3. Monitoring

The S1/S4 beach barrier will be monitored in future years by collecting water, sediment and filter samples. Water may not be present during site visits in the summer. It is expected that very large volumes of sediment will be collected in the traps during the first few years which will make removing it a challenging task with limited equipment. The larger filter box with three units was used to increase the filtering capacity of the barrier. It is anticipated that the PCB level in the trapped soil will be in the Tier I/Tier II range.

Twelve filters were placed in the filter box as shown in Figure VI-5 on 28 August 2005. These will be sampled in 2006 and replaced with fresh ones. With the new steel box design, it was possible to place four filters per box. Because of this, the arrangement of filters were placed in such a manner as to promote the best possible filtration arrangement to deal with large quantities of sediment. The front row of gravel was filled only half full. Once this initial trap is clogged with sediment, water can flow over the trap and into the space in front of the second gravel filter. The second row of gravel filters were filled to the top with gravel to help 'protect' the GAC filters. The first row of GAC was of the larger particle size and the last row of GAC consisted of smaller particle sized GAC, to encourage a 'polishing step', without the use of geotextile. The success of this filter arrangement will be monitored in 2006.

Figure VI-5: Arrangement of Filters and Sorbents in the S1/S4 Beach Filter Box at the End of the 2005 Field Season

GAC	**GAC**	**GAC**
GAC	**GAC**	**GAC**
Gravel	**Gravel**	**Gravel**
Gravel	**Gravel**	**Gravel**

Direction of Flow

D. Furniture Dump Barrier

1. General

The furniture dump and its drainage pathway were excavated in 1999. Transformers containing nearly pure PCBs were removed from the dump. All soil containing > 1 ppm PCB was removed from the original dump and its drainage pathway and large areas of exposed boulders were washed and vacuum cleaned.

In 2003, an experimental barrier was designed and constructed. The filter box system was constructed of wood so as to permit easy design modifications. The topography at the end of the dump drainage pathway where it reaches the top of huge cliffs was ideal for constructing a funnel without need for gabions. The original purpose of this barrier was used to obtain further information on the performance of the barrier system rather than as a necessary interceptor of residual PCBs. Results of analyses of sediment and filters in 2004, however, showed that PCBs were being transported in the drainage pathway and were still present in the area previously occupied by the Furniture dump and in the drainage pathway leading from it. This was despite considerable effort to remove any soil found to contain > 1 ppm PCBs with the vacuum truck; normally vacuuming is only undertaken for CEPA areas.

At the beginning of the 2004 season, it was observed that although most of the run-off was being captured by the funnel, there were two minor streams on either side of the barrier where water (and contaminated sediment) were able to flow through. These bypasses were intercepted with gravelbags and culverts to divert water into the funnel. Analyses of water and sediment from the barrier in 2004 confirmed what has been found in the S1/S4 valley; that is, water was contaminated with very low-levels of PCB. PCBs were predominantly trapped on particles and therefore the trapping of contaminated sediment was the primary goal of the barrier system. At the end of the 2005 season, gravel and GAC filters were placed in the filter box as shown in Figure VI-6. Because of the amount of PCBs trapped by the furniture dump barrier in 2004 it was decided to replace it with a permanent stainless steel one in 2005, as described in the following section.

Figure VI-6: Arrangement of Filters in the Furniture Dump Filter Box at the Start of the 2005 Field Season

