Photograph VI-8: Sieving Sand and Gravel for Filter Material

Photograph VI-9: Adapting the Filter Box for the New Filter Arrangement

b) Funnel modifications

It was realized from the amount of sediment loading that impacted the barrier system that some sediment removal should be achieved prior to reaching the ponding area directly in front of the barrier gates. If this was not done, the elements of the filter box would clog and filtration and sorption efficiencies would decrease.

The capacity of the funnel area was increased by the addition of a second sediment retention area. This would allow some PCB-contaminated sediment to settle out prior to flowing through the barrier system. A second sediment retention was created in front of the 2003 barrier. This was done by lengthening the sides of the funnel walls, by the addition of one gabion on either side (Photograph VI-10). Gabion sizes were chosen to match the barrier wall height to the topography of the bedrock. On one side, the height of the barrier was 0.5 m, on the other side, 1 m. A gabion (2 m x 1 m x 0.5 m) was placed on top of the furthest gabion on the 0.5 m height gabion side to match the barrier wall height and angle to the topography of the bedrock in the area. Both GCL layers were placed in between the two gabions (Photograph VI-11), with protection coming from two layers of non-woven needle-punched geotextile above and below the GCL. Digging to bedrock and burying the liner at depth anchored both GCLs. A black, flexible HDPE liner was placed over top of the GCL and buried in front of the GCL in the same manner. A bentonite-soil slurry was placed in the trench to help seal the front of the barrier, with rocks and sandbags placed overtop for stability.

A hard black HDPE liner was cut out to fit the inside of the second sediment retention area, in the same method and for the same reasons as mentioned for the first sediment retention area.

A sediment trap or flow impediment system was installed at the mouth of the funnel. This was achieved by building a long, pyramidal structure using pipes available on site supported by wood triangles and filled with Tier II landfill berm reject rock (Photograph VI-12). This structure was then wrapped in a geosynthetic material (Curlex^{TM}): this material is normally used for hydroseeding and embankment stability. The material consists of two polypropylene geogrids sandwiching a fibrous polypropylene material. The structure was designed to have good permeability, as well as the capacity to trap some fines. As more sediment loading occurs over the season, pore sizes within the material will become more constricted and over time, the effectiveness of the structure at trapping silt will increase.

The structure was placed in a trench so as the water must flow through it, not under it. The structure acts as a "speed bump" for the water, causing it to deposit some sediment it is carrying before entering the sediment retention areas. The structure was formed in the shape of a chevron and extended past hypothetical drainage pathway flows, to help direct the flow towards the centre of the funnel mouth. The chevron was angled to follow the topography, with the lowest point being the point of the chevron, allowing water to flow more easily over at this section.

Directly in front of the chevron assembly, a truckload of reject rock from the Tier II landfill was dumped and spread out, extending approximately 3 m from the chevron and across the drainage pathway. This upstream section of coarse aggregate was placed to trap sediment and to limit adverse effects of flow heterogeneities.

One 1 m x 2 m x 0.5 m gabion was placed as a weir, or "French Bridge" in the narrowest section of the drainage pathway in front of the aggregate (Photograph VI-13). A section of woven geotextile was cut and lined along the back and base of the gabion, angled in such a manner so that the lowest vertical point is in the center, and the highest vertical point along the sides. This structure was placed as another "speed bump" for the water, with the 400W being used to trap contaminated fines.

The bedrock topography of the northern barrier wall has a much steeper slope, that is approximately a 0.5 m drop at the mouth of the funnel. A directional flow aid was required to ensure that water on this higher section of the valley is directed to flow towards the barrier. A berm (1 m x 3 m x 0.5 m) was constructed utilizing the Tier I debris rock in the area. In front of this berm another flow impediment, sediment trap structure was placed. This structure was 3 m in length. Again, rocks were placed inside and the structure was wrapped with 400W instead of Curlex. The woven geotextile was chosen over the Curlex for its less permeable qualities. Water should not flow through this structure but be deflected back towards the barrier.

