Technical Services Section Issue

U.S. EPA Region 4 Technical Services Section Issue Paper for Polychlorinated Biphenyl Characterization at Region 4 Superfund and RCRA Sites

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PURPOSE

This document is written for Region 4 Project Managers, On-Scene Coordinators, and technical staff and provides a recommended approach for the evaluation and characterization of polychlorinated biphenyls (PCBs) in groundwater, soil, and sediment in order to support defensible and protective remedy selection at PCB contaminated sites. PCB contamination typically results from the release of PCB manufactured fluids that were used in high voltage capacitors, transformers, hydraulic oils, switches and other fire resistant products as well as the reuse of PCB waste streams in products such as dust suppression oils and foundry casting sands. Characterization of groundwater, soil and sediment for PCBs is unique because of the varied site conceptual models for PCB and PCB mixture migration and the specific analytical requirements to evaluate the presence and extent of PCB contamination. At sites where PCB groundwater contamination is present, a high percentage of those cases found PCB groundwater contamination that is the result of facilitated transport associated with solvents, colloids, or emulsions. Because of the facilitated transport mechanism, an evaluation is necessary that considers issues such as sampling techniques, turbidity, the presence of elevated carbon, etc. Determining site clean-up strategies and risk can require individual solutions depending on what processes, material types, and site hydrogeologic settings are present at the site. This document helps the site project manager begin the process of planning the site characterization using appropriate analytical procedures on adequate samples with the endpoint being that defensible data are available to support sound decision making at the often very complicated PCB contaminated sites.

Region 4 has a number of PCB sites that have already provided valuable lessons and aided in the development of this approach so that a practical and technically defensible site management strategy can be applied systematically for sampling and analysis of PCB contamination for impacts to groundwater, human health risk assessment, and ecological risk assessment. This issue paper was developed to aid site project managers, risk assessors, and hydrogeologists in characterizing PCB contaminated Superfund and RCRA sites.

EXECUTIVE SUMMARY

The following information summarizes the process of developing and implementing a successful PCB site characterization Plan.

1 Assemble The Site Team composed of the Project Manager, Hydrogeologist, Ecological Risk Assessor, Human Health Risk Assessor, Region 4 Analytical Coordinator, and Field Implementation Personnel (from here on out the paper will call this "The Site Team"). Discuss the conceptual site model and how the field sampling plan needs to be written in order to be used in the field to characterize the PCB contaminant distribution.

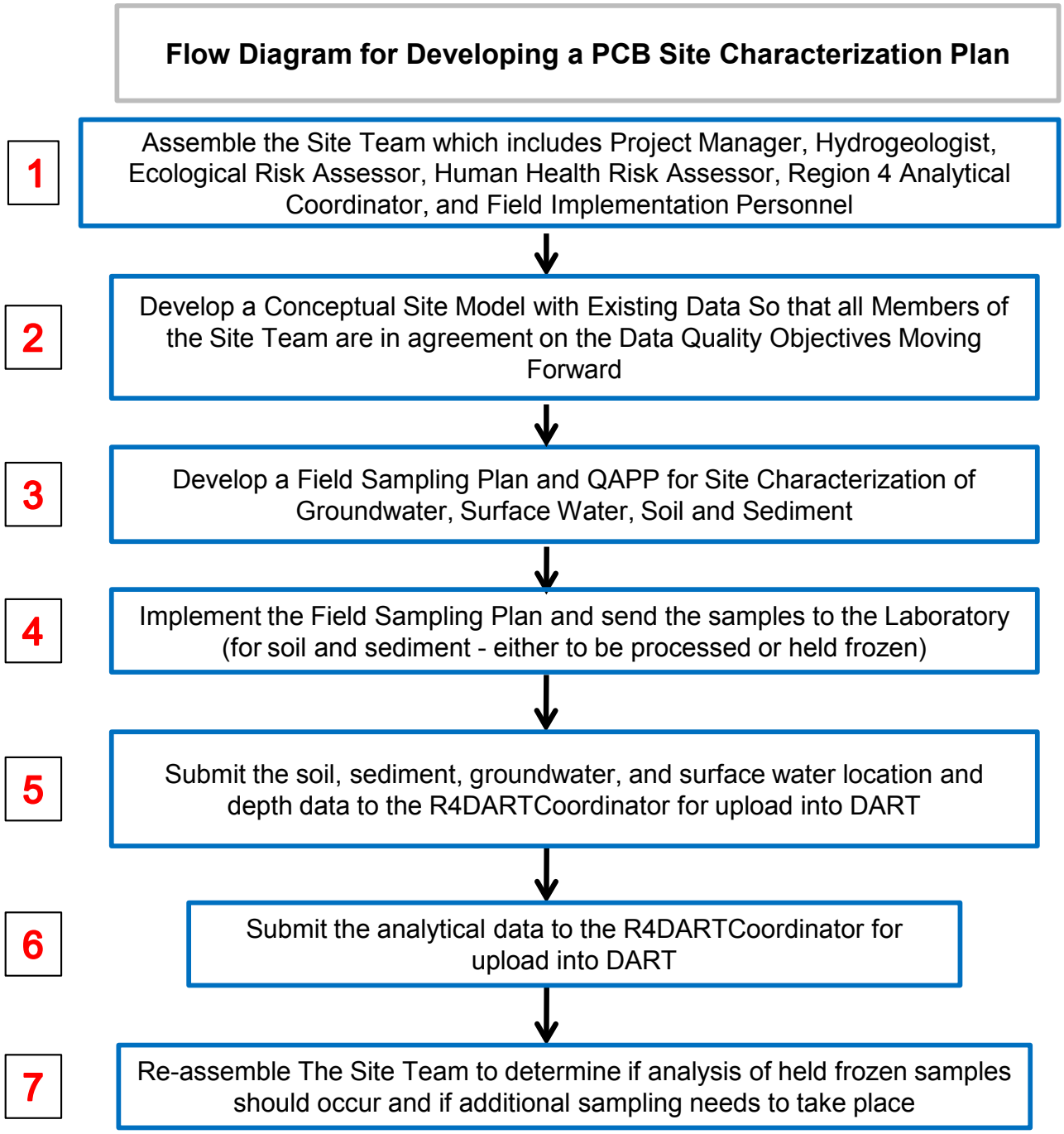

Figure ES-1: *Flow Diagram for Project Planning*

2 Develop a Conceptual Site Model (CSM). This initial CSM will allow all the parties on the Team to have a common understanding of the characterization concerns and solutions for field conditions that may pose difficulties during the sampling event. The CSM will also inform the type of sampling, the nature of the Field Sampling Plan (FSAP), and the budget for performing the characterization – an example is shown in the Figure below and the supporting text for the Figure.

