Appendix C

Chemical Extraction Bench-Scale Study Evaluation

Appendix C – Chemical Extraction Bench-Scale Study Evaluation

1. Introduction

At the request of the U.S. Environmental Protection Agency (EPA), a bench-scale study of chemical extraction was performed to more fully evaluate the chemical extraction treatment alternative (TD 4) in the Corrective Measures Study (CMS) Report for the Rest of River (ARCADIS and QEA 2008). The BioGenesis^{SM} Soil and Sediment Washing Process (Biogenesis Process) was selected as the representative chemical extraction treatment technology, and a bench-scale study of this process was conducted in accordance with a work plan developed by BioGenesis (2007) and approved by EPA on July 31, 2007.

The study was conducted during October and November 2007 using sediments and floodplain soils from the Rest of River area. A detailed description of the study and its findings were provided in the Bench-Scale Treatability Study Report (Treatability Study Report), authored by BioGenesis (2008) and included as Appendix A to the CMS Report. This Treatability Study Report, as well as other available information about BioGenesis and other chemical extraction technologies, were used as the basis for evaluating remedial alternative TD 4 in the CMS Report submitted to EPA in March 2008.

In its comments on the CMS Report (General Comment 9), EPA requested a more thorough analysis of the data and the efficacy of the technology, including a detailed analysis of the applicability of reuse and utilization of the processed material in river bottom, bank, or floodplain restoration. This document was prepared in response to that EPA comment.

1.1 Description of Process

The BioGenesis^{SM} Soil/Sediment Washing Technology is a patented low-temperature decontamination process, which uses high pressure washing and propriety chemicals to remove organic and inorganic contamination from soil and sediment particles. The technology, patented by BioGenesis in 2001, is designed to treat coarse-grained (sand-sized) and fine-grained (silt- and clay-sized) particles. The treatment involves isolating individual particles and removing contaminants and naturally occurring organic material adsorbed to the particles by both physical and chemical processes. Additional details on the process and equipment were provided in the Treatability Study Report (BioGenesis 2008).

1.2 Bench-Scale Study Design

On behalf of the General Electric Company (GE), BioGenesis prepared the Bench-Scale Treatability Study Work Plan (Work Plan) that was approved by EPA on July 31, 2007. The objectives of the study, as stated in the Work Plan, were to:

1. Evaluate the extent to which the BioGenesis^{SM} Soil/Sediment Washing Technology can reduce polychlorinated biphenyl (PCB) concentrations in soil and sediment from the Rest of River area.

2. Provide an understanding of the disposition of PCBs through the various stages of the BioGenesis^{SM} Soil/Sediment Washing Process and of the process relationships and dependencies with other project factors (e.g., percent solids, storage capacity, and water treatment), so as to assist in evaluating this technology.

3. Provide sufficient information on the BioGenesis^{SM} Soil/Sediment Washing Technology to support the evaluation of the technology for full-scale implementation, including operational uptime, equipment needs and availability for the full-scale system, effectiveness and implementability of the technology at full-scale, and health and safety considerations, and to provide a basis for developing full-scale implementation costs.

Based on these objectives, BioGenesis designed and implemented the bench-scale study in three steps:

Step 1: Jar testing – preliminary qualitative evaluation based on visual observation of site materials mixed with BioGenesis proprietary solutions.

Step 2: Process optimization – BioGenesis treated site soils and sediments through its process and collected samples of the treated and untreated materials for PCB and total organic carbon (TOC) analyses after intermediate steps in the process. The resulting data were then used to optimize the process.

Step 3: Validation testing – BioGenesis again treated site soils and sediments based on a site-specific/sample-specific optimized process, and GE collected samples for PCB analysis in accordance with the Work Plan. The resulting data were evaluated in the Treatability Study Report (BioGenesis 2008) and are discussed further in this supplemental appendix.

The Work Plan provided that the results of the jar testing and optimization testing would be used by BioGenesis to refine the specifics of the process, if needed, prior to implementation of the validation testing phase. However, no significant changes to the approach were made by BioGenesis based on the preliminary testing, and the validation testing was conducted essentially as initially developed by BioGenesis in the Work Plan. This testing is summarized below.

Three types of soil and sediment were collected by GE and provided to BioGenesis for processing:

- S1 – Coarse-grained sediment from just south of the Confluence;
- S2 – Fine-grained sediment from Woods Pond; and
- S3 – Floodplain soil.

Each material was tested independently three times, designated as runs R1, 2, and 3, respectively. For each run, treated material was re-processed two additional times, for a total of three treatment cycles. The process generated several different treated outputs based on grain size, as described below. Each solid output was weighed and samples were collected for PCB analysis. Wastewater generated from each process was also analyzed for PCBs and solids content.

2. Results and Discussion

This section discusses the overall effectiveness of the BioGenesis process and its ability to achieve concentrations that might be applicable to reuse. As discussed in detail below, the bench-scale study yielded a large and complex data set with a total of 69 different treated material outputs. These data have been evaluated in several ways to determine the factors that contribute to effectiveness. These factors included the initial material composition and PCB concentration and the effects of multiple treatment cycles in reducing concentrations. The data generated during this bench-scale study (which reflect the testing of materials with PCB concentrations ranging from 45 to 177 mg/kg) indicate that the BioGenesis process is not effective in treating Rest of River materials to concentrations that would be applicable for reuse. The details of this evaluation are presented below.

This section begins with a summary of the bench-scale results. Additional subsections discuss the results from the individual grain size outputs and from the multiple treatment cycles to understand the mechanisms and effectiveness of treatment. The final subsection provides a discussion of the lack of mass balance closure from the bench-scale process and discusses how that factor contributes to the evaluation of overall effectiveness and uncertainty in this evaluation.

2.1 Summary Evaluation

The PCB results and a summary of the solids data from the bench-scale study are compiled in Table C-1. Solids data from each test and output are presented in Table C-2. Each material (S1, S2, and S3) was tested three times (R1, R2, and R3) and each test included 3 treatment cycles (except for the two largest grain size outputs from the S1 material, which only went through one cycle). These tests produced different outputs sorted by grain size. BioGenesis calculated mass-weighted averages of the outputs from each test and cycle to represent the overall PCB concentration that each treated sample would contain if the various grain size fractions were recombined. As shown on Table C-1 and depicted on Figure C-1, mass-weighted averages of treated materials after one treatment cycle ranged from 12.5 to 29.7 mg/kg for the coarse-grained sediment, 11.5 to 48.4 mg/kg for the fine-grained sediment, and 6.8 to 19.2 mg/kg for the floodplain soil; and mass-weighted averages following three treatment cycles ranged from 4.6 to 21.8 mg/kg for the coarse-grained sediment, 11.3 to 18.4 mg/kg for the fine-grained sediment, and 4.2 to 8.5 mg/kg for the floodplain soil.

Results for the individual outputs were further evaluated to provide an understanding of the mechanics and chemistry of the process. The bench-scale study generated results for a total of 69 different treated outputs, each presented in Table C-1. Each material, test, and cycle generated both hydrocyclone outputs (medium to coarse silt) and centrifuge outputs (fine silt and clay) for a total of 54 of these outputs. In addition, 15 larger grain sized outputs were generated from the S1 material. The average concentrations of each output are shown on Figure C-2. With the exception of the very largest grain size outputs (cobbles > 6.35 millimeter in diameter), the PCB concentrations of the individual outputs for the coarse-grained sediments (S1) ranged from 2.7 to 143 mg/kg after one treatment cycle and from 10.1 to 92 mg/kg after three treatment cycles (for those outputs that went through three cycles). The lowest concentration achieved for the fine-grained (hydrocyclone and centrifuge) outputs from the S1 material was 33.4 mg/kg after two treatment cycles (results from the third cycle were slightly higher [34.1 mg/kg]). Outputs from the fine-grained sediments (S2) ranged from 8.6 to 60 mg/kg after one treatment cycle and from 8.6 to 22.9 mg/kg after three treatment cycles. Outputs from the floodplain soil (S3) ranged from 4.8 to 44 mg/kg after one treatment cycle and from 2.6 to 24 mg/kg after three treatment cycles.