Photograph VI-10: Gabions Were Used to Extend the Length of the Funnel Trap

Photograph VI-11: GCL Was Used to Line the New Area and Force All the Drainage Water Through the Filter Box

Photograph VI-12: Constructing One of the "Chevron" Water Impediment Sediment Trap Devices

Photograph VI-13: The "French Bridge" Sediment Trap

C. 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 vacuum cleaned. Some were washed and the washings removed by the vacuum truck.

In 2003, an experimental barrier was designed and constructed in the S1/S4 valley. The filter box system was originally constructed of wood and then duplicated by a stainless steel replica that was subsequently deployed in the S1/S4 valley. It was decided to use the wooden prototype in a similar barrier system at the end of the Furniture dump drainage pathway since the topography at that location was ideal for constructing a funnel without need for gabions. This second barrier was used to obtain further information on the performance of the system.

At the start of the 2004 season, some silt had collected in the funnel in front of the filter box (Photograph VI-14). This silt was sampled (RI04-012 and RI04-013) and the results for this area were found to be Tier II (11 and 13 ppm PCB respectively). Water in the funnel of the barrier system was collected and analyzed. It was found to contain 0.69 ppb of 1260 Aroclor, which is much higher than the level found in the funnel of the S1/S4 valley barrier. The PCBs found in the water are likely present on particulate matter rather than dissolved. The results shows that PCBs are being transported in the drainage pathway and are still present in the area previously occupied by the Furniture dump and in the drainage pathway leading from it. This is 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 season, it was observed that although some 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 (Photograph VI-15).

These bypasses contained mostly water and very little sediment. Analyses of this water and sediment repeat what was seen in the S1/S4 Valley: water contaminated with low-levels of PCB, indicating that PCB is mostly trapped on particles and therefore the trapping of contaminated sediment is the primary goal of the barrier system.

2. *Filter Analysis*

Filters from the 2003 field season were left in place over the winter, as less water and silt flows through this area. The filters were sampled in the same manner as for the S1/S4 filters and analysed at ASU. Analytical results are shown in Table VI-3. The arrangement of filters and absorbents in the Furniture dump filter box were left in the same configuration as originally placed in the 2003 field season. This arrangement and the mass of PCB collected for each filter can be seen in Figure VI-11.

From this data it can be seen that the top section has more PCBs than the middle or bottom sections for all materials. It can still be hypothesized that ice lenses formed and that the barrier thawed from the top down.

The GAC samples were examined to determine whether breakthrough on these samples was a measurable occurrence. Two samples were taken in the same location, the first sample being the first half-inch that the water flowed through, the second sample being the second half-inch that the water flowed through. The first half-inch resulted in a concentration of 7.0 ppm while the second half-inch of GAC only had 3.0 ppm. This data indicates that there may be breakthrough of PCB through the GAC at a filter thickness of 1½ inch.

Table VI-3: PCB Levels and Amounts for the Filter and Sorbent Materials from the Furniture Dump Barrier

Filter	Bottom Section		Middle Section		Top Section	
	ppm	mg	ppm	mg	ppm	mg
400W and 200W	21	0.63	26	0.77	18	0.52
800R	140	8.6	140	9.0	53	3.3
1200R	180	11	180	11	74	4.7
Matasorb	51	14	7.0	2.0	0.5	0.15
GAC	14	95	5.5	36	4.5	30
3M (2 filters)	22	6.7	5.8	1.8	4.0	1.3

Figure VI-11: Arrangement of Filters and Sorbents in Filter Box September 2003 to June 2004 and Mass of PCBs Collected

From the results for the geotextile filters, it is apparent that the nonwoven geotextiles (800R, 1200R) had greater success in retaining PCB rather than the woven geotextile filters (200W, 400W). This may be attributed to the fact that the nonwoven, needle-punched geotextiles had a much smaller pore opening space and could trap more fine silt particles thus retaining higher concentrations of PCBs.

In comparing the filters to the sorbents, it can be observed that the geotextiles had a higher concentration of PCB, but a lower overall mass of PCB. This reinforces the need to integrate entrapment of fine particles into the overall barrier system.