Example Pathways:

- Leaching through
  - subsurface soil to groundwater
  - waste disposal units to subsurface soil
- Migration
  - from ground water to surface water features
  - from plumbing features to surface impoundments and surface water features
  - through plumbing features to subsurface piping/trenches
  - through plumbing features to ground surface
- Overland flow to surface water features
- Deposition by
  - particles blown onto the ground surface
  - Particles carried down to the ground surface during rainfall events

In looking at the CSM and Example Pathways above, several issues may need to be addressed:

- Aroclor (plus Aroclors 1262 and 1268) and congener analysis may be necessary in order to evaluate the weathering that may have occurred.
- If PCB NAPL is suspected then the lab should be notified so they can prepare to handle a highly contaminated sample.
- For characterization of subsurface soil and groundwater nature and extent, the recommended procedure is for a percentage (10% or no less than 5) of samples be subjected to congener analysis

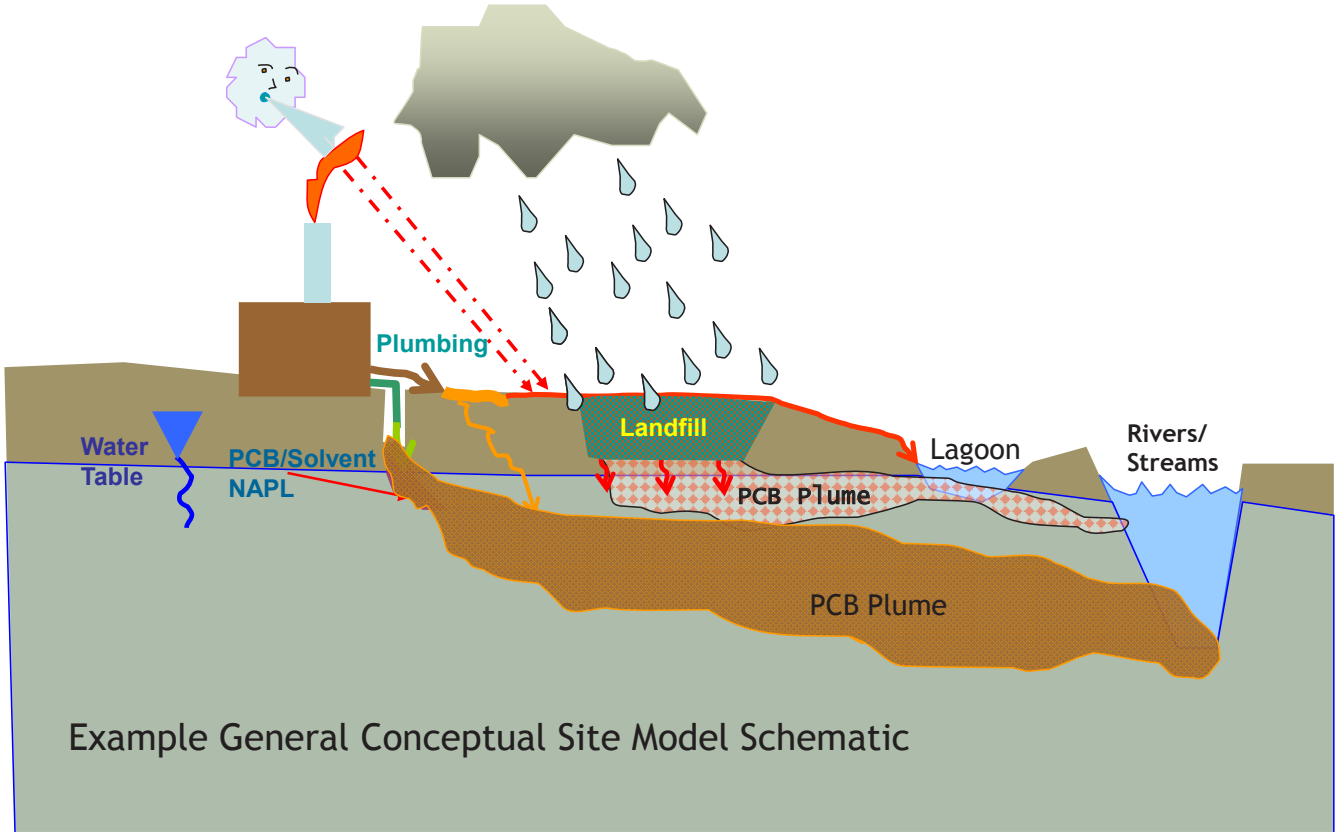

Figure ES-2: *Example of a General Conceptual SiteModel Schematic*

- For the Risk Assessment 10% of the surface soil samples (but no less than 5) should be analyzed for congeners
- On a site specific or case by case basis, for the Ecological Risk Evaluation surface water and sediment samples may need to be analyzed for congeners 77, 123, 118, 114,1 05, 126, 153,167, 156, 157, 169, 189
- If a groundwater plume is known to be present, an evaluation for facilitated transport is highly recommended

3 Develop the Field Sampling Plan and QAPP for the site w**ork.**

In order to get the proper data for remedy selection several analyses need to be performed for various environmental media. Aroclor analysis is the least expensive method for analyzing samples for PCBs, so Aroclor data will generally be gathered for all media. In order to correlate the Aroclor data and determine where it is representative, congener data also should be obtained for nature and extent. There are exceptions to this suggestion. For example, in the instance where the site is an old landfill and removal has been called in to do a final action and no additional federal or state actions will take place, consideration should be given to what is known about the site at the time removal authority is in the execution planning stage. If one portion of the site is highly contaminated and aroclor data already indicate an action, then congener analysis may only be necessary for verifying the nature and extent of that portion of the site. If another portion of the site is contaminated but concentration data is borderline actionable, then congener analysis may be necessary to verify the definition of the actionable extent. The most important thing to do is **CONSULT WITH THE SITE TEAM** in order to develop a practical removal execution plan.

Though Aroclor was the original product, it weathers as it moves through the soil column or as it resides in sediment or sludges. The curve matching process used for Aroclor analysis can underestimate the total PCBs, if weathering has occurred. An evaluation of the correlation between the congener and Aroclor data is necessary so that total PCBs can be extrapolated over the entire site and for various environmental media. Region 4 TSS suggests that soil samples be obtained in suspected source (highly contaminated) areas, moderately contaminated areas and suspected clean areas and analyzed for both Aroclors and congeners so that the representativeness of the Aroclor data can be adequately evaluated. A curve produced by plotting congener total PCBs versus Aroclor total PCB data, can be used to provide correlation for the soil sampling data so that site managers can determine whether or not Aroclor data alone can be trusted at other locations to represent the total PCB concentrations in soil and water. Congener analysis may be necessary for surface soil and sediment so that the information can be incorporated into the ecological risk evaluations. The sections provided below include information that will inform the Field Sampling Plan and QAPP.

