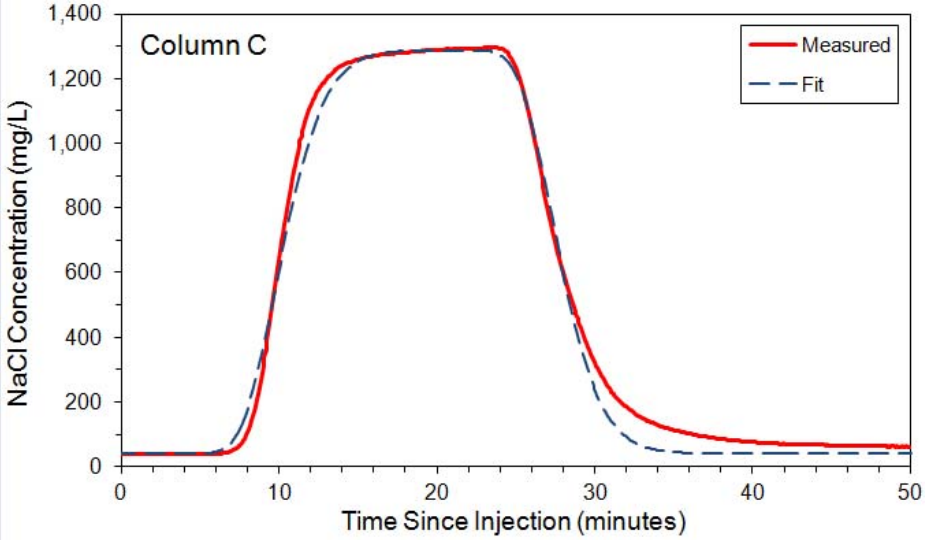
Measured and modeled tracer breakthrough curves along with fitted parameters derived for each column are provided on the following pages.



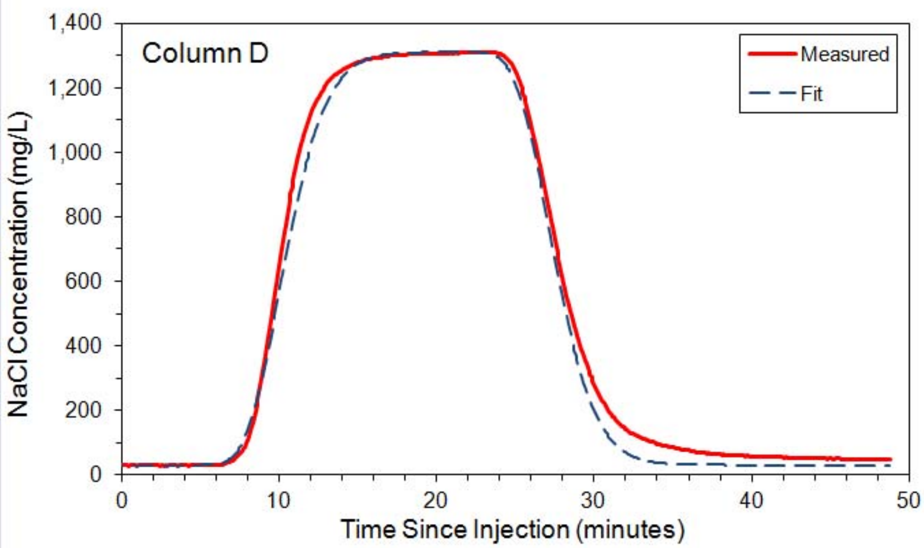
Column	A
Specific Discharge:	0.0343 cm/s
Tracer Pulse:	1014 s
Peak Concentration:	1226 mg/L
Pore Velocity:	0.0783 cm/s
Effective Porosity:	0.438
Dispersion Coefficient:	0.0585 cm^2/s