Again GAC proved to be the most effective sorbent for the barrier, retaining the highest mass of pure PCB. The Matasorb was second, followed by the 3M booms. Matasorb is a hydrophobic sorbent and the 3M booms are hydrophilic sorbents. The hydrophobic sorbent preferentially sorbs oil particles from the water, and water preferentially flows around the material rather than through, as opposed to the hydrophilic sorbent that attracts both water and PCB, in effect absorbing PCB from both water and in colloidal form. Matasorb may have retained more PCBs than the 3M booms because it is the first absorbent filter.

It is helpful in this situation to compare the data from 2003 and 2004 in the S1/S4 valley (Figures VI-5 and VI-6). In comparing results from the furniture dump barrier with the barrier in the S1/S4 valley, it is important to keep in mind that the data from the S1/S4 valley is for one season, whereas this data is obtained from filters that remained in place in the barrier for two seasons. The clear vertical trend that was seen in 2003 in the S1/S4 barrier and in 2004 in the furniture dump barrier sorbents is not present in the furniture dump filters. GAC proved to be the most effective sorbent in all cases, retaining the highest mass of pure PCB. The Matasorb was second, followed by the 3M booms in the furniture dump. This is different than what one sees in the S1/S4 valley barrier. In the S1/S4 valley barrier (particularly in the 2003 results), the hydrophilic sorbent was more effective at retaining PCB as opposed to the hydrophobic sorbent. This may indicate that there are more PCBs in the furniture dump drainage pathway associated with oil particles. This may be due to the history of contamination at this particular location. At the furniture dump, nine transformers were found in this area and removed as described in the 1999 ASU Resolution Island report. The area was excavated thoroughly, but due to the nature of the fractured bedrock, inevitably some PCB contamination would have remained. This contamination could be present in DNAPL form and migrating slowly through the soil, which may explain why the hydrophobic sorbent retained more PCB than the hydrophilic one. The furniture dump over the period of 2003-2004 trapped approximately 0.24 g of pure PCB in the gate, with an additional amount of PCB contaminated silt in the funnel; an additional silt fence, previously installed by Sinnani, prior to the entrance to the funnel captured much of the sediment. The S1/S4 valley barrier over the period of 2003 and 2004 trapped approximately 450 g of PCB.

3. Barrier Modifications and Recommendations

Modifications were made to redirect water which was escaping the funnel. This was done by placing culverts with sandbags on northern side on top of bedrock to help direct flow towards the funnel. On the right hand side, in front of the upgradient silt fence, sandbags were placed on the southern side to ensure that water flowed through this silt fence instead of around it, which would then flow around the barrier.

At the end of the field season, new filters were placed into the gate, consisting of GAC that had a larger particle size, but decreased particle distribution to decrease effects on hydraulic performance from freeze-thaw. Granular sand filters with a thickness of 1½ inch were placed in front of the GAC filters, to offer filtration protection against clogging from silt build-up.

It is proposed, based on the results above, that a more permanent barrier in the form of stainless steel one replace the wooden furniture dump barrier. Since the form of PCB sorption appears to be preferentially hydrophobic but still present in relatively high concentrations in water, this indicates that the PCBs should be remediated.

Photograph VI-14: Sediment Collected by the Funnel in the Furniture Dump Contained PCBs at the Tier II Level

Photograph VI-15: The Furniture Dump Barrier at the Start of the 2004 Season: Note That Some Water and Sediment Had Not Passed Through the Funnel

D. 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 sorptive properties of the GAC filter, or due to its nature as a granular filter.

It was also important to determine the sorption capacity of adsorbents that were being used in the barrier. There is a steady amount of PCB flowing the barrier throughout the season. The sorption capacity of the adsorbents needs to be much greater than the amount of PCB the filters were exposed to in the field. Batch tests are used to determine the sorbtive capacity of sorbents at equilibrium. Both the 3M booms and the GAC were analysed via batch tests, as these were the most promising sorbents from the 2003 field data.