Overall, multiple treatment cycles appear to reduce concentrations to plateau levels, below which further reduction appears to be incrementally smaller or not possible within the limits of the testing. These plateau levels are above 2 mg/kg. With the exception of the cobble (> 6.35 mm [0.25 inch]) fraction from the S1 material, the lowest concentration achieved at bench-scale for a single grain size output was 2.6 mg/kg (S3R2 hydrocyclone solids after three cycles), and the great majority of treated outputs had considerably higher PCB concentrations (Table C-1 and Figure C-2).

2.2 Effects of Grain Size Distribution and Multiple Treatment Cycles

In evaluating the available data to determine the lowest possible theoretically achievable concentration for all types of Rest of River materials, it is helpful to review the results for the finer grained outputs that were common to each of the materials tested (hydrocyclone and centrifuge). These hydrocyclone and centrifuge data are presented in Figures C-3, C-4, and C-5. For these finer grained outputs, the lowest concentrations achieved were from the hydrocyclone outputs. Of these, the lowest concentrations were from the floodplain soil (S3). These S3 hydrocyclone outputs achieved PCB levels ranging from 2.6 to 3.9 mg/kg after three treatment cycles. For the fine-grained sediment from Woods Pond (S2), the final hydrocyclone outputs ranged from 8.6 to 11 mg/kg. As shown in Table C-1 and depicted on Figures C-3 and C-4, the third treatment cycle did not appreciably reduce the concentrations of these outputs. These data indicate that multiple treatment cycles will not result in significant further reductions.

The data for the finer grained fractions of the S1 material are slightly different from those for the S2 and S3 materials discussed above. A plateau was not observed in the bench-scale study for the hydrocyclone and centrifuge outputs from the S1 material (see Figure C-5). Although the data suggest that a plateau might be reached at approximately 33 or 34 mg/kg (based on the lowest concentration achieved after 2 and 3 cycles), very little of this material remained after treatment (0.3 to 1.0 kg after 3 treatment cycles, or less than 2% of the total initial mass) (Table C-2). For comparison, 24% to 38% of the initial mass was recovered in these outputs (i.e., hydrocyclone and centrifuge) from the S2 and S3 materials following three cycles (Table C-2), and these were the only treated outputs from the S2 and S3 materials. For the S1 material, it is impossible to know whether additional treatment cycles would achieve plateau levels or whether the additional cycles would only serve to remove the finer grained material, thereby eliminating the finer grained materials as outputs for this type of heterogeneous grain size material.

For the S1 material, the mass-weighted averages were calculated from a large proportion of relatively low concentration, large grain size material and a small proportion of high concentration fine-grained (hydrocyclone and centrifuge) material. Repeated treatment cycles lost proportionally more of the finer grained material, resulting in significantly lower mass-weighted averages. The concentrations of the individual treated outputs were not reduced to the same extent as the mass-weighted average. The concentration of the fine-grained outputs (hydrocyclone and centrifuge solids) from S1 ranged from 34 to 92 mg/kg following three cycles. The overall effectiveness of the process thus appears more directly related to the loss of this high-concentration finer grained material, rather than a reduction in the PCB concentrations of the individual grain size outputs.

2.3 Wastewater Results

To evaluate the treatment and disposition of solids and PCBs, the results from the wastewater analyses were evaluated. Table C-3 presents the total and dissolved PCB and total suspended solids (TSS) concentrations in the wastewater after the various tests. As shown in Table C-3, total PCBs in wastewater ranged from 160 micrograms per liter (ug/L) (S3) to 3,340 ug/L (S1) and dissolved concentrations of PCBs in wastewater were significantly less, ranging from non-detect to 36 ug/L. These data indicate that the majority of PCBs recovered in wastewater are not in dissolved phase and are in association with particulate materials. Table C-3 also includes the calculated PCB concentration on the solids in the wastewater, and a summary of these results is presented below and graphically on Figure C-2:

Calculated Concentration of PCBs (mg/kg) on Solids in Wastewater

Material type*	Average initial soil/sediment PCB concentration	Average calculated PCB concentration of the solids in wastewater
S1	72	1,687
S2	142	201
S3	50	36

* wastewater collected following three cycles for S1 and S2 and following the first cycle for S3

As shown in this table, for the S1 material, the calculated concentrations of PCBs on solids in the wastewater are significantly higher than the initial material concentrations. The calculated concentrations of PCBs on solids in wastewater for the S2 and S3 materials are generally similar to the starting material concentration. The S1 material consisted of a heterogeneous mix of grain sizes and the S2 and S3 materials were relatively consistent, homogenous, finer grained materials. These wastewater data are generally consistent with the hypothesis that the treatment process involves, at least in part, the washing of high concentration, fine grained material into the aqueous wastewater phase.

2.4 Mass Balance Results

The evaluation of the effectiveness of the process and of multiple treatment cycles is complicated by the loss of solids observed during the bench-scale testing. In the Treatability Study Report (BioGenesis 2008), BioGenesis stated that the loss of solids was primarily due to limitations in the bench-scale equipment – i.e., that the loss of solids was related to fine-grained material suspended in aqueous solution trapped in hoses and at the bottom of containers in between treatment steps. One significant aspect of these losses is that bench-scale process equipment operated in batch mode did not completely replicate the expectations for full-scale continuous mode operations. The loss of material within the system diminishes confidence in calculated values of treatment effectiveness.

It is reasonable to assume that the equipment limitations resulted in a higher proportion of loss of the finer grained material suspended in aqueous solution rather than the coarser grained material that was transferred more effectively in the bench-scale batch process (and the recovered solids data shown in Table C-2 indicate that this is the case). The finer grained fractions of the materials are also expected to have higher concentrations of PCBs than coarser grained fractions, and as noted previously, the data also support this. This effect of the loss of fine grained solids is most evident for the more heterogeneous S1 material, where much of the finer grained fraction was lost over the 3 cycles (Table C-2) and the concentrations of the fine grained solids fraction recovered in the wastewater were high relative to the initial concentrations (Section 2.3). A large percentage of PCBs were lost from the S1 materials by transfer of fines into the wastewater phase (Figure C-2). Therefore, the loss of solids is biased towards the loss of the higher-concentration finer grained materials, thus resulting in an associated reduction in mass-weighted PCB concentration.

Table C-4 and Figure C-6 show the reduction in PCBs and the loss of solids for each treatment cycle. A summary of these results is presented in the following table:

Summary of Cumulative PCB Reduction and Loss of Solids

Parameter	1 cycle	2 cycles	3 cycles
PCB reduction (% concentration)	62 - 90%	66 - 89%	73 - 94%
solids lost (% mass)	11 - 40%	23 - 54%	23 - 60%

As shown in the table above, additional treatment cycles continue to reduce the PCB concentrations and also increase the loss of solids. These data suggest that additional treatment cycles may serve only to continue to remove more solids and that the PCB concentrations will achieve a plateau representative of the concentration of the finest grained material.