Soil and Sediment

- For subsurface soil leaching to groundwater and for nature and extent, Aroclor and congener analysis are recommended. A percentage (10% or no less than 5) of samples should be analyzed by congener analysis.
- For soil and sediment, it is recommended that if little is known about PCB distribution at the site, soil and/or sediment samples should be run using Aroclor analysis and then a subset of samples can be selected for congener analysis, once the Aroclor data are reviewed. For PRP lead sites, taking a greater number of samples during the initial field work and holding them in a frozen state should be considered so that if there is poor correlation between the Aroclor and congener analysis, the archived samples can be used to fill data gaps, as necessary. Note that soil and sediment samples can be held frozen for up to one year for congener analysis. If the site is Fund Lead and samples are being collected for the EPA Lab in Athens, or for an EPA contracted Non Routine Analytical Services, the labs may not be able to hold frozen samples (See Figure ES-1 on page ix for freezing requirements for samples).
- Typically for Ecological Risk evaluations congeners 81-TeCB, 77-TeCB, 123-PeCB, 118-PeCB, 114-PeCB, 105-PeCB, 126-PeCB, 153-HxCB, 167-HxCB, 156-HxCB, 157-HxCB, 169-HxCB, 189-HpCB are the most significant. Ten

Table ES-1: Analytical Details for Sample Handling

Site Lead	Media	Analysis Objective	Recommended reporting limits based on MCLs, RSLs and AWQC	Recommended Analytical Method	Holding Times
EPA Region 4 Fund Lead	Ground Water/ Surface Water	Aroclor	0.014 ug/L for Groundwater/surface water issues; 0.5 ug/L for groundwater not influencing surface water	EPA Method 8082A (be sure and include 1262 and 1268)	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	For Athens - run EPA Method 1668B or Non-Routine Analytical Services for 1668A or B	If stored in the dark at less than 6 °C, aqueous samples may be stored for up to one year.
	Soil/ Sediment	Aroclor	33 ug/kg: 330 ug/kg max	**EPA** Method 8082A (be sure and include 1262 and 1268)	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	For Athens - run **EPA** Method 1668B or Non-Routine Analytical Services for 1668A or B	Up to 1 year frozen - Store in in the dark at less than -10 °C
PRP	Ground Water/ Surface Water	Aroclor	0.014 ug/L for Groundwater/surface water issues; 0.5 ug/L for groundwater not influencing surface water	EPA Method 8082A (be sure and include 1262 and 1268)	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	EPA Method 1668B	If stored in the dark at less than 6 °C, aqueous samples may be stored for up to one year.
	Soil/ Sediment	Aroclor	33 ug/kg: 330 ug/kg max	EPA Method 8082A	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	EPA Method 1668B	Up to 1 year frozen - Store in in the dark at less than -10 °C

Note: consultation between the Region 4 Analytical Coordinator, the RPM/OSC, Human Health Risk Assessor, Hydrogeologist, and Ecological Risk Assessor are paramount since labs and analytical method details require clear direction

Regional Screening levels (RSL's) - http://www.epa.gov/region9/superfund/prg/

Maximum Contaminant LeveL (MCL's)

Ambient Water Quality Criteria (AWQC)

NOTE: Reporting levels can be customized to specific site needs to some extent for both the Regional laboratory and the CLP. In the absence of special requests, the routine approach for the Regional laboratory is to lower reporting levels to Maximum Contaminant Limits (MCLs) for only those contaminants which have an MCL. In the absence of special requests, the routine approach for the CLP, when the lowest reporting levels available from the contract are requested, provides the following results: Polychlorinated Biphenyls analyzed as Aroclor mixtures do not meet MCLs.
Reporting Limit: *Region 4 normally uses this term for the Sample-Specific Quantitation Limit, which has been adjusted for dilutions, moisture content, or other sample-specific factors. This value is the quantitation limit actually achieved in the analysis, and may be the same as the Quantitation Limit that was set as the goal for project planning. However, often, this value will be higher than the Quantitation Limit, since the goal of this Minimum Reporting Limit can only be achieved for relatively clean samples. This is the value that normally appears on the data sheet for data reporting. This is a data reporting value and will vary according to sample matrix of the specific sample.*

percent of the sediment samples (no less than 5) should be analyzed for this list of congeners. Details of the ecological sampling strategy should be based on consultation with The Site Team.

Groundwater and Surface Water

- Groundwater samples should be collected using the low flow/low stress technique (See Yeskis and Zavala, 2002 - *http://www.epa.gov/tio/tsp/download/gw_sampling_guide.pdf* and the Appendix A). This technique (versus the conventional low flow sampling) purges the well at the approximate rate that water enters the well so that if the well is productive, sampling can progress at a reasonable rate without invoking turbulent flow and turbidity. This also reduces the possibility of getting only stagnant water in the well casing. Both Aroclor and congener analyses are recommended for water samples. A percentage (10% or no less than 5) of samples should be run using congener analysis. A correlation analysis of the Aroclor and congener data is recommended.
- If turbidity is an issue, and in Region 4 that is > 10 Nephelometric Turbidity Units (NTU's), redevelop the well and resample. If turbidity remains an issue and is inherent in a low yield well, filtration with a 2 micron filter can be considered, NOT a 0.45 micron filter. Colloidal material can transport PCBs and removal of that material through filtration can provide a false negative sample result.
- Analysis for dissolved organic carbon (DOC) should be performed if facilitated transport is suspected (see FAQ).
- Surface water samples, obtained using conventional sample gathering methods for ecological assessments, may require sample analysis for Aroclor and congener's 81-TeCB, 77-TeCB, 123-PeCB, 118-PeCB, 114-PeCB, 105-PeCB, 126-PeCB, 153-HxCB, 167-HxCB, 156-HxCB, 157-HxCB, 169-HxCB, 189-HpCB. If ground water discharge to surface water is a pathway of interest, the detection limit of 0.014 ug/L should be used for surface water and groundwater analysis. **Consultation with The Site Team for the detection limits and congeners to be analyzed for is necessary.**

Aroclor Analysis for soil and groundwater – EPA Method 8082A (*http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/8082a.pdf*). Be sure and note that in addition to Method 8082A for Aroclors, analysis must also include Aroclors 1262 and 1268.

Congener Analysis for soil and groundwater – EPA Method 1668B (*http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2009_01_07_methods_method_1668.pdf*) or if the Region 4 Lab in Athens is used, Method 1668A is sufficient.

Congener Analysis for Dioxin like PCBs and Ecological PCBs – Use the same statement of work (SOW) as employed for the regular congener analysis and specify the individual congeners to be reported. There are 12 PCB congeners that have been designated by the World Health Organization (WHO) (Van-den Berg et al, 1998) as having "dioxin-like" (or non-ortho-substituted) toxicity. They are as follows: 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189. There are 18 PCB congeners that have been designated by the National Oceanic and Atmospheric Administration (NOAA) as always appearing in sediment and fish tissue and that do not readily degrade. This NOAA Congener List includes congener number: 8, 18, 28, 44, 52, 66, 77, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, and 206.

Initially homolog analyses was proposed by Region 4 because the analysis cost has typically been less than congener analysis, but because Method 680 is not an EPA promulgated method and because complications in executing Method 680 have emerged, the Region has reconsidered advocating a wholesale recommendation for the homolog analysis. Region 4 has become aware that private sites have been running the congener analysis using EPA Method 1668B (the Congener Analysis method) and then summing the congeners into the homolog groups and presenting the data as a homolog analysis. This is fine, but the cost of the analysis is the same or higher than running the samples for congeners, so Region 4 is now simplifying our process approach to consider only Aroclor and congener analysis.