GAC	**GAC**
Gravel	**Gravel**
empty	**empty**
empty	**empty**

↑ Direction of Flow

2. 2005 Barrier Modifications

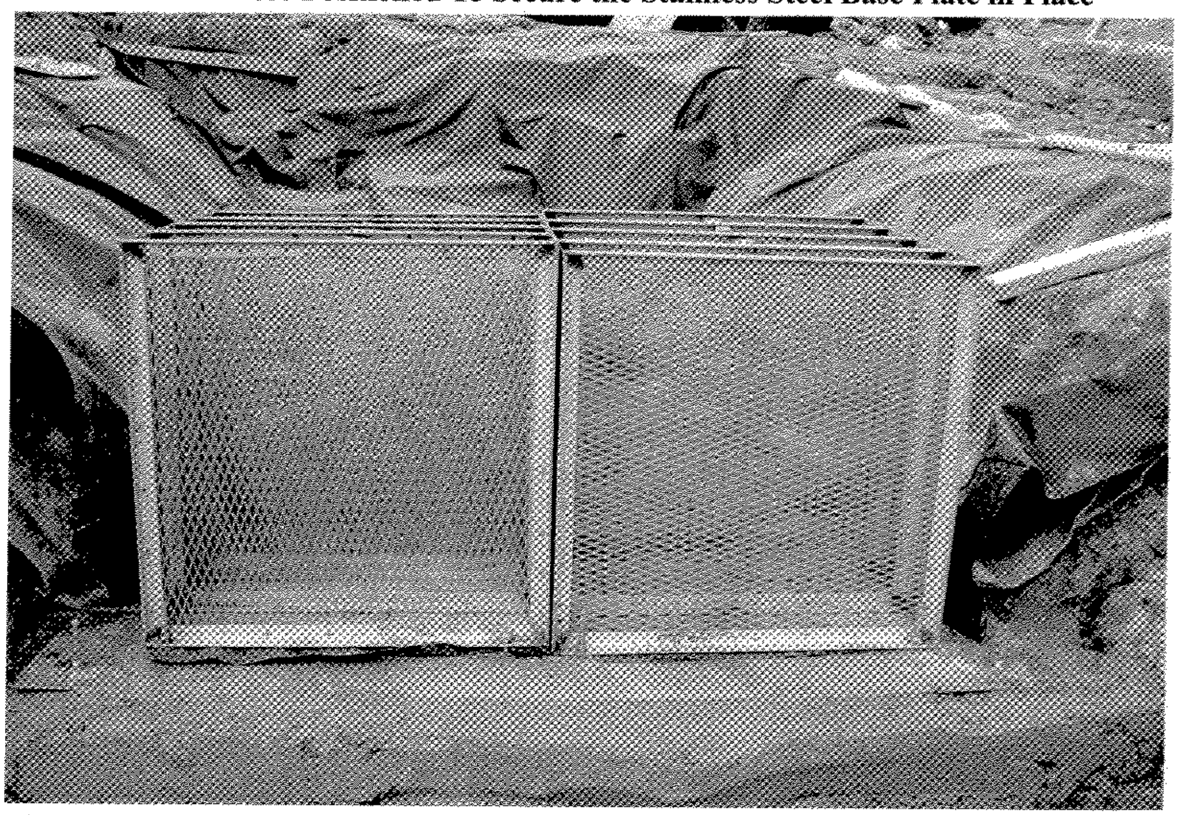
The barrier was inspected on 29 June 2005. It was observed that the barrier had stood up well to the winter weather and the spring runoff. Very little soil had been collected by the trap. Approximately 100 L of sediment was shoveled from the trap and transported to the Tier II landfill in an action packer by an ATV and trailer. The filters were removed from the box and sampled. As no water was flowing and little sediment had been collected, the filter box was left open. On 8 August 2005 the wooden filter box was removed and replaced with a stainless steel one. This involved creating a solid flat concrete base for the box (Photograph VI-15) and sealing the sides of the box to the lined catchment area (Photograph VI-16). New GAC and gravel filters were then placed in the filter box on 13 August 2005 as shown in Figure VI-7.

Figure VI-7: Arrangement of Filters in the Furniture Dump Filter Box at the End of the 2005 Field Season

GAC	**GAC**
GAC	**GAC**
Gravel	**Gravel**
Gravel	**Gravel**

↑ Direction of Flow

Photograph VI-15: After Removing the Wooden Filter Box, a Concrete Base was Poured and Rock Bolts were Positioned To Secure the Stainless Steel Base Plate in Place



Photograph VI-16: A New Stainless Steel Filter Box was then Placed Over the Lined Catchment Zone in the Furniture Dump Drainage Pathway

3. Monitoring

a) <u>Water</u>

A water sample collected on 11 July 2005 was analysed for PCBs. A relatively high result of 0.89 ppb was found.

b) <u>Sediment</u>

Six sediment samples were collected for analysis from the locations given in Table VI-5. There was very little soil and so the results given in Table VI-5 are from small volumes of sediment trapped in isolated pockets. The high values found paint a similar picture to the results obtained in 2004, that is, that there are small quantities of sediment contaminated at higher concentrations than found in the S1/S4 valley. This is likely due to the very highly contaminated soils that were found in the furniture dump and which although they were removed small quantities remain. The total amount of pure PCBs removed with the sediment was approximately 2.2 g.