Understanding the effects of the loss of solids is an important component of estimating the effectiveness of full-scale implementation. One possible hypothesis is that the BioGenesis process is primarily a size separation process and that the solids material lost during the bench-scale study would be transferred to the aqueous wastewater phase in full-scale operations. Under this hypothesis, full-scale operations would be expected to produce results similar to the bench-scale study. PCB concentrations could probably be lowered to less than 50 mg/kg with a single treatment cycle for most materials. Multiple treatment cycles would be expected to remove a proportionally greater quantity of high-concentration, fine-grained materials. The treated material would achieve a final concentration plateau proportional to the relative mass and concentration of the finest grained material retained by the system. The reduction in PCBs would be dependent on the removal of high-concentration fine-grained solids (23 to 60% of solids were lost following three treatment cycles). In other words, although the mass-weighted average concentration of the final treated material could be lowered to a plateau level with multiple treatment cycles, this would necessitate the removal of up to 50% or more of the material in the “washing” process, which would ultimately go to the wastewater treatment plant. In that case, the wastewater treatment plant would need to include a major treatment component to remove this fine-grained and heavily contaminated sediment. Specifically, the wastewater treatment plant would have to include an appropriately sized thickener or other removal system for very fine-grained particles, which is capable of handling perhaps 50% of the total sediment plant feed. This would result in significant incremental capital and operational costs and plant complexity.

A second possible hypothesis for full-scale implementation is that the solids lost during bench scale would not be apportioned to the aqueous phase but would be recovered in the treated materials. Because the concentration of the lost solids is not known, the possible impact of such recovery on the concentration of treated materials cannot be reasonably estimated. It is possible that the concentration of the lost solids could range anywhere from the concentration of treated material (4 to 22 mg/kg after three cycles) (see Table C-4) to as high as the estimated concentration of the solids in the wastewater (average of 36 to 1,700 mg/kg) (see Table C-3). Therefore, understanding the disposition and concentration of these solids is critical to understanding the effectiveness of the process and of multiple treatment cycles.

3. Applicability of Reuse

It is expected that the treatment process would have to reliably and consistently achieve PCB levels at least as low as 1 or 2 mg/kg in the treated materials in order for those materials to be approved for reuse as backfill, and even these concentrations may not be low enough to allow reuse in some areas, notably in the river bed. The backfill approved by EPA for use by GE in the restoration of other properties in Pittsfield has had no detected PCBs. Further, to the best of our knowledge, EPA has not permitted the use of PCB-containing treated material as replacement fill for river sediments. As discussed above, data from the bench-scale study indicate that the BioGenesis^{SM} Soil and Sediment Washing Process will only treat material to certain plateau levels and these plateau levels do not approach 2 mg/kg.

Thus, the data from the bench-scale study indicate that the BioGenesis^{SM} Soil/Sediment Washing Technology would not meet reuse standards. It appears that the lowest achievable PCB concentration is a function of the grain size composition of the original feed material and the PCB concentrations of those grain size fractions. With the exception of the larger size (cobble and gravel) materials that are only present in some of the river sediments, the lowest theoretically achievable concentrations appear to be those represented by the hydrocyclone outputs for the floodplain soil, approximately 3 to 4 mg/kg, and for the fine-grained sediment, approximately 8 to 11 mg/kg (Table C-1). For these types of materials, the PCB concentrations in the centrifuge outputs, as well as the mass-weighted PCB averages in the combined outputs, were higher. For the heterogeneous coarse-grained (S1) material, apart from the very largest output (cobble), the PCB concentrations of the individual outputs, as well as the mass-weighted averages, all exceeded 2 mg/kg and were generally substantially above that level (Table C-1 and Figure C-2). It is highly unlikely that this material could be reliably treated to levels anywhere close to 2 mg/kg, and possibly not even below 50 mg/kg unless the significant majority of high concentration finer grained material was separated from the coarser material and disposed of separately.

4. Comparison to Findings at Other Sites

The findings discussed above are similar to the conclusions reached regarding the applicability of the BioGenesis process at other PCB sites. For the Lower Duwamish Waterway Superfund Site, one of the conclusions in the Engineering Evaluation/Cost Analysis (EE/CA) for the Terminal 117 early action area was that BioGenesis "has not been able to provide mass balance information from the previous testing, and it is not known how much of the PCBs would simply be transferred to other waste streams such as sludges and wastewater" (WindWard Environmental et al. 2005). The EE/CA stated further that "EPA believes that BioGenesis is not viable for the early action sites in the Lower Duwamish Waterway Site because its effectiveness is unproven." In the Responsiveness Summary for the Terminal 117 EE/CA, EPA stated:

> "[N]one of the completed pilot tests of this treatment technology have treated the concentrations of PCBs that exist at T-117, or measured how much of the PCBs were actually destroyed. Residual risks associated with the treated soils and the various waste streams from this process have not been evaluated. At this time, EPA cannot determine the effectiveness of the Biogenesis or similar processes for the T-117 soils/sediments." (EPA 2005)

Similarly, for the Slip 4 early action area of the Lower Duwamish, EPA stated that "EPA believes that BioGenesis is not viable for the early action sites in the Lower Duwamish Waterway Site because its effectiveness is unproven" (EPA 2006).

The ROD Amendment for the Fox River concluded that, "[b]ased on initial PCB concentrations for Fox River sediments and PCB removal efficiency, the 1.0 ppm PCB remedial action limit for cleanup of the Fox River sediments often would not be achieved by the BioGenesis process" (EPA 2007).

Thus, data from other sites provide further support for the conclusion drawn from the bench-scale testing data using Rest of River sediment and soil – namely, that the BioGenesis process has not been demonstrated to be effective at achieving concentrations that could be considered for reuse at the site.

5. References

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EPA. 2007. Record of Decision Amendment, Operable Unit 2 (Deposit DD), Operable Unit 3, Operable Unit 4, and Operable Unit 5 (River Mouth) Lower Fox River and Green Bay Superfund Site. June 2007.

EPA. 2006. Responsiveness Summary for Public Comments on the Engineering Evaluation/Cost Analysis Slip 4 Early Action Area Lower Duwamish Waterway Superfund Site, Seattle, WA. May 5, 2006.

EPA. 2005. Responsiveness Summary for Public Comments on the Engineering Evaluation/Cost Analysis for the Terminal 117 Early Action Area, Lower Duwamish Superfund Site Seattle, WA. July 18, 2005.

Windward Environmental LLC; Dalton, Olmsted & Fuglevand, Inc; Onsite Enterprises, Inc. 2005. Lower Duwamish Waterway Superfund Site Terminal 117 Early Action Area; Terminal 117 Engineering Evaluation/Cost Analysis. July 13, 2005.

Tables

Table C-1 -- Summary of Bench Scale Treatability Study Results

Appendix C – Chemical Extraction Bench Scale Study Evaluation
Response to EPA Interim Comments on CMS Report, Housatonic River - Rest of River
General Electric Company - Pittsfield, MA