Perform Aroclor analysis:

- **For Region 4, Aroclor analysis should be run for all samples.**[1]
- When the Gas Chromatography/Electron Capture Detector (GC/ECD) pattern is unaltered and matches the standard pattern. For example the chromatogram represents peaks that are easily assigned to an Aroclor and there are a few "renegade" peaks, making the chromatogram noisy.
- When high concentrations of PCB is present in the soils due to DNAPL presence.
- When only one Aroclor is found or the Aroclor mixture has widely different chlorination levels. For example, a site where only 1016 or 1260 were disposed, the chlorination level between these Aroclors is significant so the chromatogram will clearly discern the peaks assigned to each of the Aroclors.
- When objectives include assignment of a specific responsible party to a specific Aroclor release.

Perform Congener analysis:

Congener analysis can be performed using High Resolution long column/long run time Gas Chromatography/Electron Capture Detection (HRGC/ECD), Gas Chromatography/Low Resolution Mass Spectrometry (GC/LRMS), or High Resolution Gas Chromatography/High Resolution Mass Spectrometry (HRGC/HRMS). Pesticide interferences can occur (Toxaphene) when using GC/ECD Analysis, whereas they do not occur with HRGC/ECD. Congener analysis using GC/ECD has been used predominantly for tissue and biological analysis. Congener analysis by GC/LRMS Selective Ion Monitoring (SIM) is used when:

- Aroclor patterns have been altered or when chlorinated species interferences are present. It is especially sensitive in the low chlorination range where mono-, di-, tri- and tetra- species are present.
- When the National Oceanic and Atmospheric Administration (NOAA) 18 congeners are to be analyzed and also needed to determine total PCB.
- When the data user desires to determine what congeners are present and which congeners have been lost due to weathering.
  - GC/LRMS may not be sensitive enough to quantitate congeners #77, #81, #126, and #169 the most toxic of the World Health Organization (WHO) high risk congeners due to their very low concentrations in manufactured Aroclors.
  - Gas Chromatography/High Resolution Mass Spectrometry (GC/HRMS) is used to determine the concentrations for the 12 WHO dioxin like congeners
  - Congener analysis is used over homolog analysis because there is a promulgated EPA Method, it is more sensitive, more selective, and more suited for risk assessment purposes. GC/ECD is acceptable to analyze the NOAA 18 congeners, however, it cannot be used to determine all 209 congeners.

Use in Risk Assessment: The use of congener data for risk assessment is different than with Aroclors. Slope factors for 4 PCB Aroclors (1016, 1242, 1254, 1260) have been developed but not for all Aroclors or all congeners. The Risk Assessor may use the total PCBs (sum of congeners) to calculate a total PCB risk and hazard. The dioxin-like PCB congeners will be assessed separately.

Note that when risk is calculated the provision for preventing double counting should be employed. Congener analysis for the dioxin like PCBs (WHO-12 and/or NOAA-18) may be necessary and this case by case determination should be determined by The Site Team as they establish the data needs (Data Quality Objectives) for the soil, groundwater, surface water, and sediment data.

4 Implement the Field Sampling Plan and QAPP.

5 Submit the soil, sediment, groundwater, and surface water location and depth data to the Region 4 DARTCoordinator for upload into DART.

1 **NOTE:** This paper will use the term Aroclor analysis which are the Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268. **Method 8082A does not include 1262 and 1268, so this analysis must be added in the Work Plan.** Region 4 SESD has incorporated Aroclor 1268 into their PCB Aroclor analysis process, but private CLP labs have not.)

6 Once the analytical data is returned, submit the analytical data to the Region 4 DART Coordinator for upload into DART.

7 Once the field work has been implemented and the analytical data is uploaded into the Region 4 DART data management system, convene The Site Team and review the data and determine if frozen, held samples need to be run and if additional samples need to be collected and analyzed.

Region 4 Technical Services Section Issue Paper for Polychlorinated Biphenyl Sampling at Region 4 Superfund and RCRA Sites

INTRODUCTION

Polychlorinated biphenyl's (PCBs) were produced commercially in the United States between 1929 and 1977. Approximately 99% of the PCBs used by U.S. industries were produced and marketed under the trade name of Aroclor. PCBs have been identified at over 1,600 hazardous waste sites proposed for inclusion on the EPA National Priorities List.

This document provides a recommended approach for the evaluation and characterization of polychlorinated biphenyls (PCBs) in water, sediment, and soil. The approach presented is suggested in order to accurately determine the presence of PCBs in the environment; as well as, to support a defensible and protective remedy selection where PCB contamination is present. High voltage capacitors, transformers, switches, hydraulic fluids, caulks, and paint are some of the sources of PCB contamination. In a high percentage of cases PCBs are found in groundwater as the result of facilitated transport either associated with solvents, colloids, or emulsions. Because of the facilitated transport mechanism, an evaluation is necessary that considers issues such as sampling techniques, turbidity, the presence of elevated carbon, etc. In general, the document uses the ambient water quality criteria (AWQC) of 0.014 µg/L (for water samples), as the quantitation limit goal for examining the impacts of PCBs to groundwater and to evaluate the possibility of facilitated transport. Impacts for soil and sediment can be compared to the EPA Remedial Screening Level (RSL) table concentrations (http://www.epa.gov/region9/superfund/prg/). The AWQC was chosen as a goal because most ground waters will impact surface waters at some point during the migration of the water and this concentration is less than EPA's maximum contaminant level (MCL) of 0.5 µg/L. Determining site clean-up strategies and risk is an individual solution depending on what processes, material types (i.e. soil sediment and waste textures and characteristics), and site hydrogeologic setting is present at the site. Using this document, a Project Manager/On-Scene Coordinator may begin the process of planning the site characterization using appropriate analytical procedures on adequate samples with the endpoint being that defensible data are available to support sound decision making at the often very complicated PCB contaminated sites.

Figure 1. *Boring for PCB NAPL in suspected source area*

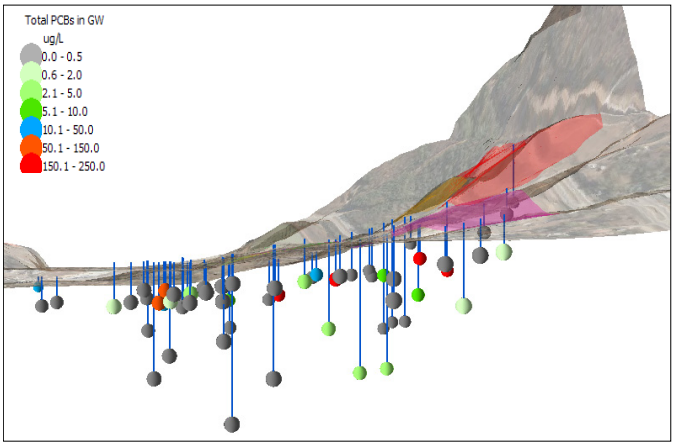

Figure 2. *An Example showing an actual site PCB Groundwater Contaminant distribution*

PCB CHEMISTRY AND CHARACTERISTICS

PCBs in the US were produced by Monsanto from 1930 to 1979, under the trade name of Aroclors.