1. Batch tests

Batch tests were conducted in 2003/2004 to determine sorption capacity and establish if concentration isotherms between the sorbent and the water could be seen with PCBs. In these 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 sorbent, with various PCB in water concentrations, plus sample blank and one 1260 Aroclor spike. Samples were mixed for varying amounts of time on a rotating apparatus to ensure that the reactions reached equilibrium. The PCB on the adsorbent and in the water were both analyzed and the corresponding adsorption efficiencies were determined [5].

The procedure was conducted as follows. Distilled, deionized water (800 mL) was added to a 1L 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 allowed to tumble for various periods of time: 12 hours, one day, three days and one week. At the end of the allotted period of time, the samples were then filtered through pre-weighed filter paper (Q8 Fisher) into separatory funnels. PCB analysis was performed on the resulting water. The 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 before Soxhlet extraction.

a) 3M Booms

For all periods of time and concentrations (25 to 1000 ppb in water) of PCB, the sorbent proved to be very effective at adsorbing the PCBs under these static conditions. Recovery of the PCBs in the sorbent was averaged over 39 samples and found to be 96 % ± 13 %. In all cases, the amount of PCB detected in the water was below detection levels (<3 ppb). It was noted that there was no significant difference between the varying periods of time of tumbling, which indicated that the reaction reached equilibrium by 12 hours.

More batch tests were conducted to determine the maximum sorption capacity of the sorbent and to determine whether efficiencies changed, as a greater concentration of PCB was present in the solution. It was found that as amounts of PCB approached 600

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[5] 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.

ppm in 1 g of sorbent that efficiencies were notably less (Figure VI-12). In the field, there has been no evidence to suggest that the materials would be exposed to these levels of PCB in such a short period of time. This evidence is promising indicating that the 3M booms selected from 2003 are capable of accommodating accumulated high concentrations of PCBs.

b) GAC

GAC was tumbled for two different time periods, 12 hours and 24 hours at varying concentrations (25 to 1000 ppb in water). As seen with the 3M boom batch tests, there was no detectable PCB in the water and recovery for the GAC (92 % ± 6 %, n=14) demonstrated that GAC is as effective a sorbent as the geosynthetic booms under the prior mentioned conditions. In the field GAC adsorbed significantly more PCB than the other sorbents. From the 2003 field data it was speculated that it was possible that the GAC acted as a fine particle filter. It is now conclusive that the sorption kinetics for GAC and PCB are comparable to the other leading sorbent in the barrier, and although acting as a granular filter may be one PCB retaining mechanism, the sorption kinetics may be more suited for non-equilibrium field applications rather than the hydrophilic geosynthetic sorbent. The maximum sorption capacity of the GAC was not reached with 100 % sorption at 800 ppm. This indicates as was demonstrated in the field that GAC is the best adsorbent for PCBs.