				PCB Concentration (mg/kg)									Summary	
	% Solids Data***			S1 - Course-Grained Sediment			S2 - Fine-Grained Sediment			S3 - Floodplain Soil			Total Number of Outputs	PCB Concentration Range (mg/kg) ***
Material Type/Run #	**S1**	**S2**	**S3**	**S1R1**	**S1R2**	**S1R3**	**S2R1**	**S2R2**	**S2R3**	**S3R1**	**S3R2**	**S3R3**		
Untreated Material Concentration (mg/kg)				74	62.6	80	177	110	139	55	45	50		
Untreated Material Average Initial Mass (kg)	74	30	32											
Treated Material Output														
Following First Treatment Cycle	**% of total recovered solids**													
greater than 6.35 mm* (cobble)	6-10	0	0	0.08	0.38	0.68	--	--	--	--	--	--		0.08 - 0.68
425 microns to 6.35 mm* (gravel)	69-79	0	0	2.7	2.8	25	--	--	--	--	--	--		2.7 - 25
75 to 425 micron (sand)	9-13	0	0	40.3	49.8	40.6	--	--	--	--	--	--		40.3 - 49.8
hydrocyclone solids (medium to coarse silt)	2-3	23-36	55-65	60	55.3	54.7	21.6	20.2	16.3	5.4	4.8	6.5		4.8 - 60.0
centrifuge solids (fine silt and clay)	4-5	53-69	25-36	143	133	134	60	8.6	43.8	40	44	7.4	**27**	7.4 - 143
mass weighted average				**12.5**	**15.9**	**29.7**	**48.4**	**11.5**	**32.7**	**19.2**	**17.3**	**6.8**		
	solids lost (% of initial mass)													
	18-33	11-31	25-40											
Following Two Treatment Cycles	**% of total recovered solids**													
75 to 425 micron (sand)	5 -9			34.7	25.6	50.8	--	--	--	--	--	--		25.6 - 50.8
hydrocyclone solids (medium to coarse silt)	0.3-3	21-32	42-58	207	53.2	33.4	12.9	11.9	8.4	4.4	2.6	4.2		2.6 - 207
centrifuge solids (fine silt and clay)	2-3	42-58	18-31	96	300	96	29.6	21.5	25.7	24	12	40	**21**	12 - 300
mass weighted average				**8.4**	**10.6**	**27.3**	**25.2**	**18.9**	**18.1**	**12.4**	**5.7**	**12.6**		
	solids lost (% of initial mass)													
	23-37	42-54	29-54											
Following Three Treatment Cycles	**% of total recovered solids**													
75 to 425 micron (sand)	2-6			23.9	24.4	10.1	--	--	--	--	--	--		10.1 - 24.4
hydrocyclone solids (medium to coarse silt)	0.3-2	10-17	32-48	79	34.1	40.4	11.1	10.7	8.6	3.9	2.6	3.1		2.6 - 79
centrifuge solids (fine silt and clay)	0.5-2	37-50	16-24	73	92	41.8	15.3	11.4	22.9	15	7.3	24	**21**	7.3 - 92
mass weighted average				**4.6**	**6.6**	**21.8**	**14.6**	**11.3**	**18.4**	**8.2**	**4.2**	**8.5**		
	solids lost (%of initial mass)													
	26-39	55-59	23-60										**Overall Summary**	
													69	**0.08 - 300**
Wastewater**														
PCB Concentration (ug/L)				1,520	3,340	2,310	660	1,450	720	280	160	200		
TSS Concentration (mg/L)				1,260	1,310	1,700	4,010	4,540	6,030	4,590	12,800	5,580		

Results are summarized from Tables 4-1 through 4-9 in the Treatability Study Report (Appendix A to the CMS Report)
* fraction not included in subsequent treatment cycles
** wastewater collected following three cycles for S1 and S2 and following the first cycle for S3
***where applicable, the range for the 3 runs is presented.

Table C-2 - Bench Scale Treatability Study Solids Data

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Response to EPA Interim Comments on CMS Report, Housatonic River - Rest of River
General Electric Company - Pittsfield, MA

	mass of solids (kg)	% of recovered solids	% of initial solids[1]	solids lost (%)[2]	mass of solids (kg)	% of recovered solids	% of initial solids[1]	solids lost (%)[2]	mass of solids (kg)	% of recovered solids	% of initial solids[1]	solids lost (%)[2]
Material Type/Run #	**S1R1**				**S1R2**				**S1R3**			
Untreated Material Initial Mass (kg)	52.4				59.4				69			
Treated Material Output												
Following First Treatment Cycle												
greater than 6.35 mm* (cobble)	2.4	5.5%	4.6%		2.8	6.8%	4.7%		4.5	9.8%	6.5%	
425 microns to 6.35 mm* (gravel)	33.8	78.6%	64.5%		29.6	72.7%	49.8%		31.9	69.2%	46.2%	
75 to 425 micron (sand)	4.0	9.2%	7.6%		4.8	11.8%	8.1%		6.1	13.3%	8.8%	
hydrocyclone solids (medium to coarse silt)	1.0	2.3%	1.9%		1.4	3.4%	2.4%		1.3	2.8%	1.9%	
centrifuge solids (fine silt and clay)	1.6	3.6%	3.1%		1.8	4.5%	3.0%		1.9	4.0%	2.8%	
Total:	**42.7**	**99.2%**	**81.7%**		**40.5**	**99.2%**	**68.0%**		**45.7**	**99.1%**	**66.2%**	
Solids Lost (%):				**17.9%**				**31.3%**				**33.1%**
Following Two Treatment Cycles												
75 to 425 micron (sand)	2.2	5.4%	4.2%		3.6	9.4%	6.1%		4.0	9.1%	5.8%	
hydrocyclone solids (medium to coarse silt)	0.3	0.8%	0.6%		1.0	2.6%	1.7%		0.9	2.1%	1.3%	
centrifuge solids (fine silt and clay)	1.1	2.6%	2.1%		0.6	1.5%	1.0%		1.5	3.4%	2.2%	
Total:	**3.6**	**98.4%**	**76.0%**		**5.2**	**98.4%**	**63.3%**		**6.4**	**98.2%**	**62.0%**	
Solids Lost (%):				**23.0%**				**35.7%**				**36.7%**
Following Three Treatment Cycles												
75 to 425 micron (sand)	0.9	2.4%	1.7%		2.1	5.7%	3.5%		2.6	6.2%	3.8%	
hydrocyclone solids (medium to coarse silt)	0.3	0.8%	0.6%		0.9	2.4%	1.5%		0.7	1.6%	1.0%	
centrifuge solids (fine silt and clay)	0.5	1.4%	1.0%		0.8	2.2%	1.3%		1.0	2.4%	1.4%	
Total:	**1.7**	**97.5%**	**72.3%**		**3.8**	**97.5%**	**60.9%**		**4.3**	**97.2%**	**59.0%**	
Solids Lost (%):				**25.7%**				**37.4%**				**39.2%**

Material Type/Run #	**S2R1**				**S2R2**				**S2R3**			
Untreated Material Initial Mass (kg)	8.1				10.3				10.9			
Following First Treatment Cycle												
hydrocyclone solids (medium to coarse silt)	2.1	28.2%	25.9%		1.8	23.3%	17.5%		2.7	35.9%	24.8%	
centrifuge solids (fine silt and clay)	4.7	65.0%	58.0%		5.4	69.4%	52.4%		4.0	53.2%	36.7%	
Total:	**6.8**	**93.3%**	**84.0%**		**7.3**	**92.7%**	**69.9%**		**6.7**	**89.1%**	**61.5%**	
Solids Lost (%):				**10.6%**				**23.9%**				**31.2%**
Following Two Treatment Cycles												
hydrocyclone solids (medium to coarse silt)	1.0	20.8%	12.3%		1.0	20.7%	9.7%		2.0	32.5%	18.3%	
centrifuge solids (fine silt and clay)	2.7	58.3%	33.3%		2.6	55.4%	25.2%		2.6	41.6%	23.9%	
Total:	**3.7**	**79.2%**	**45.7%**		**3.6**	**76.1%**	**35.0%**		**4.7**	**74.1%**	**42.2%**	
Solids Lost (%):				**42.3%**				**53.7%**				**42.1%**
Following Three Treatment Cycles												
hydrocyclone solids (medium to coarse silt)	0.4	9.7%	4.9%		0.5	12.2%	4.9%		0.9	16.8%	8.3%	
centrifuge solids (fine silt and clay)	1.9	50.5%	23.5%		2.0	47.3%	19.4%		2.0	37.2%	18.3%	
Total:	**2.2**	**60.2%**	**28.4%**		**2.5**	**59.5%**	**24.3%**		**2.9**	**54.0%**	**26.6%**	
Solids Lost (%):				**54.6%**				**59.1%**				**51.0%**