Table VI-5: PCB Concentration of Sediment Samples From the Furniture Dump Barrier System After Spring Runoff

Sample Number	Units	PCB Concentration	Location
RI05-134	ug/g	24	In main sediment trap
RI05-135	ug/g	<1.0	In front of Sinnani sediment trap
RI05-136	ug/g	58	In front of Sinnani sediment trap
RI05-137	ug/g	31	Between the barrier and the cliff
RI05-138	ug/g	2.8	Near cliff edge to the south of the barrier

c) <u>Filters</u>

The four filter cassettes removed from the filter box on 7 August 2005 were sampled in the same manner as for the S1/S4 filter cassettes. Results of analyses of their contents are given in Table VI-6. Most results were below the limit of 0.5 ppm. The mass of PCB collected in the gravel filters was 33 mg and by the GAC was 48 mg.

The amount of PCB collected on the filters was much lower in 2005 than in 2004. This knowledge, combined with several other key pieces of evidence indicate that the barrier system would benefit with the re-introduction of geotextile filters, however, the hydraulic performance of the barrier must still be taken into consideration. By reducing the vertical height of the geotextile filters, it may be possible to trap PCB contaminated fines without impeding water flow through the barrier.

Table VI-6: PCB Concentration of Filter Box Materials From the Furniture Dump Barrier System in Operation From 9 July 2004 to 7 August 2005

Sample No	Units	Medium	Location	PCB Conc.
RI05-330	ug/g	Gravel	Left filter bottom third	1.8
RI05-331	ug/g	Gravel	Left filter middle third	<0.5
RI05-332	ug/g	Gravel	Left filter top third	<0.5
RI05-344	ug/g	Gravel	Right filter bottom third	1.4
RI05-345	ug/g	Gravel	Right filter middle third	<0.5
RI05-346	ug/g	Gravel	Right filter top third	<0.5
RI05-347	ug/g	GAC	Left filter bottom third	<0.5
RI05-348	ug/g	GAC	Left filter middle third	<0.5
RI05-349	ug/g	GAC	Left filter top third	<0.5
RI05-355	ug/g	GAC	Right filter bottom third	9.3
RI05-356	ug/g	GAC	Right filter middle third	<0.5
RI05-357	ug/g	GAC	Right filter top third	<0.5

d) metals

High levels of cadmium (0.004 ppm), copper (0.406 ppm), nickel (0.527 ppm) and zinc (0.220 ppm) were found in the water from the furniture dump runoff above the barrier this year. Last year the respective levels were (<0.001 ppm), (0.088 ppm), (0.078 ppm) and (0.048 ppm). These high results may represent the leaching of metals from the disturbed area. Some copper was trapped by the GAC but metal levels in the GAC were all less than in the sediment.

Table VI-7: Metal Concentrations the Furniture Dump Barrier System (ppm)

Sample	Date Sampled	Material	Cobalt	Copper	Nickel	Zinc
RI05-015W	11 July 2005	Water	0.082	0.406	0.527	0.220
RI05-134	11 July 2005	Sediment	6.2	56	16.9	31
RI05-137	11 July 2005	Sediment	8.1	108	24	52
RI05-347	8 August 2005	GAC	<5.0	45	10.7	<15
RI05-348	8 August 2005	GAC	<5.0	21	<5.0	<15
RI05-349	8 August 2005	GAC	<5.0	10.1	<5.0	<15
RI05-355	8 August 2005	GAC	<5.0	38	7.8	<15
RI05-356	8 August 2005	GAC	<5.0	16.1	<5.0	<15
RI05-357	8 August 2005	GAC	<5.0	7.3	<5.0	<15
RI05-330	8 August 2005	Gravel	5.5	21	21	21
RI05-330D	8 August 2005	Gravel	6.2	20	25	22
RI05-331	8 August 2005	Gravel	6.1	18.7	21	22
RI05-332	8 August 2005	Gravel	6.4	19.6	24	21
RI05-344	8 August 2005	Gravel	5.3	17.4	24	20
RI05-345	8 August 2005	Gravel	<5.0	19.4	18.1	16
RI05-346	8 August 2005	Gravel	5.5	22	24	18