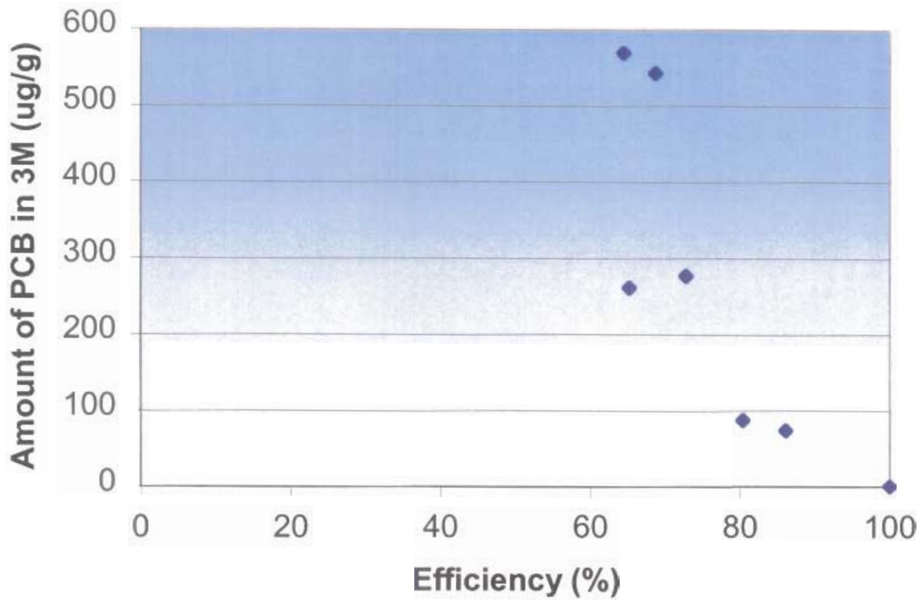

Figure VI-12: Efficiency at Capturing PCB in 3M Boom Material Batch Test Results

2. Column Tests

A column apparatus has been designed and built over 2004 that allows for both testing of sorption kinetics and to model clogging in the various filter materials. The preliminary column design (Photograph VI-16) was found to be functional for vertical testing only. Adjustments were made to the design that allowed for higher pressures to be reached, as well as a watertight seal for both vertical and horizontal testing. This involved moving away from using a filter box design similar to those in the field, in exchange for utilizing the column chambers themselves to test filter material (Photograph VI-17).

Pressure sensors are being used throughout the apparatus to observe effects of clogging on hydraulic head pressure (Photograph VI-18). If clogging occurs, this phenomenon will be reflected an increase of hydraulic head, which can be measured via pressure sensors. Pressure sensors chosen were two-ported sensors. One of these ports will act as a 'wetted' port, and will remain in contact with DDI water, and will be connected to a compartment of the column, while the second port is a 'dry' port, used as a reference port to ambient air pressure. The original column design had to be altered to ensure that no air bubbles would enter the tubing and affect the readings and that no soil particles could enter the tubing, which would also affect the sensor readings. The sensors were tested and calibrated manually by checking voltage output readings to head pressure readings to determine whether they would be suitable for this sort of testing. By monitoring and data logging changes in pressure of the different column compartments, it will be possible to model clogging in filters. This data will enable modelling the capacity of the filter material void spaces under dynamic flow conditions, such as seen on site. This data will help to design filters for the dynamic hydrogeological and temperature conditions as seen on site. The column apparatus allows for the testing of filters in various dimensions to be tested in series. By monitoring for clogging, soil and solute transport, it will be possible to evaluate the best filter arrangement for the barrier.

The column apparatus is primarily comprised of an entrance drain, filter sections and an exit drain (Photograph VI-18). Each middle section is interchangeable, providing for greater flexibility in testing varying filter thickness. A specially-designed soil chamber can be added after the entrance drain, with an injection port for PCB in water, as well as aeration holes that allow for the soil to be aerated as water flow passes through the chamber, increasing mobilization of soil in water for the experimentation. 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 (Photograph VI-19). The filter materials and water are tested periodically to ensure exiting water is 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.[6]

By modelling the dynamic and static equilibrium of various particle sizes of GAC, it will be possible to establish the ideal particle fraction for use in a GAC filter, and optimize the dual nature of this granular filter: filtration and adsorption. Column apparatus that was designed and built over the last year will be used for modelling the dynamic equilibrium behaviour. These experiments will be designed to mimic hydrological conditions as seen in the arctic. This will involve conducting tests under fluctuating temperatures coupled with dynamic hydraulic flows through the column. Since adsorption rate is dependent upon temperature, it will be particularly interesting to examine temperature effects upon the selection of an appropriate GAC filter particulate size, as this area of research is not covered in the literature.

The kinetics for PCBs and GAC are fairly simple to attain from both batch and column tests with comparisons to literature values. Adding a new contaminated matrix such as soil increases the complexity of the kinetics. The kinetics for PCB desorption from soil particles to PCB sorption onto GAC have not been fully investigated. Partitioning coefficients will be attained from both batch and column testing data. The effects of GAC particle size on these coefficients will be investigated, mimicking the methods outlined above.

Currently the prototype column apparatus is made out of ¼ inch plexiglass material, which appears to be suitable for testing soil/water/GAC kinetics, however not for testing water/PCB/GAC kinetics. The clear material is useful, as it is possible to visually inspect soil migration profiles through the GAC material and visually determine particulate breakthrough.