Material Type/Run #	**S3R1**				**S3R2**				**S3R3**			
Untreated Material Initial Mass (kg)	17.2				24.8				21.1			
Following First Treatment Cycle												
hydrocyclone solids (medium to coarse silt)	5.7	54.9%	33.1%		10.5	56.2%	42.3%		9.5	64.0%	45.0%	
centrifuge solids (fine silt and clay)	3.8	36.4%	22.1%		4.9	26.4%	19.8%		3.7	25.4%	17.5%	
Total:	**9.5**	**91.3%**	**55.2%**		**15.4**	**82.6%**	**62.1%**		**13.2**	**90.4%**	**62.6%**	
Solids Lost (%):				**39.5%**				**24.9%**				**30.6%**
Following Two Treatment Cycles												
hydrocyclone solids (medium to coarse silt)	3.6	45.8%	20.9%		7.4	42.1%	29.8%		6.8	58.5%	32.2%	
centrifuge solids (fine silt and clay)	2.5	31.4%	14.5%		3.7	21.1%	14.9%		2.1	17.8%	10.0%	
Total:	**6.1**	**77.2%**	**35.5%**		**11.2**	**63.2%**	**44.8%**		**8.9**	**76.0%**	**42.2%**	
Solids Lost (%):				**53.7%**				**28.9%**				**52.7%**
Following Three Treatment Cycles												
hydrocyclone solids (medium to coarse silt)	2.6	37.0%	15.1%		6.2	32.3%	25.0%		5.8	48.1%	27.5%	
centrifuge solids (fine silt and clay)	1.6	23.6%	9.3%		3.2	16.5%	12.9%		2.0	16.7%	9.5%	
Total:	**4.2**	**60.6%**	**24.4%**		**9.3**	**48.9%**	**37.9%**		**7.8**	**64.8%**	**37.0%**	
Solids Lost (%):				**59.8%**				**23.3%**				**51.6%**

Data are reported from Tables 4-1 through 4-9 in the Treatability Study Report (Appendix A to the CMS Report) except as noted below.

1 Percent of initial solids calculated as the mass recovered/initial mass *100.

2 Solids lost are from Tables 4-1 through 4-9 in the Treatability Study Report and account for the solids recovered in wastewater.

* fraction not included in subsequent treatment cycles

Table C-3 -- Summary of PCB and TSS Concentrations in Wastewater and Calculated Concentration of PCB on Solids

Appendix C – Chemical Extraction Bench Scale Study Evaluation
Response to EPA Interim Comments on CMS Report, Housatonic River - Rest of River
General Electric Company - Pittsfield, MA

Material Type	Material Type and Run #	Initial Untreated Material Average PCB Concentration (mg/kg)	Total PCB (ug/L)*	Dissolved (Filtered) PCB (ug/L)	TSS (mg/L)*	Calculated PCB on Solids in Wastewater (mg/kg)**	Average Calculated PCB Concentration on Solids in Wastewater (mg/kg)
	S1R1		1,520	36	1,260	1,178	
S1	S1R2	72	3,340	30.7	1,310	2,526	1,687
	S1R3		2,310	2.7	1,700	1,357	
	S2R1		660	0.93	4,010	164	
S2	S2R2	142	1,450	1.1	4,540	319	201
	S2R3		720	ND	6,030	119	
	S3R1		280	3.2	4,590	60	
S3	S3R2	50	160	2.45	12,800	12	36
	S3R3		200	0.36	5,580	36	

* wastewater collected following three cycles for S1 and S2 and following the first cycle for S3
**calculated as (total PCB concentration-dissolved PCB)/TSS concentration x 1,000 gm/kg

Table C-4 -- Summary of Treated Material PCB Concentrations and Percent Reduction Following Multiple Treatment Cycles

Appendix C – Chemical Extraction Bench Scale Study Evaluation
Response to EPA Interim Comments on CMS Report, Housatonic River - Rest of River
General Electric Company - Pittsfield, MA

Material and Run #	Untreated Material PCB Concentration (mg/kg)	1 Cycle			2 Cycles			3 Cycles		
		PCB Weighted Average Concentration (mg/kg)	Percent PCB Reduction*	Percent Solids Loss*	PCB Weighted Average Concentration (mg/kg)	Percent PCB Reduction*	Percent Solids Loss*	PCB Weighted Average Concentration (mg/kg)	Percent PCB Reduction*	Percent Solids Loss*
S1R1	74	13	83%	18%	8	89%	23%	5	94%	26%
S1R2	63	16	75%	32%	11	83%	36%	7	90%	37%
S1R3	80	30	63%	33%	27	66%	37%	22	73%	39%
S2R1	177	48	73%	11%	25	86%	42%	15	92%	55%
S2R2	110	12	90%	24%	19	83%	54%	11	90%	59%
S2R3	139	33	76%	31%	18	87%	42%	18	87%	51%
S3R1	55	19	65%	40%	12	77%	54%	8	85%	60%
S3R2	45	17	62%	25%	6	87%	29%	4	91%	23%
S3R3	50	7	86%	31%	13	75%	53%	9	83%	52%
minimum	45	6.8	62%	11%	5.7	66%	23%	4.2	73%	23%
maximum	177	48	90%	40%	27	89%	54%	22	94%	60%

*Percentages of PCBs and percent solids are cumulative (i.e., calculated from the initial concentration and mass)