E. Laboratory Studies

As part of determining the most suitable materials to use in the barrier, it is important to conduct laboratory studies that can confirm and support observations and data obtained in the field. The need for batch tests and column tests of the barrier materials was outlined in the 2003 ASU report. From the 2003 field data, it was seen that the most effective adsorbent in the barrier was found to be the GAC filter. At the time, it was not known whether this was due to the adsorptive properties of the GAC filter, or due to its nature as a granular filter. To improve hydraulic performance of the barrier, granular filters were placed in the barrier system at the end of the 2004 field season. In 2005, it was seen that the barrier materials were effective in trapping large amounts of PCB contaminated soil, while maintaining good flow through the filters. However, by increasing the hydraulic performance of the barrier, it is possible that PCB fines are escaping the system.

In the laboratory, it is possible to evaluate barrier materials using batch and column tests. Batch tests can evaluate filter material under static equilibrium conditions and can give good indications for effective PCB adsorbing materials under these specific sets of conditions. Column tests evaluate filter materials under dynamic equilibrium conditions and are more indicative of how filter materials behave under field conditions.

At this point in time, it is thought that the main function of the GAC filter is particle retention, while adsorbing some PCBs from water. The GAC filter is still important to use in the barrier system to treat the PCB contaminated water. Preliminary batch studies were conducted in 2005 to examine differences in GAC particle size and their effects on adsorption of PCBs as well as particle retention. Two different types of GAC are being evaluated: BC1240, the initial GAC used, which is being sieved to a uniform particle size of 2 mm; and CNS612, which has a particle size of 2 mm – 3.35 mm and was introduced to the barrier system in the 2004 field season.

If the primary function of the GAC turns out to be particle retention, as is being hypothesized, it may be possible to move to a less expensive material, such as gravel or sand that will be as effective as the GAC material in filtering out PCB contaminated soil. Column studies are being conducted to examine whether this is the case and will help to optimize the design for filtration in the barrier system.

1. *Batch tests*

Batch tests were conducted in 2005 to evaluate adsorption of PCBs between the two different types of GAC. In the current barrier system, a larger particle size in the GAC filter is required to improve hydraulic performance of the barrier. However, as particle size of the carbon is increased, the number of adsorption sites for PCBs are decreased, thus reducing the overall capacity for sorption of the filter, as well as reducing the availability of sorption sites for higher velocity flows of PCB contaminated water through the barrier. Rapid adsorption of PCBs from water is still a necessary function that the GAC must perform and therefore it was important to investigate whether increased particle size hindered adsorption behaviour. In batch tests, a sample of the material to be tested (1.0000 ± 0.0005 g) was added to a bottle of water containing a known amount of PCBs and shaken for a known time period. At the end of this time, solid and liquid were separated and analysed for PCBs. All samples were air dried prior to testing and analysed using the Soxhlet extraction procedure. Each series of experiments consisted of a sample of adsorbent (GAC), with various PCB in water concentrations, plus a sample blank and one Aroclor 1260 spike. Samples were mixed 24 hours on a rotating apparatus to ensure that the reactions reached equilibrium, previously determined from experiments in 2003/2004. The PCB on the adsorbent and in the water were both analyzed and the corresponding adsorption efficiencies were determined[1].

The procedure was conducted as follows. Distilled, deionized water (800 mL) was added to a 1 L Teflon bottle. To this water, Aroclor 1260 (1000 μg/mL) was added, in varying amounts. The resulting solution was tumbled in a revolving box, at a rate of 30 ± 2 rpm, as per Ontario Leachate Testing Regulations 558/00. After one hour of tumbling (to allow time for the solution to mix thoroughly), the bottles were removed and 1.0000 ± 0.0005g of pre-measured sample (sorbent) was added to the solution. The bottles containing 1260 Aroclor, water and geosynthetic were tumbled for 24 hours. At the end of the allotted period of time, the samples were then filtered through pre-weighed filter paper into separatory funnels. PCB analysis was performed on the resulting water. The

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[1] Crittenden, John C., Luft, Paul, Hand, David W., Oravitz, Jacqueline L., Loper, Scott W. and Metin Arl. 1985. Prediction of Multicomponent Adsorption Equilibria Using Ideal Adsorbed Solution Theory. Environmental Science and Technology, Vol. 19, No. 11, pp. 1037-1043.

bottles were rinsed and rinsate was poured through the funnels, to ensure that all material was retrieved. The solid samples were then allowed to dry prior to Soxhlet extraction.