PCBs are a family of chlorinated organic

compounds formed by two benzene rings linked by a single carbon-carbon bond (the biphenyl molecule). Various degrees of substitution of chlorine atoms for hydrogen are possible on the remaining ten carbons atoms. There are 209 possible arrangements (congeners) of chlorine atoms on the biphenyl molecule. Each individual arrangement or compound is called a congener.

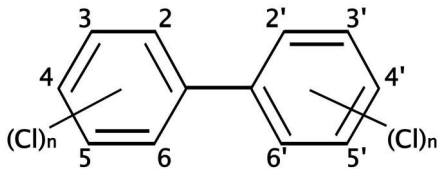

Figure 3. *Chemical Structure of PCB*

The name of a congener specifies the total number of chlorine substituents and the position of each chlorine. For example: 4,4'-Dichlorobiphenyl is a congener comprising the biphenyl structure with two chlorine substituents, one on each of the #4 carbons of the two rings.

Homologs are subcategories of PCB congeners having equal numbers of chlorine substituents. For example, the tetrachlorobiphenyls are all PCB congeners with exactly 4 chlorine substituents that may be in any arrangement. There are 42 tetrachlorobiphenyls.

The most common Aroclor designations are 1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268. The first number in the designation is related to the 12 carbons in the molecule, and the second number is related to the average percentage of chlorine, by weight, attached to the molecule. For example, Aroclor 1242 represents a biphenyl that has 12 carbons and is 42% chlorine. Aroclor 1016 is an exception because it does not use this same numbering scheme; rather, Aroclor 1016 was made from a vacuum distillation fraction of Aroclor 1242 and contains only mono-, di-, tri-, tetra-, and penta homologs. The percentage of chlorine is approximately 41%. A series of Aroclors were produced which varied in consistency from that of a light mobile oil (e.g. Aroclor 1016) through to a thick syrupy stage (e.g. Aroclor 1254) to a solid resinous or crystalline state (e.g. Aroclor 1268). The higher the percentage of chlorine the more viscous the Aroclor was at room temperature. For example, when Aroclor 1260 was produced, it was a waxy semisolid at ambient temperature and had to be diluted with trichlorbenzene (a.k.a. Askarel) so that it could be poured into a transformer and fill all the voids within copper windings.

Penning (1930), described that the Aroclor viscosity increases gradually up to 40 percent chlorine and then very rapidly when the chlorine content exceeds 40 percent. The exception is Aroclor 1016 which is an oil despite the fact it is 41% chlorine.

Figure 4 shows the congener and homolog make-up for Aroclors 1016, 1254, and 1268. This figure displays the percent by weight of the individual PCB congeners; as well as, the homolog designation for the PCB congeners. From this chart, Aroclor 1016 is shown containing the lesser chlorinated PCB congeners and 1268 contains the most chlorinated PCB congeners. One thing to remember is that the homologs are groupings of congeners based on the number of chlorines. All the other Aroclors have a congener distribution that is also distinctive. The other Aroclor make-ups are found in Appendix H.

Figure 5 on the following page shows the homolog composition of important Aroclors with an explanation of the properties that generally control the fate and transport of PCBs. The most soluble Aroclor is 1221 and the least soluble is 1268. Aroclor 1221 has the lowest log K_{ow} so is the least likely of the Aroclors to sorb to soil. On the other hand, Aroclor 1268 has the highest log Kow and the lowest solubility so it is most likely to sorb to soil and less likely to move with groundwater flow. Of course, under conditions of co-solvency and colloidal transport, Aroclor 1268 will dissolved more readily or become entrained in groundwater and become more mobile.

Aroclor 1221 is made up of the lower chlorinated homologs which are more soluble and less sorptive; whereas, Aroclor 1268 is made up of the highly chlorinated homologs which are less soluble and more sorptive. The reason these observations are significant is that if the subsurface soil shows up as containing highly chlorinated homologs or congeners, and there is no transport with solvents or colloids (see the following Section PCB "Physical Properties That Control Fate and Transport" for more detailed discussion), then migration to groundwater is less likely and a higher subsurface soil concentration for protection of groundwater can be considered protective.

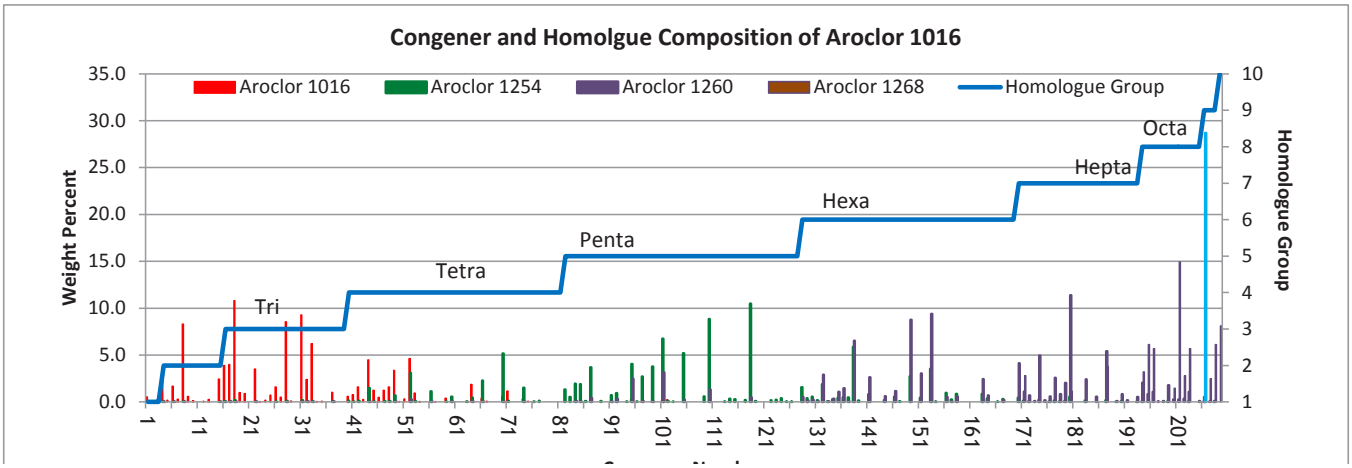

Figure 4. *The composition of Aroclor 1016, 1254, and 1268.*
Note: For example, the Mono homolog designation means that the homolog group contains one chlorine; the Di homolog designation means that the homolog group contains 2 chlorines, and so on.