Figures

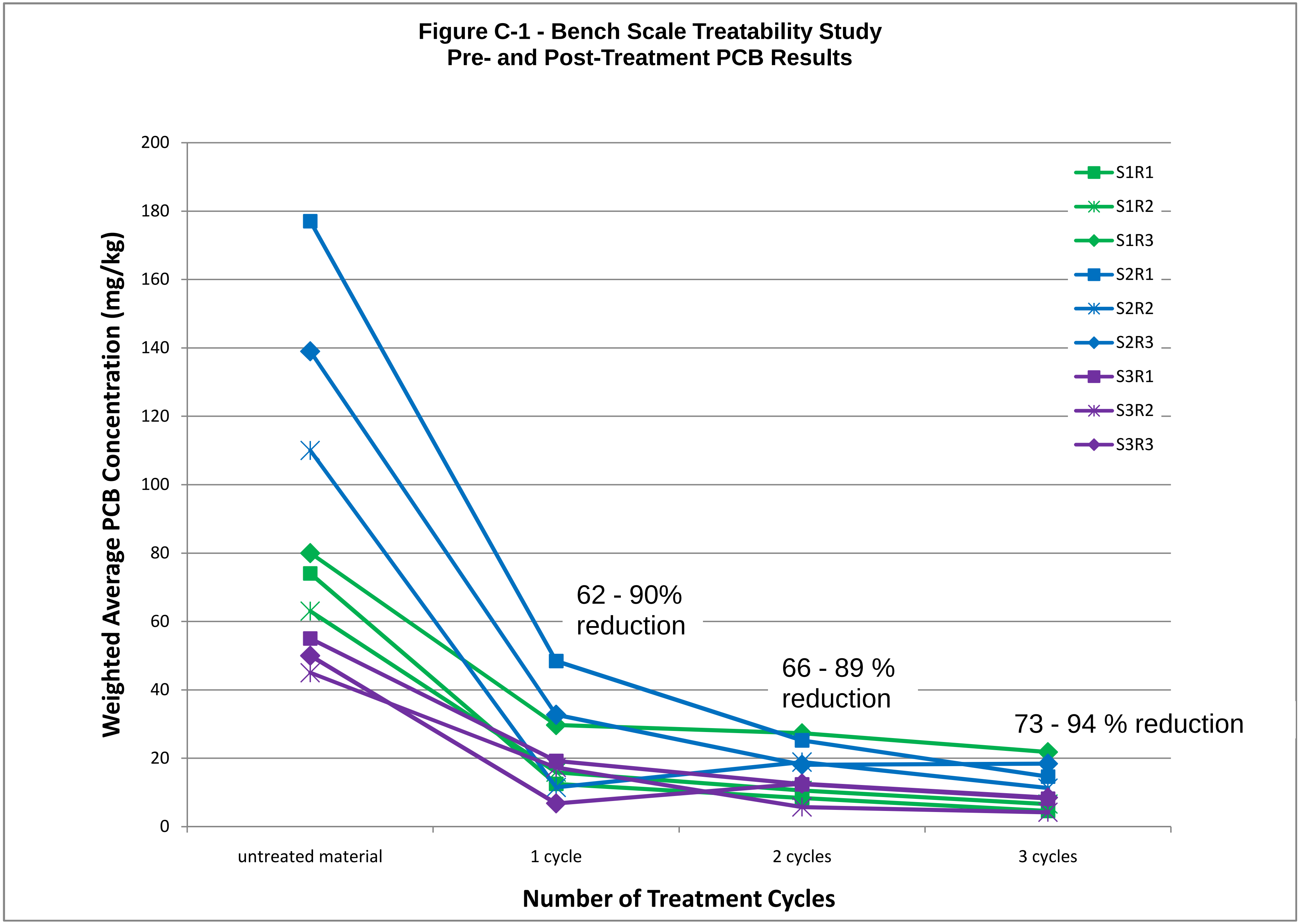
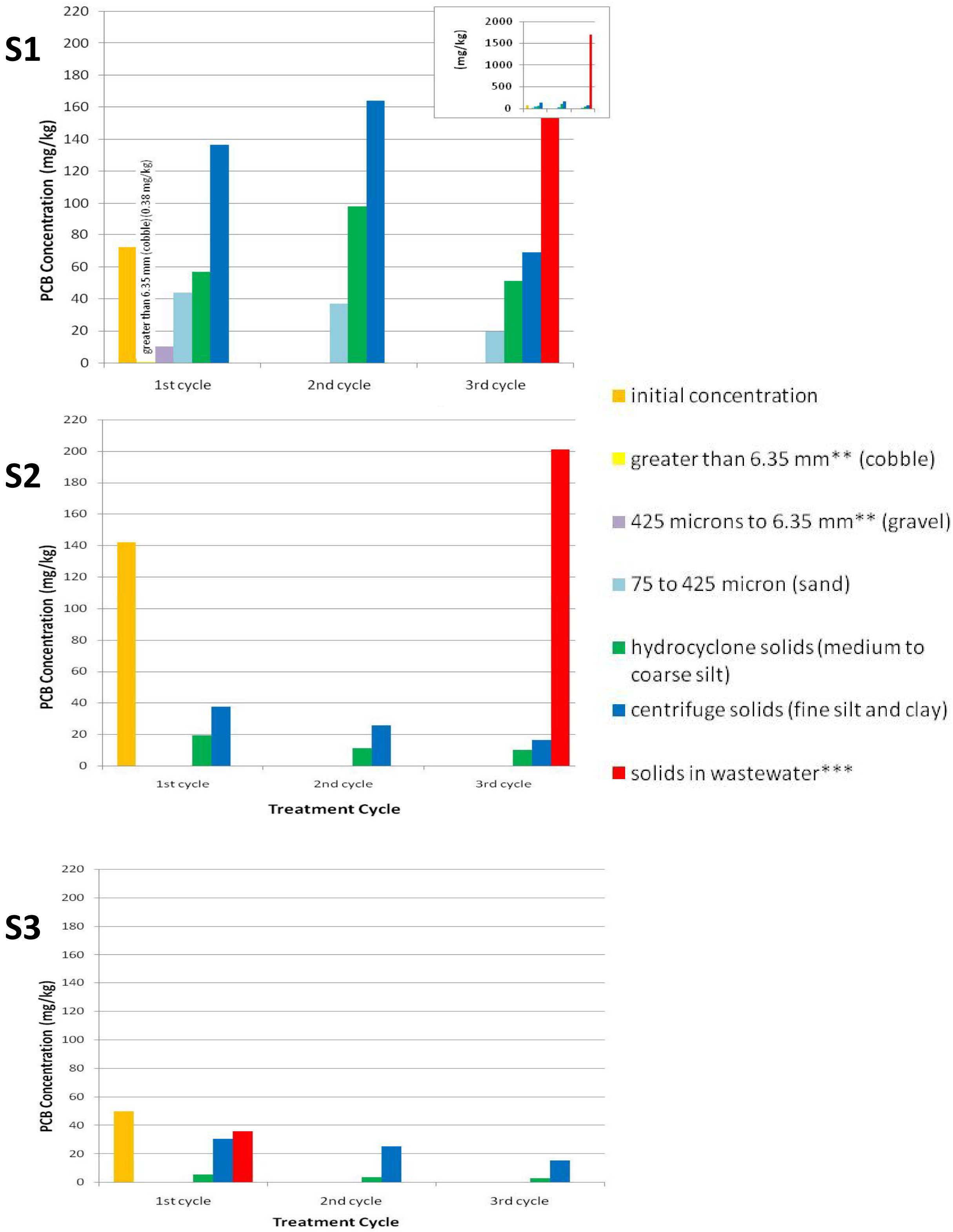


Figure C-1 - Bench Scale Treatability Study
Pre- and Post-Treatment PCB Results
Weighted Average PCB Concentration (mg/kg)
200
180
160
140
120
100
80
60
40
20
0
untreated material
1 cycle
2 cycles
3 cycles
Number of Treatment Cycles
62 - 90% reduction
66 - 89 % reduction
73 - 94 % reduction
S1R1
S1R2
S1R3
S2R1
S2R2
S2R3
S3R1
S3R2
S3R3

Figure C-2 - Average PCB* Concentrations of Bench Scale Inputs and Outputs Chemical Extraction Bench Scale Study Evaluation