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[6] 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.

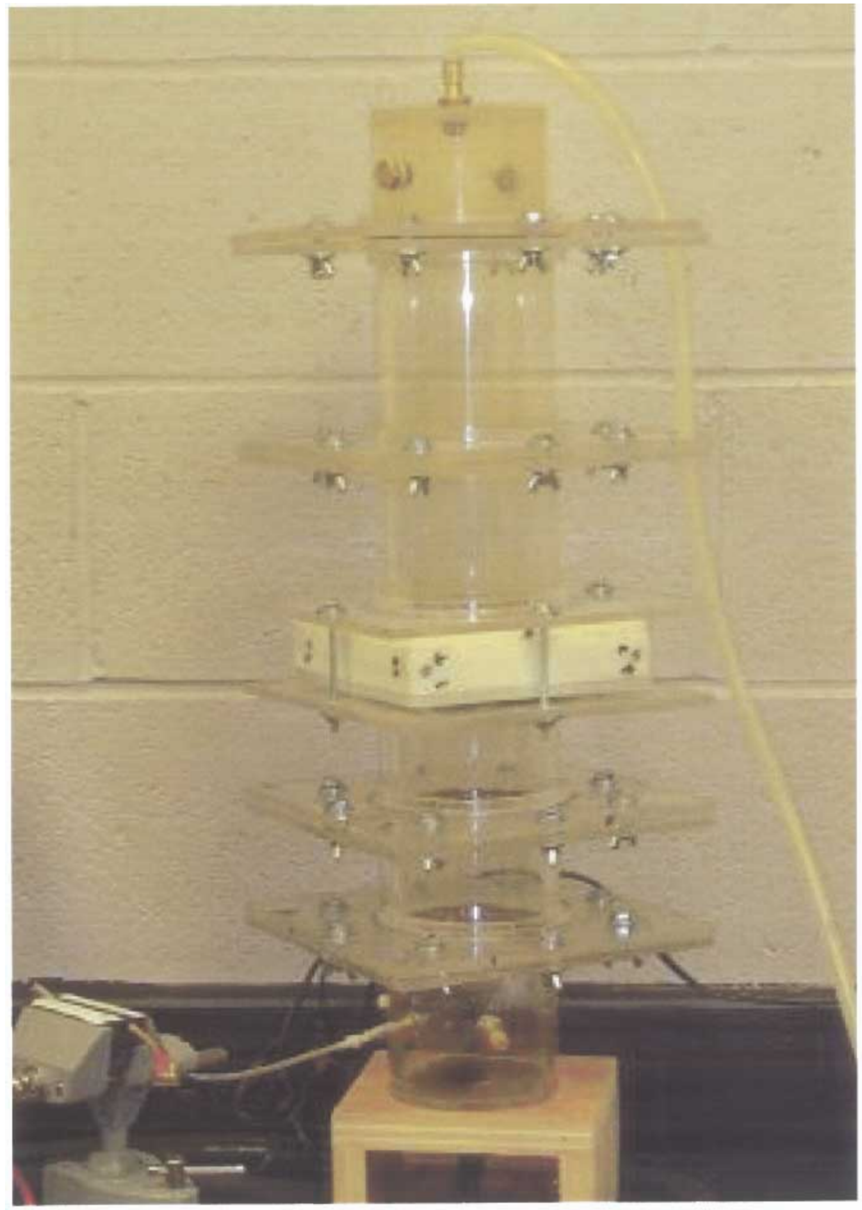
Column tests will be important to help determine the best grain size of activated carbon that optimizes both mechanical filtration of PCB contaminated silt and adsorption of PCB molecules. Initial runs on the column apparatus have been carried out to test whether sorption of PCB onto GAC is instantaneous.