Both GAC samples were spiked with 50 ug of 1260 Aroclor and run in triplicate. The BC1240 (particle size 2 mm) retained 55 ug of 1260 Aroclor, whereas the CNS612 (particle size 2 – 3.35 mm) retained 45 ug of 1260 Aroclor. Standard deviations were found to be less than significant digits. The method error is ± 5 ug, so there was no discernible difference in adsorption between the two types of GAC.

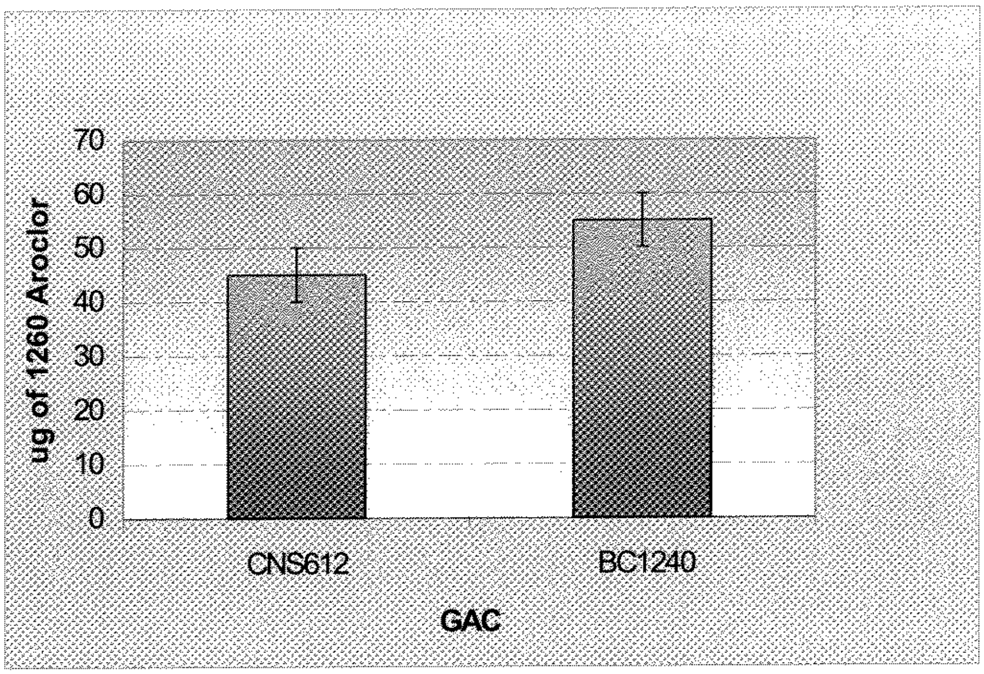

Figure VI-8: Total ug of Aroclor 1260 retained by two different types of GAC (BC1240 and CNS612).

Batch studies were also conducted on the tubing to be used for the column apparatus experiments. Since PCB contaminated water would be flowing through the tubing, it was important to evaluate how much would be lost to the tubing to be able to establish proper mass balances. Results showed that for batch tests with soil and water, the amount of PCB that is lost to the tubing is negligible and falls within error. It was expected that more PCB would be lost from water to the tubing, and it was found that the average lost to tubing from PCB contaminated water was 36 ± 4.3 ug out of an initial total of 1000 ug, which translates to a loss of 4%. These losses had to be established prior to using the column testing apparatus, to evaluate whether an acceptable error would be associated with the experimental design. It was found that the average lost to tubing from soil was 3.1 ± 1.2 ug out of an initial total of 226 ± 6.7 ug. This translates to a loss of 1%.

2. Column Tests

Column tests are useful for evaluating filter performance under dynamic conditions, such as seen in the field. Variables such as temperature, flow rate and soil quantity can be controlled for and modified to mimic on-site field conditions. Column tests offer enough information to enable the design of the most effective barrier for the site with minimal effort. A column apparatus has been designed and built in 2004 for evaluation of dynamic equilibrium scenarios. Initially, a plexiglass column was used for several reasons. Firstly, the material was cheaper and all design modifications could be adjusted with the cheaper material. Plexiglass was also clear; there were certain advantages to being able to see the filter materials and soil transport through the column. However, it was found that a mass balance could not be achieved with a plexiglass column as PCBs tended to stick to the material. Plexiglass could not be wiped down with solvent in between experiments, so there was a risk of contaminating further runs. The final, stainless steel column was designed and built in 2005 (Photograph VI-17). Advantages to using this material are numerous. The stainless steel mimics field conditions better as the field barrier is made of stainless steel, PCBs tend not to adsorb to stainless steel and welding ensures that the apparatus is water tight even under high pressures.