*Data presented are the averages from 3 runs

** Fraction was generated from first cycle only and was not included in subsequent treatment cycles

***Waste water collected following three cycles for S1 and S2 and following the first cycle for S3

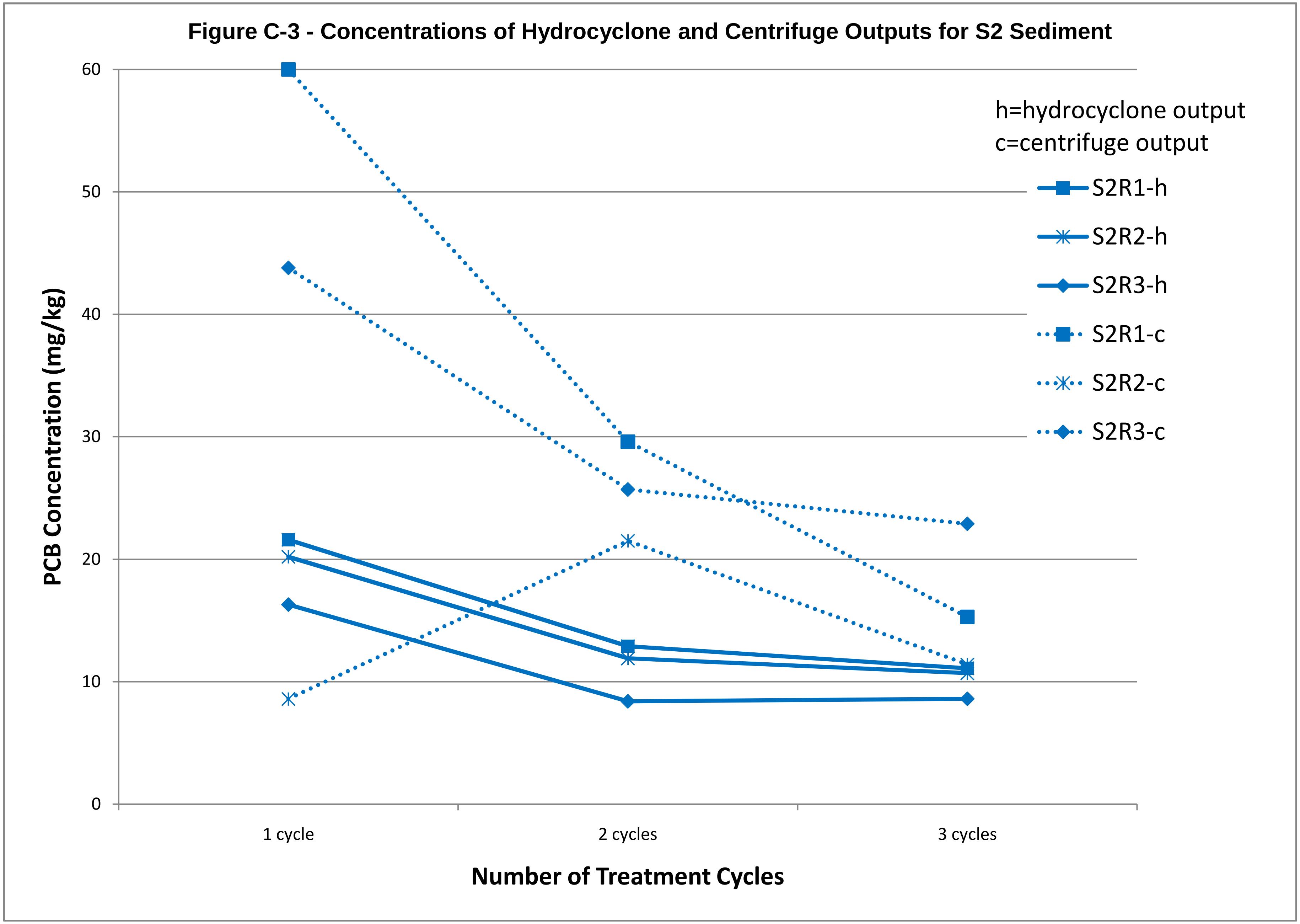


Figure C-3 - Concentrations of Hydrocyclone and Centrifuge Outputs for S2 Sediment
60
50
40
30
20
10
0
PCB Concentration (mg/kg)
1 cycle
2 cycles
3 cycles
Number of Treatment Cycles
h=hydrocyclone output
c=centrifuge output
S2R1-h
S2R2-h
S2R3-h
S2R1-c
S2R2-c
S2R3-c

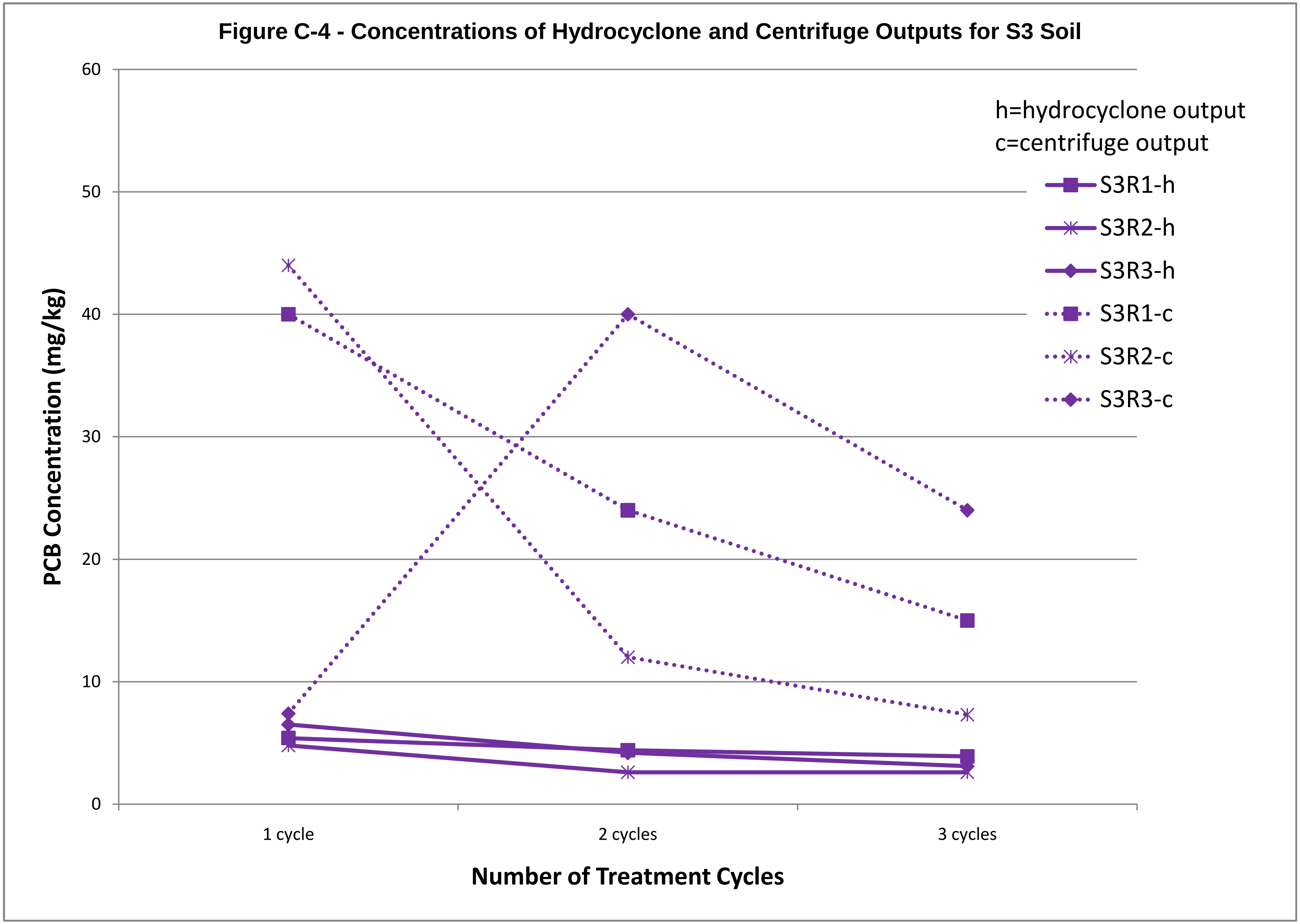


Figure C-4 - Concentrations of Hydrocyclone and Centrifuge Outputs for S3 Soil
PCB Concentration (mg/kg)
60
50
40
30
20
10
0
1 cycle
2 cycles
3 cycles
Number of Treatment Cycles
h=hydrocyclone output
c=centrifuge output
S3R1-h
S3R2-h
S3R3-h
S3R1-c
S3R2-c
S3R3-c