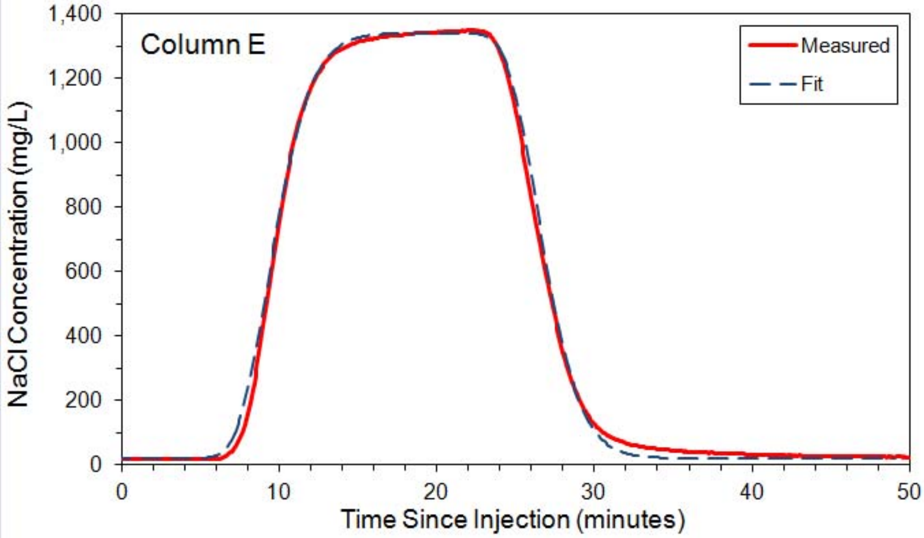
Column	B
Specific Discharge:	0.0343 cm/s
Tracer Pulse:	1008 s
Peak Concentration:	1246 mg/L
Pore Velocity:	0.0778 cm/s
Effective Porosity:	0.440
Dispersion Coefficient:	0.0699 cm^2/s



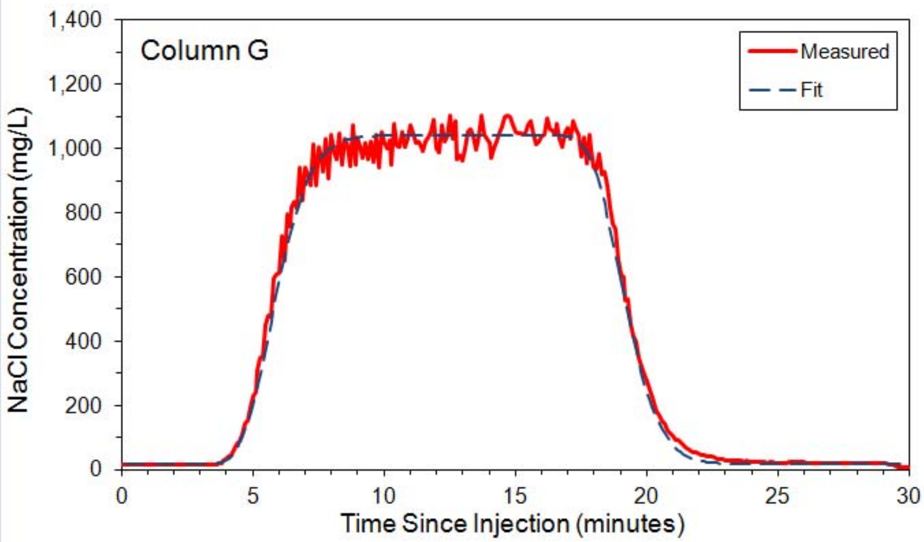
Column	C
Specific Discharge:	0.0343 cm/s
Tracer Pulse:	1050 s
Peak Concentration:	1248 mg/L
Pore Velocity:	0.0745 cm/s
Effective Porosity:	0.460
Dispersion Coefficient:	0.0692 cm^2/s



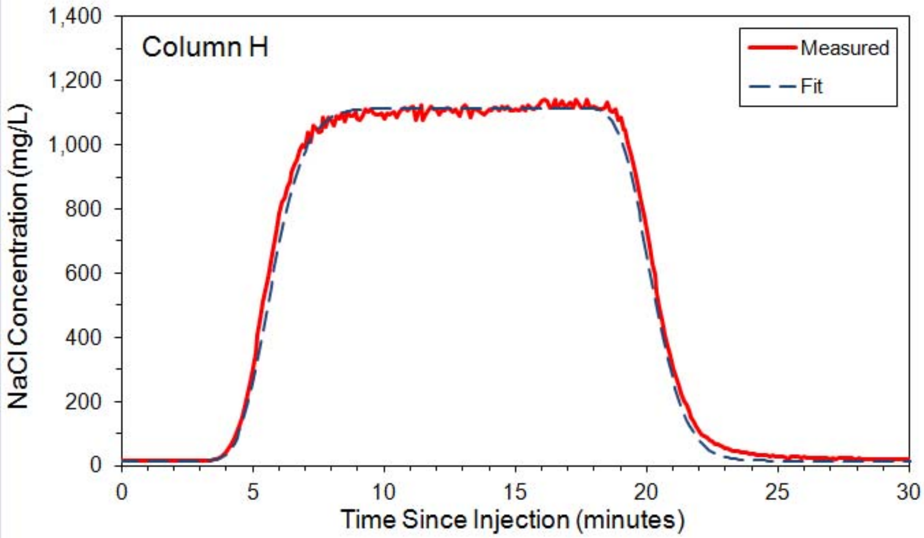
Column	D
Specific Discharge:	0.0343 cm/s
Tracer Pulse:	1025 s
Peak Concentration:	1279 mg/L
Pore Velocity:	0.0731 cm/s
Effective Porosity:	0.469
Dispersion Coefficient:	0.0614 cm^2/s