The first column experiment consisted of 300 μg of PCB (1260 Aroclor) in water run through a GAC filter (particle size 1.7 –3.35 mm). The GAC filter was dried, homogenized, sampled and extracted via Soxhlet extraction. The average concentration of sample was found to be 0.18 μg/g and the total mass of PCB calculated to be collected by the GAC filter was 60 μg. After a mass balance was conducted, it was concluded that the rest of the PCB had adhered to the plexiglass prior to being flushed through the GAC filter. From the results of this test, it is recommended that a stainless steel column be used based on the design from the plexiglass prototype for column analysis of PCBs. Although the clear plexiglass was originally chosen partially for its optic properties, kinetic experiments do not require visual observations and the loss associated with the plexiglass is not suitable for adequate kinetic experimentation.

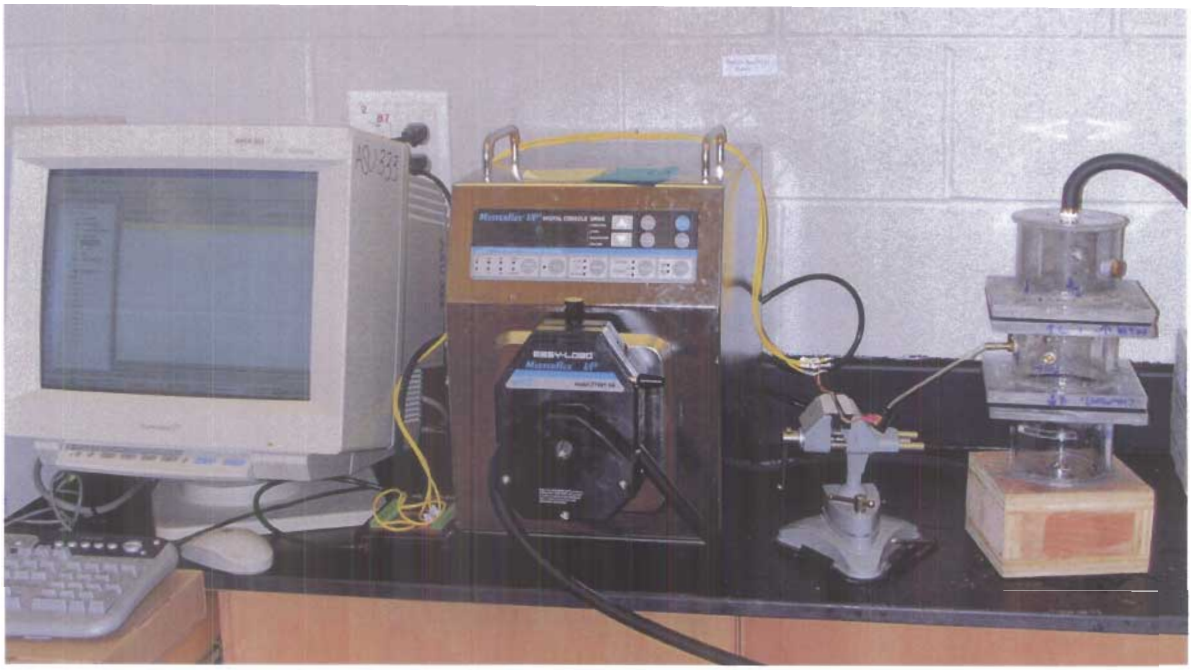
A follow-up experiment was conducted to determine whether the same problem would occur with soil and the filter. It appears that in this scenario the PCB in soil does not transfer to the plexiglass column, as it stays bound to the soil particles as they float through. PCB was not found on the plexiglass column after this experiment. This preliminary study of PCB-contaminated soil through the column was only conducted as a mass-balance experiment to determine whether the plexiglass column could be utilized under this scenario. PCB soil was trapped prior to entering the GAC on wire mesh that is used to contain the GAC at the flow rate used, that would represent 60 L/min in the field. However, it was found that after soil was removed, no PCB was adhered to the plexiglass, therefore, the plexiglass column apparatus can be used for studying PCB contaminated soil and filter sorption/filter trapping kinetics.

The understanding of the movement of PCBs via absorption onto small particles will be investigated as well as the adsorption kinetics between PCBs and small particles such as granulated activated carbon. Laboratory analysis will examine whether there is preferential sorption kinetics between varying PCB congeners and the sorbents. The effects of preferential sorption will be examined and compared for both static and dynamic equilibrium conditions. The studies are critical to ensure the optimal barrier materials are selected for the onsite barrier. These results and their applicability to barrier performance will be explored. Further experiments with soils and various GAC grain sizes are ongoing.