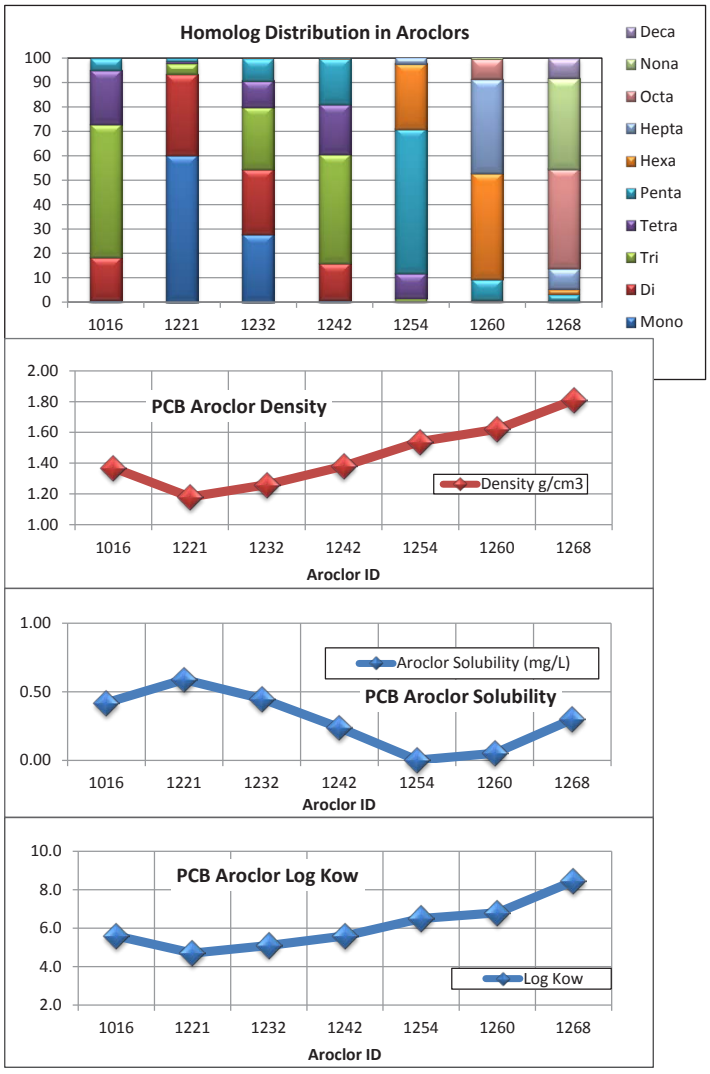

Figure 5. *Aroclor composition and some physical chemical properties affecting transport in groundwater*

In the Aroclor pattern shown in Figure 6 for Aroclor 1254, the peak pattern is represented by the green lines. When Aroclor analysis for PCBs is performed by gas chromatography (GC) with a conventional detector (e.g., electron capture), the chromatographic pattern for the Aroclor is matched against the chromatographic pattern for the sample being run. If the peaks are a match then the Aroclor has been identified. The intensity (height) of a selected number of peaks, or the sum of the heights of all of the peaks, establishes the concentration for that Aroclor in the sample. If the PCB is "weathered", there may be a number of peaks that are displayed (i.e. PCB is present in the sample), but because the pattern is not matched, the Aroclor cannot be identified, and the concentration for that sample would either be reported as a non-detect, or a very coarse estimate of the concentration would be made. If a congener or homolog analysis is performed on the sample, a total PCB concentration for the sample can be established that is accurate since no pattern matching is involved. Congener and/or homolog analysis is performed by GC with a mass spectrometer detector (GC/MS). The mass spectrum will uniquely identify the congeners in the sample, and the summation of a selected mass or masses provides the homolog total. Weathering is discussed in detail in the following Section **"PCB Environmental Weathering".**

Note that if congener or homolog concentrations are compared with the Aroclor concentrations and found not to be consistent with the Aroclor composition, Aroclor contaminant weathering has taken place and the contaminant is really not an Aroclor, simply an assemblage of PCB homologs/congeners that appeared to match the Aroclor chromatograph curve most closely. The reason this distinction is important is that the lab analysis for determining the total PCBs in soil or groundwater is more accurately determined by congener analysis because Aroclor analysis may yield false negative data.

PCB was produced and under certain conditions is present as unweathered Aroclor. In one scenario, once the Aroclor comes to the soil column, various natural processes take place that change the make-up of the Aroclor. The more chlorinated PCB (more chlorinated congeners within the Aroclor) will sorb to the soil and the more soluble congeners will move down the soil column with pore water. When the soil is analyzed the results might indicate that the Aroclor is a more chlorinated and look more like Aroclor 1260, whereas a groundwater analysis may indicate a less chlorinated version of the Aroclor, such as Aroclor 1221. Actually the original Aroclor could have been 1242 or 1248.

In another scenario Aroclor could be mixed with solvent, such as would develop when transformers were refurbished and cleaned with trichloroethylene (TCE) prior to being refilled with Aroclor 1254 or 1260. This mixture of PCB and solvent will be very soluble and the more chlorinated congeners, which would ordinarily sorb to soil, could be carried down into deeper soil and groundwater.

In a third scenario, Aroclor that did not make the specifications necessary for use in capacitors or transformers, could have been used for paint, caulk or other applications and could exist in both a weathered and unweathered form. The analysis of samples won't necessarily look like a discernible

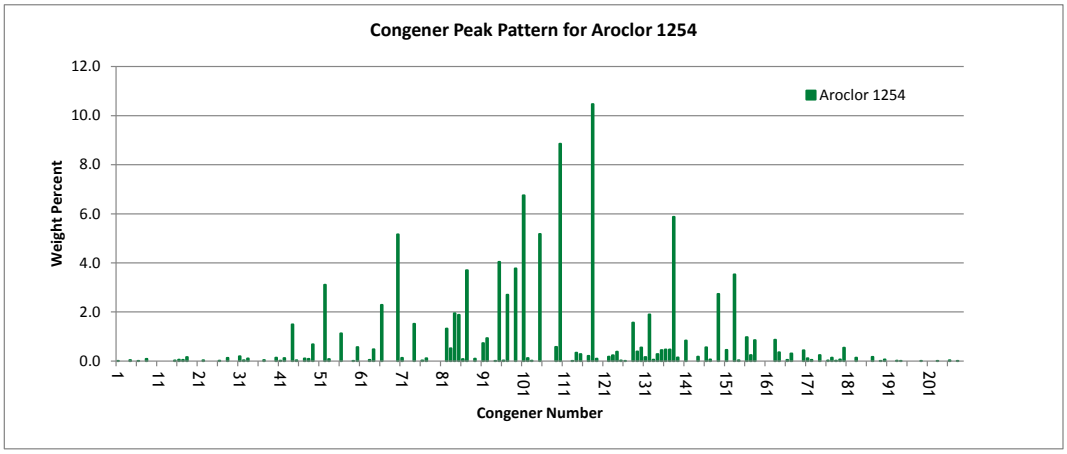

Figure 6. *Congener peak pattern for Aroclor 1254.*

set of peaks for a specific Aroclor, but PCB could be present in soil and sediment samples in an unrecognizable pattern at significant concentrations.

The density for all Aroclors is greater than water so they create a contaminant mix that is a "sinker". The solubility decreases with increasing chlorine content so more chlorinated PCB is not as mobile but when combined with chlorobenzenes or another solvent to decrease the viscosity, the effective solubility increases.

There are 12 PCB congeners that have been designated by the World Health Organization (WHO) (Van-den Berg et al, 1998) as having "dioxin-like" (or non-ortho-substituted) toxicity. They are: 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189.

There are 18 PCB congeners that have been designated by the National Oceanic and Atmospheric Administration (NOAA) as always appearing in sediment and fish tissue and that do not readily degrade. NOAA congeners are: 8, 18, 28, 44, 52, 66, 77, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, and 206.