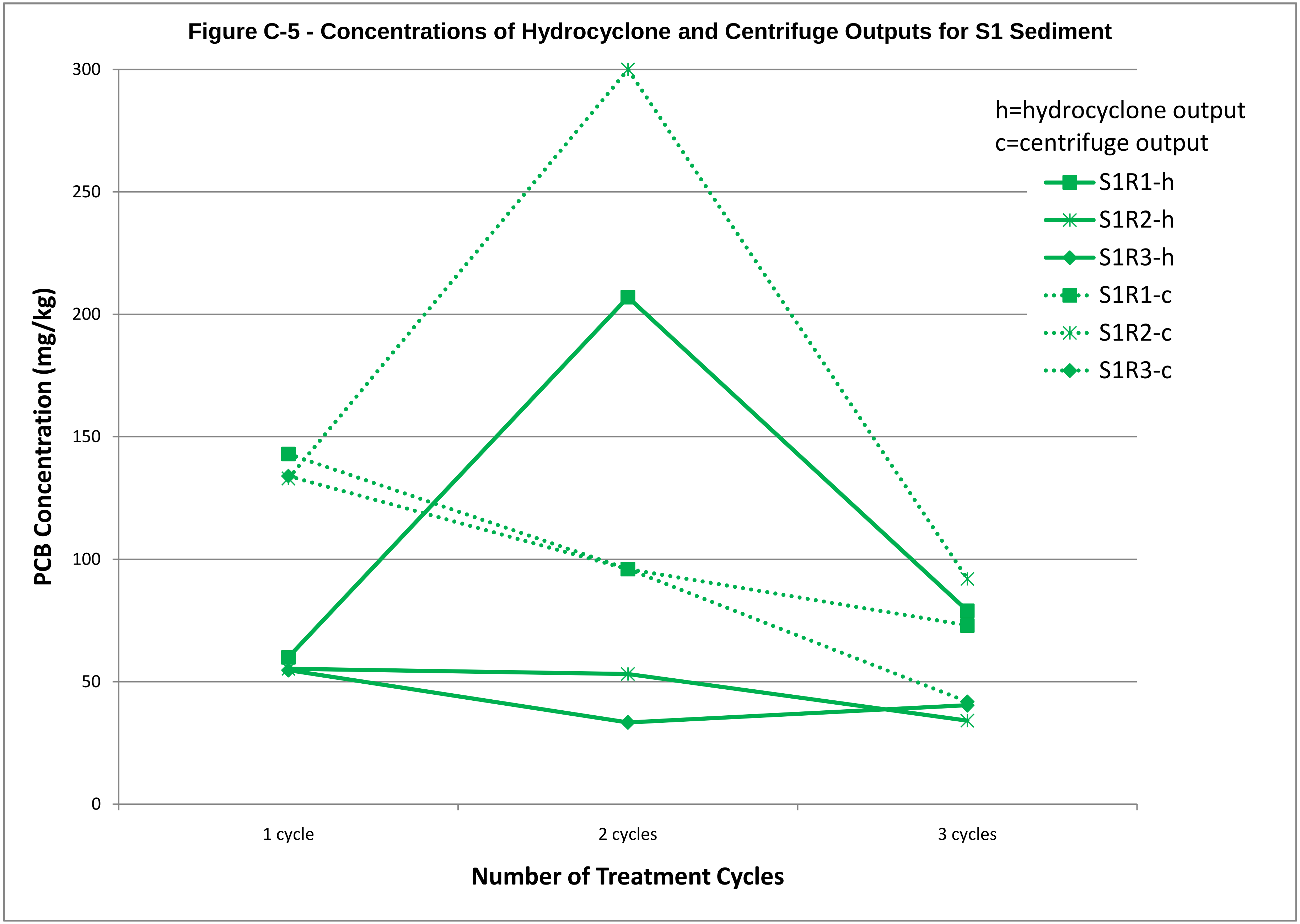


Figure C-5 - Concentrations of Hydrocyclone and Centrifuge Outputs for S1 Sediment
PCB Concentration (mg/kg)
300
250
200
150
100
50
0
1 cycle
2 cycles
3 cycles
Number of Treatment Cycles
h=hydrocyclone output
c=centrifuge output
S1R1-h
S1R2-h
S1R3-h
S1R1-c
S1R2-c
S1R3-c

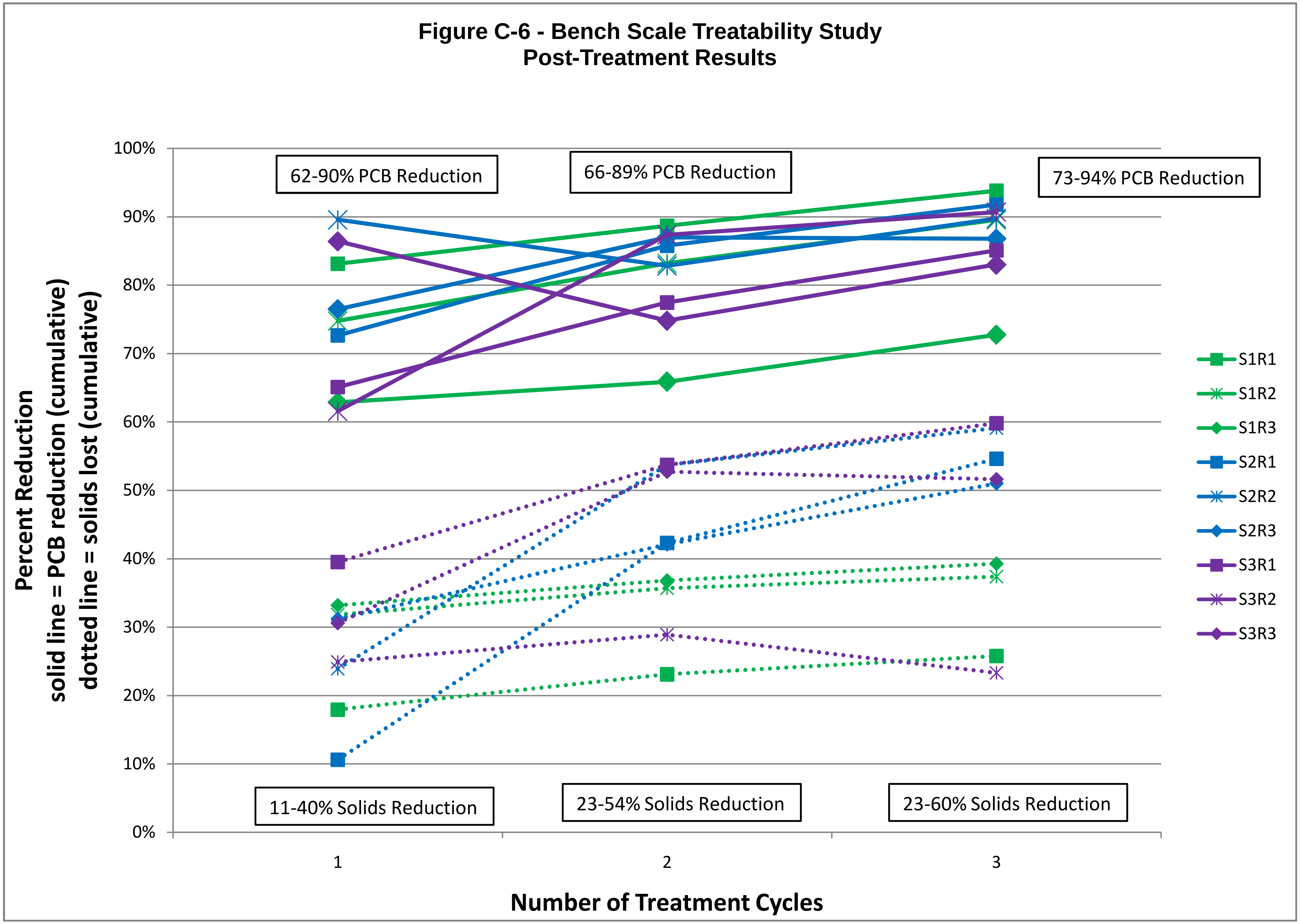


Figure C-6 - Bench Scale Treatability Study
Post-Treatment Results
Percent Reduction
solid line = PCB reduction (cumulative)
dotted line = solids lost (cumulative)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
62-90% PCB Reduction
66-89% PCB Reduction
73-94% PCB Reduction
11-40% Solids Reduction
23-54% Solids Reduction
23-60% Solids Reduction
1
2
3
Number of Treatment Cycles
S1R1
S1R2
S1R3
S2R1
S2R2
S2R3
S3R1
S3R2
S3R3