The column apparatus is primarily comprised of an entrance drain, filter sections and an exit drain (Photograph VI-18). Each middle section is interchangeable in 1" and 3" partitions, providing for greater flexibility in testing varying filter thickness. Water flow is controlled using a water pump. Contaminated exit water enters through a sand and gravel filtration system prior to being dumped or re-used. The filter materials and water are tested periodically to ensure exiting waters are PCB free.

The column apparatus has been designed to allow for both vertical (preferential for kinetics testing) and horizontal (preferential for mimicking field conditions) orientation of testing.

In the current barrier system, a larger particle size in the GAC filter is required to improve hydraulic performance of the barrier. However, as particle size of the carbon is increased, the number of adsorption sites for PCBs are decreased, thus reducing the overall capacity for sorption of the filter, as well as reducing the availability of sorption sites for higher velocity flows of PCB contaminated water through the barrier. Recent studies have shown that not partitioning, but adsorption is the main mechanism for sorption of hydrophobic organic compounds to soot and soot-like materials, such as GAC.[2]

Prior to using the larger particle size in the field, it was imperative to evaluate whether by moving to a larger particle size a significant amount of PCB fines would be lost. As described above in section D.1, batch tests indicated that there was not a significant difference between BC1240 and CNS612. For field conditions the two types of GAC needed to be investigated under non-equilibrium conditions. In 2005, initial experiments using the plexiglass column were set up before the field season. Soil was flushed through the column through a 3" GAC filter. Only the top 1" layer was sampled and reported. This experiment was conducted using the two different types of GAC, BC1240 and CNS612. As in the batch tests, there was no significant difference between the two materials. In the one-inch layer, BC1240 retained 1.8 ± 0.7 ug/g of 1260 Aroclor, whereas the CNS612 filter retained 1.6 ± 0.8 ug/g of 1260 Aroclor.

With the construction of a new stainless steel column at the end of 2005, it became possible to run experiments more efficiently. The stainless steel column could be wiped down with solvent, whereas the plexiglass one could not between runs. Prior to running adsorption experiments, it was important to evaluate whether a mass balance could be achieved on the new apparatus. PCB contaminated soil was made up using contaminated soil from Resolution Island. The mixture was sieved and then mixed for two days using the tumbling apparatus that was used for the batch tests, to ensure homogeneity. The soil was analysed by soxhlet extraction in triplicate and found to have a concentration of 44 ± 3.3 ug/g.

In the first experiments conducted on the column a complete mass balance was obtained. As in the above experiments, the focus was comparing the different particle

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[2] Van Noort, Paul, C. M., Jonker, Michiel, T.O., and Albert A. Koelmans. 2004. Modelling Maximum Adsorption Capacities of Soot and Soot-like Materials for PAHs and PCBs. Environmental Science and Technology, Vol. 38, No. 12, pp. 3305-3309.

size fractions of GAC. In addition, the gravel and sand filter materials were compared to GAC. The amount of soil retained/trapped by these filter materials (BC1240, CNS612, gravel, sand) was recorded and compared.

A known quantity of this soil was flushed through the column apparatus horizontally at a constant flow rate. The GAC and gravel filters were dried and extracted for PCBs. The effluent was captured at the other end of the column. After collection, the effluent was filtered through filter paper with a pore size of 2 um. Entrance tubes were flushed with water and any remaining soil was captured on filter paper. All filter papers were dried and analysed for PCBs. Previous experiments have shown that the amount of PCB remaining in the filtered water is negligible, so this fraction was not analysed. The source beaker was rinsed and any remaining soil captured on filter paper. The column was taken apart carefully to ensure that each fraction of PCB contaminated soil remained within their sections. The initial ug of PCBs are calculated from the mass of soil used. The concentration of the soil is based on the triplicate analysis.