PCB Physical Properties That Control Fate and Transport

Characterization of the fate and transport of PCBs is different from that of other compounds because of the analytical peculiarities, facilitated transport resulting from PCB mixtures, colloidal transport, and past disposal practices. Consequently, inaccurate conceptual site models for PCB migration may state that migration of PCB in soil is not expected to reach groundwater; when, actually site data at many sites, with the proper evaluations, show that PCB migration/leaching does develop and groundwater concentrations can exceed both the AWQC and the MCL.

Site histories have shown PCB contamination results from many waste streams associated with (1) primary manufacture and production of PCBs, (2) secondary uses of waste streams/off-specification PCB material, (3) the known and unknown incorporation of PCB into industrial products to meet flame retardant property requirements, and (4) ruptured transformers and capacitors used in large industrial settings such as steel manufacturing, foundries, etc. PCBs (Aroclors) were produced at manufacturing facilities (Francis, 1994; Gold & Bloom, 2000) and shipped to facilities that used them to produce capacitors, transformers, switches and other fire and heat resistant products. During production of these mixtures, some Aroclors also were compounded with trichlorobenzenes to create a flowable fluid that was dielectric and heat resistant at high temperatures. This resulted in the production of wastes in the form of PCBs, trichlorobenzenes, and trichloroethylene (used in cleaning operations). Some of the off specification waste was then packaged and sent to recyclers or other end users that compounded the PCB into paint, caulk, hydraulic oil, polymers, vinyl tile, rubber or heat transfer agents. If PCB is mixed with other compounds, the weathering of these mixtures can produce a condition that can make sample analysis more complex. As a result, capturing the nature and extent of contamination with conventional Aroclor analysis (EPA Method 8082 which is gas chromatography (GC) with pattern recognition analysis, explained in detail later in this document) is inadequate because of the weathering process and co-solvency issues. As a result congener analysis is recommended to evaluate the nature and extent and risk for both soils and groundwater.

In the resulting waste mixtures, PCB solubility and adsorption is altered so that the hydrophobic paradigm historically conceived for PCBs is inaccurate for the development of proper site characterization. Association with solvents creates a highly soluble, migration-prone mixture that has the ability to migrate (leach) through subsurface soil and into groundwater in both a non-aqueous phase and a dissolved groundwater phase. Aroclor analysis of these mixtures is often inadequate.

In settings such as fractured rock and karst, PCBs have been found at depths of greater than 175 feet, with free phase PCB/trichlorobenzene mixtures greater than 50 feet deep. PCB migration is facilitated as a co-solvent mixture with chlorinated solvents, colloids, and, as reported by Kueper et al (2005), emulsions. The mixtures often present analytical complications that can falsely present the nature and extent of PCB plumes. For instance, if extensive weathering has occurred, the Aroclor analysis may be meaningless because the Aroclors have been altered, making pattern identification

(the method for determining Aroclor concentrations) impossible or inaccurate. Also, disposal practices that mix PCB waste with other compounds could create a mixture that can only be identified by congener analysis.

Spills of Aroclors 1254, 1260, 1262, and 1268 will tenaciously adhere to organic soils and do not readily degrade or migrate. If the receiving soils are sandy and have a very low organic content, the PCB can migrate downward until it reaches a confining layer such as clay or bedrock. Many times Aroclor 1260, diluted with trichlorobenzene (Askarel), will migrate to greater depths because the viscosity of the mixture is much lower than the pure PCB. The PCB is transported downward faster due to the solvent content and high density.

Highly chlorinated PCBs of low water solubility can, during the process of migrating through the soil along with rainwater, become colloids due to the natural surface active agents and humic substances contained in natural soils. This allows the PCB to form very small particles that are in the colloidal particle range. The PCB colloid particles that are surrounded by some surface-active material (surfactant) can move through the ground water and can migrate through small soil pores with the same ease as water. When the water containing the colloids is analyzed, the pattern found is usually that of the original Aroclor with little environmental weathering and congener losses. The amount of pure PCB liquid released and the organic nature of the soils may have a great deal to do with how and why colloids are formed. At the same time, humic and fulvic acids in the organic soils can complex with the PCB forming a water soluble chelate that will move with the percolating water or ground water. The actual chelating action is not well characterized at this time but is being researched.

Highly chlorinated, insoluble, high specific gravity (1.5+) PCB oils released onto low organic soils or sands can rapidly migrate downward and coalesce as a Dense Non-aqueous Phase Liquid (DNAPL) that resides within the groundwater. DNAPLs usually migrate to some depth and are held by some barrier layer such as dense clay layers or bedrock. DNAPL has been found at the very bottom of both shallow and deep residuum and bedrock wells in layers up to 2 feet thick. Once there is a preferential downward path, such as fractures in bedrock, the DNAPL can migrate further down and be present at a much greater depth than expected.

Once PCB mixtures are transported into groundwater, the altered solubility and adsorption properties allow migration to surface water, resulting in contaminated sediment and surface water. Often the pathway from surface runoff to surface water is the only pathway evaluated because the groundwater is inadequately characterized. Therefore, the ground water/surface water connection is ignored; and the ecological risk evaluations and surface water, sediment, and groundwater remedial alternatives are inadequate. Surface soil and sediment are then remediated, but groundwater continues to migrate into surface water, and recontamination takes place.

PCB Environmental Weathering

Environmental weathering is a complicated, multifaceted process that is manifested in the changes in the PCB mixture. These changes show up in the gas chromatographic pattern when compared to the pattern found in the pure PCB standard. Weathering is due to one or a combination of the following: solubilization, volatilization, preferential adsorption, photolysis, microbial degradation, changes due to metabolism by benthic organisms, and other unknown physical/environmental factors. Lower chlorinated species tend to weather faster because they are more volatile and water-soluble and eventually come in much closer proximity to the microbes in the water column. The microbes in soils and sediments metabolize the PCB, chewing up the lower chlorinated species, and in some cases discharging the higher chlorinated species into the surrounding media with no degradation changes (Natarajan et al, 1997; Quenson et al, 1998; Focht et al, 1999; Comeau & Stidsen, 1994).

The following are examples of environmental weathering found in actual settings.

- The capacitor fluid Aroclor 1242 was discharged into the Hudson River and eventually found its way into river sediments. It has fractionated/weathered over time, causing the Aroclor pattern to change. The original Aroclor 1242 GC pattern in sediment changed considerably, indicating more congeners in the Aroclor 1221 range (mono-, di-, and tri- substituted congeners).

It still has the tetra- and penta-substituted congeners in the Aroclor 1242 range, but less of them. There is no actual Aroclor 1221 in the original PCB, but due to environmental conditions in the sediment and river, the predominant congeners now are less chlorinated.