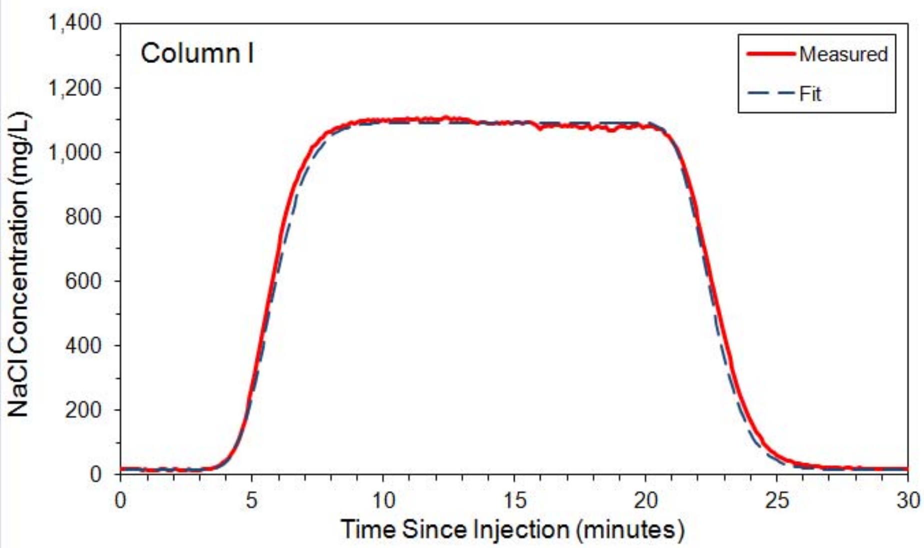
Column	E
Specific Discharge:	0.0343 cm/s
Tracer Pulse:	1025 s
Peak Concentration:	1320 mg/L
Pore Velocity:	0.0788 cm/s
Effective Porosity:	0.435
Dispersion Coefficient:	0.0660 cm^2/s



Column	G
Specific Discharge:	0.0394 cm/s
Tracer Pulse:	798 s
Peak Concentration:	1025 mg/L
Pore Velocity:	0.1298 cm/s
Effective Porosity:	0.303
Dispersion Coefficient:	0.0894 cm^2/s



Column	H
Specific Discharge:	0.0394 cm/s
Tracer Pulse:	870 s
Peak Concentration:	1100 mg/L
Pore Velocity:	0.1333 cm/s
Effective Porosity:	0.295
Dispersion Coefficient:	0.0915 cm^2/s



Column	I
Specific Discharge:	0.0394 cm/s
Tracer Pulse:	1002 s
Peak Concentration:	1075 mg/L
Pore Velocity:	0.1317 cm/s
Effective Porosity:	0.299
Dispersion Coefficient:	0.1039 cm^2/s

APPENDIX B – XRD REPORT

X-ray Diffraction Analysis of Two Samples

W.O. # A11-0912
Invoice # A11-0912

Client: Anchor QEA LLC.
6650 SW Redwood Lane, Suite 333
Portland, OR 97224
USA

Attn: Jessica Goin

Date Reported: February 22, 2011

ACTIVATION LABORATORIES LTD.
1336 Sandhill Drive, Ancaster, Ontario Canada L9G 4V5 TELEPHONE +1.905.648.9611 or +1.888.228.5227 FAX +1.905.648.9613
E-MAIL ancaster@actlabs.com ACTLABS GROUP WEBSITE http://www.actlabs.com

Experimental

Two samples were submitted for mineral identification and semi-quantitative analysis.

Portions of powdered samples were packed into standard holders. The quantities of the crystalline mineral phases were determined using Rietveld method. The Rietveld method is based on the calculation of the full diffraction pattern from crystal structure information. The X-ray diffraction analysis was performed on Panalytical X'Pert Pro diffractometer equipped with Cu X-ray source and operating at the following conditions:

X-ray conditions:
Voltage: 40 kV
Current: 40 mA
Range: 4-80 deg 2θ
Step size: 0.02 deg 2θ
Time per step: 1 sec
Divergence Slit: Fixed, angle 1^0
Receiving Slit Size: 0.2 mm
Sample rotation: 1 rev/sec

Results

The following minerals were identified in the samples: quartz, albite, microcline/orthoclase, muscovite/illite, chlorite and amphibole. The samples may contain X-ray amorphous material. The minerals identified in the sample and their semi-quantitative amounts are in Table 1. Enclosed are two pages with the diffraction patterns.