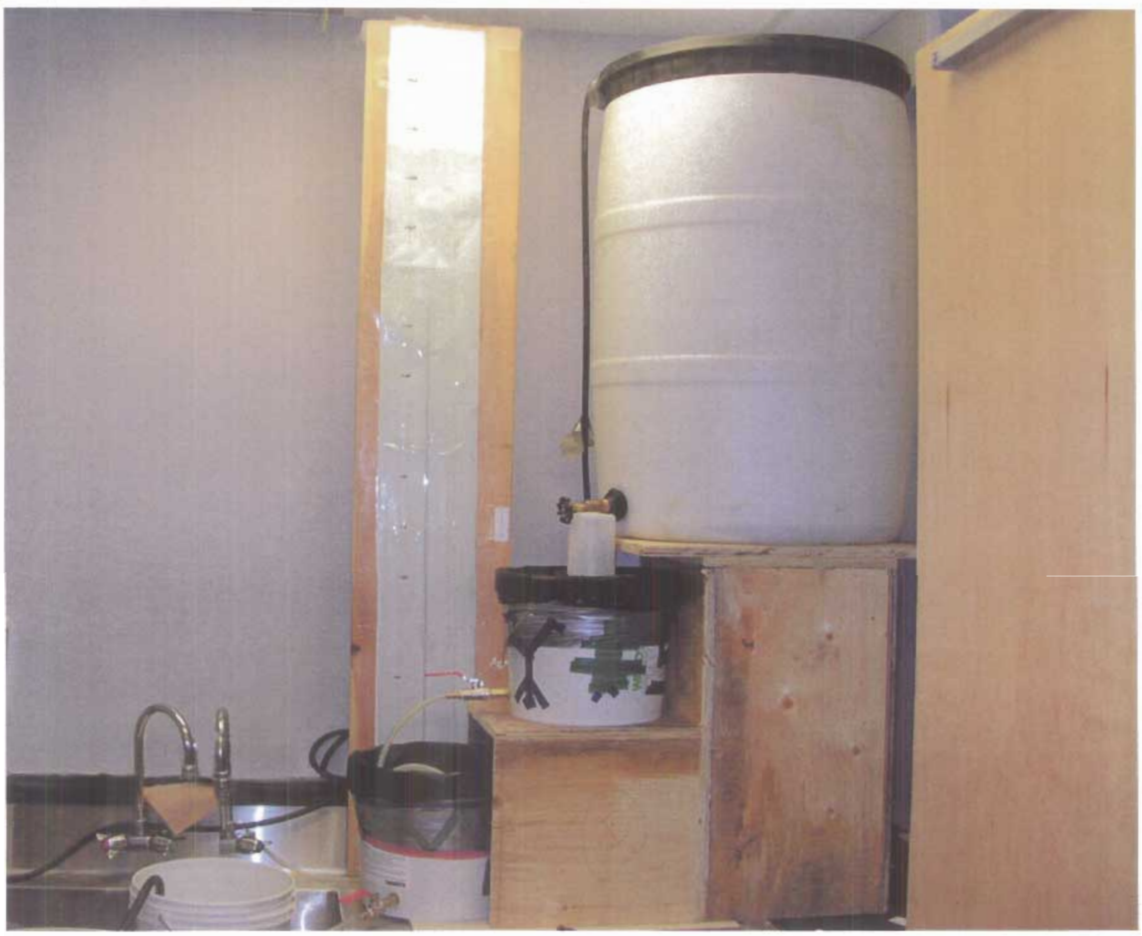
Photograph VI-17: The New Column Currently in Use



Photograph VI-16: The Original Prototype Column Used in 2003



Photograph VI-18: The Experimental Set Up Including Computer, Pump, Pressure Sensor and Extraction Apparatus



Photograph VI-19: The Water Clean Up System Associated With the Extraction Apparatus