All soil/contaminated water that remained in front of the filter was tallied together and results can be found in Table VI-6 under the 'Source' heading. Results for PCBs found in the effluent can found under the heading 'Exited'. After emptying out the column, the column was wiped down with a swab and DCM and analyzed. This result falls under 'Lost on Column'. Results can be seen below in Table VI-8. From these results, it can be seen that mass balance has been achieved with the apparatus, with results varying from 82% to 102%. Acceptable error limits for mass balance fall within a ± 20% error limit. Mass balance calculations are based on the initial ug of 1260 Aroclor used in the experiment, minus the sum of PCBs found in various partitions, as discussed in the above section and seen below.

Table VI-8: Column Mass Balance Experimental Results.

	Initial (ug)	Source (ug)	Filter (ug)	Lost on Column (ug)	Exited (ug)	Percent Recovery (%)	Trapped by Filter (%)	Escaped (%)
CNS 612	2513	1769	95	55	357	91	74	14
CNS 612	1815	1037	220	73	520	102	69	29
BC 1240	1961	1224	272	51	313	95	76	16
Gravel	1329	676	162	36	213	82	63	16
Sand	2201	1068	340	74	443	87	64	20

As was seen in previous experiments, the larger particle size of GAC retains the same amount of PCB as the smaller particle size. It is possible that BC1240 behaves similarly to CNS612 in particle retention because the BC1240, although it has a smaller particle size, has a higher coefficient of uniformity, whereas the CNS612 has more variation in particle sizes. This means that the CNS612 is more likely to have smaller pore throats as compared to the uniform BC 1240, which will have uniform pore throat sizes. Porosity may be similar in the two types of GAC. Porosity can vary widely with packing the column. The tighter the packing in the CNS612, the greater effect on porosity as smaller particles can trickle down and compact to fill different sized holes. Experiments will be repeated to confirm these results.

The mass balance experiment was repeated on a 3" gravel filter with particle sizes varying from 2 mm to 8 mm and a 1" sand filter with particle size and distribution equal to that of the BC1240. Surprisingly, the 3" gravel filter appeared to trap equivalent amounts of PCB contaminated soil as the 1" filters. It was assumed prior to the experiment that the 3" filter would trap more, however, given that the particles range to much greater sizes than in the 1" filters, it is probable that the overall porosity of the granular filters is greater than the smaller particle 1" filters. In the field, this design was useful to minimize impacts of clogging prior to reaching the GAC filters and improving overall hydraulic performance of the barrier. The gravel filters were originally placed as more "protective" filters for the GAC filters rather than straight particle retention. The 1" sand filter appeared to trap the same amount as the GAC filters, behaving similarly to the BC1240 filter after which it was designed. These preliminary experiments indicate that it may be possible to replace more expensive GAC cartridges with cheaper gravel or sand cartridges.

F. Summary and Conclusions

S1/S4 valley barrier performed well this year and the sediment trapping modifications implemented in 2004 were successful. With the modifications of the furniture dump barrier and the construction of the S1/S4 beach barrier both completed; the focus will now be on monitoring these barriers and optimizing the materials used in the gate. Monitoring of the barriers is discussed in Chapter 1 Section D Long Term Monitoring Plan. Laboratory studies will focus on trapping the maximum amount of PCBs in the barrier. As sediment loadings decrease it may be possible to use materials which will adsorb more PCBs in the water and on finer particles.

Laboratory studies have shown that particle retention appears to be the most important function for trapping PCBs for the barrier systems on Resolution Island. For this purpose, it may be possible to replace more expensive GAC filters with less-expensive sand or gravel materials. Future column studies will enable the selection of the appropriate materials and filter thickness, by taking into account parameters such as soil loading and adsorption under dynamic flow and temperature conditions. Although particle retention appears to be the most important filter function for PCB remediation, filter design still needs to take under consideration PCBs in water. Further adsorption studies using the stainless steel column apparatus will be required to evaluate optimal thickness of GAC filter to trap PCBs in water. Adsorption kinetics under dynamic equilibrium scenarios such as varying flow rates and temperatures needs to be examined. The thickness of the GAC filter may need to be increased to accommodate required contact time between the GAC filter and PCB molecules in water. Additional experiments will also look at the efficiency of the filters in tandem to ensure the optimal arrangement of filters in the field.