Table 1. Minerals identified in the samples and their semi-quantitative amounts.

Client Sample ID/ ActLabs Sample ID	Identified Minerals	Semi-quantitative amounts weight %
Sand >18 Sieve A11-0912-1	Quartz	68
	Albite	14
	Microcline/Orthoclase	3
	Muscovite/Illite	7
	Chlorite	8
Sand <18 Sieve A11-0912-2	Quartz	69
	Albite	15
	Microcline/Orthoclase	8
	Muscovite/Illite	4

	Chlorite Amphibole	3 1

Please do not hesitate to contact us if you have any questions.

Reported by:

Elitsa Hrischeva, Ph.D.
MLA Research Scientist
Activation Laboratories

Approved by:

Sagar Lachmansing, MSc
Life Sciences Operations Manager
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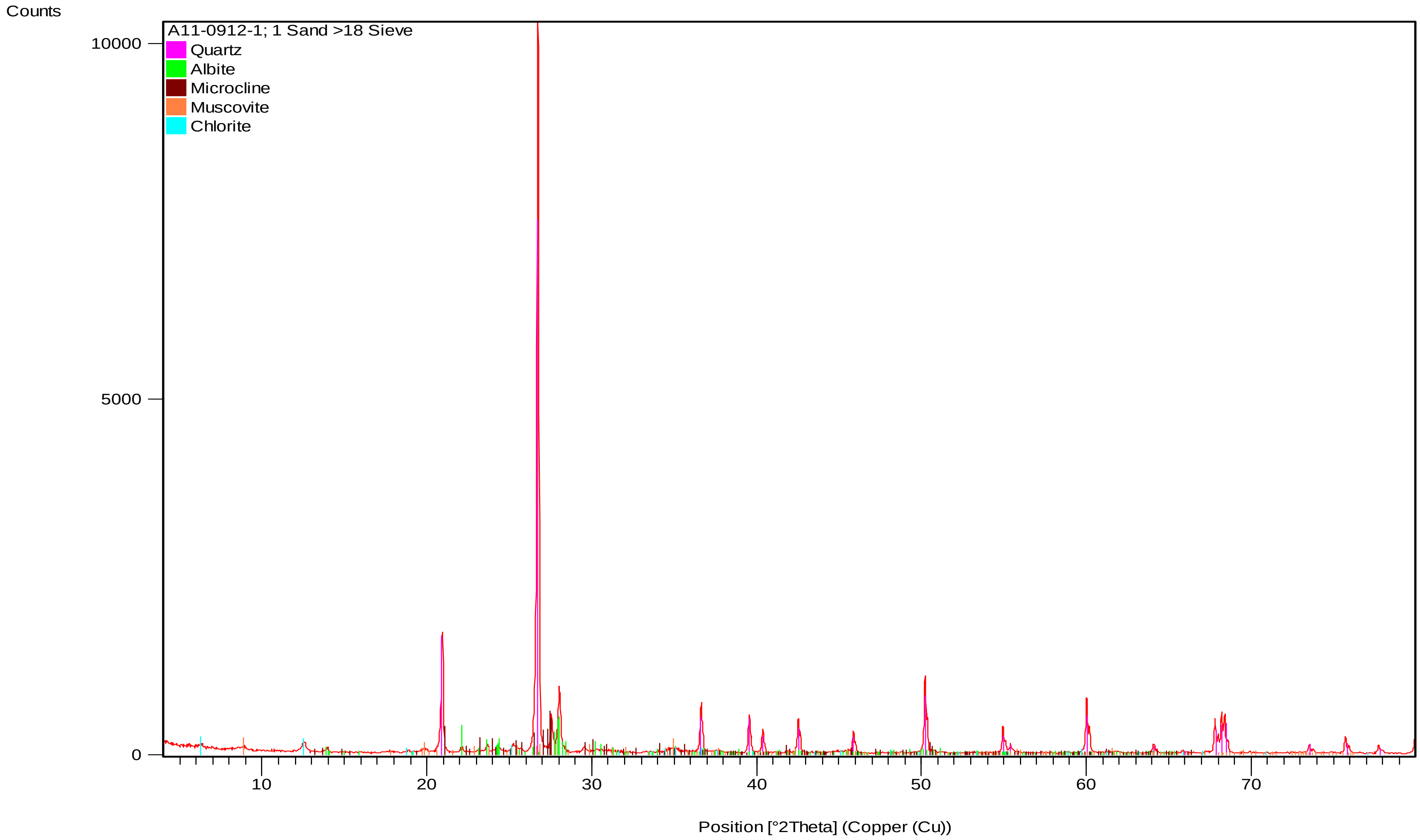
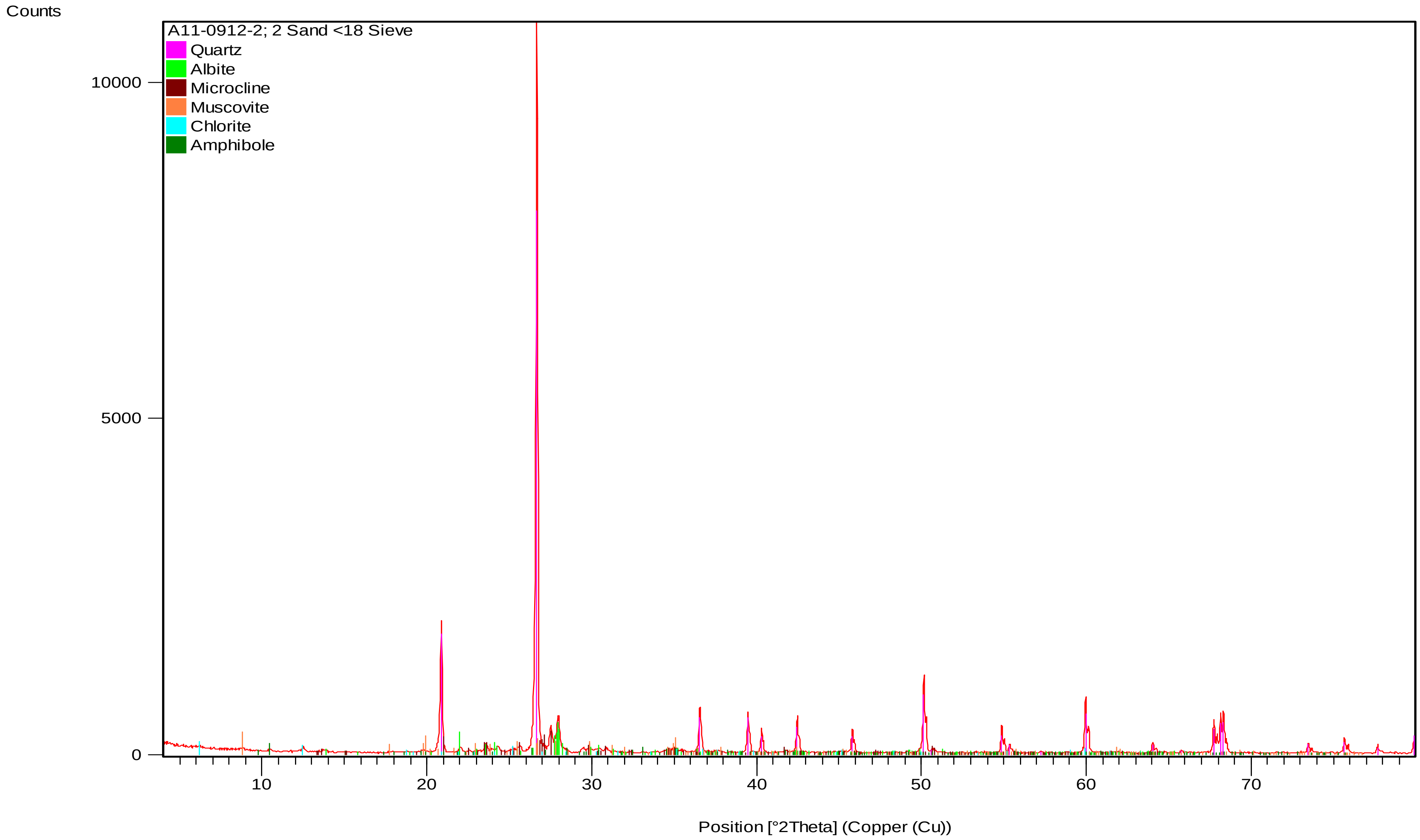

Counts
A11-0912-1; 1 Sand >18 Sieve
Quartz
Albite
Microcline
Muscovite
Chlorite
10000
5000
0
10
20
30
40
50
60
70
Position [°2Theta] (Copper (Cu))


Counts
A11-0912-2; 2 Sand <18 Sieve
Quartz
Albite
Microcline
Muscovite
Chlorite
Amphibole
10000
5000
0
10
20
30
40
50
60
70
Position [°2Theta] (Copper (Cu))