- In the Hudson River, the PCBs in sediments have changed from their original Aroclor 1242 pattern. The farther from the original source, the more drastic the pattern changes. These changes happened at a very slow rate. The Hudson River sediments show that some of the lower congeners have solubilized into the water column and now can evaporate into the air above the surface of the water.
- There is evidence that Aroclor 1242, disposed in a landfill/wetland, has fractionated into higher chlorinated congeners in the soil/sediments. When these soils were analyzed, the GC pattern resembled the higher chlorinated congeners in Aroclor 1248, whereas the GC pattern of the surface and groundwater had a lower chlorinated GC PCB pattern that resembled Aroclor 1221. The original Aroclor 1242 fragmented probably due to the adsorption of the high-chlorinated congeners into the soils and dissolution of the low chlorinated congeners into the water. Again, the PCB in the groundwater was not Aroclor 1221, but a mixture of congeners.

Environmental Fate Due to Use

At DoD, DOE, and NASA facilities, as well as a heavily industrialized area where onsite power plants are present, the distribution of PCBs can take place as the result of use. For example, when paint containing PCBs is sand blasted off of structures, the dust deposits on the ground surface and is available for movement into surface soil, surface water and sediment through the infiltration and runoff process. Paint usually contained off-spec PCB that was mixed until the flame retardancy paint specification was met. Another example is PCB as insulating oil for electric equipment and other purposes because of its superior insulation and incombustibility properties. PCB was widely used at thermal power stations until around 1965. Consequently, the distribution and PCB type can be confusing unless the process activities are determined and recorded in the Conceptual Site Model.

Overheated PCB transformers and capacitor fires allow PCBs to volatilize and pyrolize, thus dispersing the PCB vapors into the air (Matson, 2001). The PCB eventually cools and condenses on surrounding environment, whether it is soils, water bodies, roads, or solid surfaces in buildings such as concrete pads, wood floors, and walls. During this process of volatilizing and condensing there is some fractionation of the PCB where the lighter PCB stays in the air longer and moves away, and the heavier PCB condenses on surrounding surfaces. PCB contamination on surfaces adjacent to electrical equipment fires is expected, but the PCB can disperse much farther. In buildings where a transformer fire or explosion has occurred, the PCBs can be found on walls and floors and outside surfaces many yards away from the original source. In some cases, air handling and exhaust equipment can amplify this.

Concrete pads that support larger electrical equipment have been shown to be highly absorbent of PCBs. It has been observed that PCB migrating away from transformers with very slow leaks not only migrates down, but also spreads out laterally as much as ten feet from the origin, forming a subsurface cone. This conical pattern of dispersal might not be seen on the surface, but under the surface (at the interface between the base of the concrete and the soil/crusher run) the PCB is spreading out. The PCB can saturate the concrete until it reaches the soil beneath, and even extend into the soil below the concrete. Remediation of the concrete from these types of leaks can be very expensive.

Incineration of waste oils containing PCBs creates volatile PCB gases that can be released as an exhaust if the flue gases are not scrubbed before they reach the end of the stack. PCB gases and PCBs attached to dust particles can also escape and can migrate into the upper atmosphere and move with the prevailing winds (Matson, 2001). Stack gases containing PCBs escaped in this manner prior to the Clean Air Act and found their way via the jet stream and other currents into colder climates, where gases and dust condensed onto the ocean and land. Large concentrations of PCBs developed in seals and polar bears that

ate fish from the oceans that were affected by the condensed PCB. The incineration of industrial and municipal waste containing PCBs has caused PCBs to spread over every inch of North America and beyond [National Oceanic and Atmospheric Administration (NOAA), 1989].

Associated Contaminants

During the production of Aroclor mixtures, the PCB became contaminated with very small concentrations (low parts per million [ppm]) of Polychlorinated dibenzofurans (PCDFs) and even smaller quantities of polychlorinated dibenzodioxins (PCDDs) (Burkhard and Lukasewycz, 2008). When PCBs were used to cool high voltage electrical devices, such as transformers and capacitors, the levels of PCDD/PCDF increased over time. This increased amount (10-50 ppm) of PCDDs and PCDFs was combined with the waste PCB and also ended up in the dense non-aqueous phase liquid (DNAPL) found at some sites that reconditioned and refilled transformers.

Chlorobenzenes used as diluents in Askarels (⅔ PCB 1260 + ⅓ trichlorobenzene) (USDoC, 1976) are also released when PCBs are released. The chorobenzenes can dissolve in water as well as evaporate into the air. Trichloro- and dichloro-benzenes can dimerize when overheated to form 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) and 2,3,7,8-Tetrachlorodibenzofuran (TCDF). The discovery of chlorobenzenes in soil and water is usually a good indication to look for PCB transformer or capacitor leaks and/or releases.

Sediment Conditions Affecting PCBs

Organic sediment in drainage ditches, brooks, rivers, streams, lakes, and ponds is a very good absorber of PCB because of the natural presence of total organic carbon from decaying organic matter. When PCB is released into the environment, rain washes the PCB into brooks, creeks and streams where the PCB sinks due to its high density. The natural sediment organics will adsorb the PCB onto the fine surface particles. When the water starts to flow more rapidly due to high rainfall and flooding, these particles will erode and move with the water and will eventually find their way to larger bodies of water. Surface sediments having very fine particles are subject to erosional forces and depending on the severity of the water flow, the PCB/particles can move for miles down a river until the particles reach a slower moving section, deeper section, or natural or man-made barrier (dam or impoundment) and the particles fall out of suspension and deposit on the river bottom. In some cases this action happens only during flood events at different weather and seasonal periods. This seasonal action can form layers in the sediment column containing different concentrations of PCB depending on the forces of erosion at the time of the flooding. Marine sediments also are impacted due to rivers flowing into the water bodies during the daily tidal flow events. Sediments, both marine and freshwater, appear to be very good sinks for PCB released from the land into the adjacent water bodies. The investigation of PCBs in sediments can pose a daunting task when the PCB particles have traveled considerable distances and have overflowed the banks of the water body onto adjacent land such as happens along low lying flood plains and marshes.

The PCB Aroclor pattern may change due to anaerobic microbes eating the PCB as food and degrading the original PCB pattern causing reductive dechlorination. Reductive dechlorination can occur when the chorines at the periphery of the biphenyl molecule are removed lowering the chlorination level of the PCB. The dechlorination in anaerobic conditions is a very slow process that changes the ratios of peaks in the congener pattern and can be different from location to location due to different anaerobic biomolecules. This type of action, although not always, can cause major changes in the PCB pattern; but, depending on the severity of the weathering changes homolog or congener analysis may be required to get good quantitative results.

PCB Transport and Ecological Pathways

PCB transported via surface water run-off into rivers and other water bodies ending up in surface and subsurface sediments can impact many different ecological receptors. Fish, frogs, ducks, benthic invertebrates, and aquatic mammals can be severely impacted by PCB wastes dissolved in surface water, adsorbed to sediments, and contaminated groundwater entering the surface water. Surface runoff from PCB contaminated surface soil areas into wetlands is probably the worst case scenario. If PCBs are located in saturated surface soils and attached to small

particulates, and, rainfall continually percolates through these soils the water may run off into sensitive wetland environments and may cause an ecological impact on lower and higher organisms via the food chain. PCB can also be sequestered in sediments that are the habitat of benthic invertebrates. These invertebrates are the food for smaller bottom feeding fish, which are the food for larger fish and so on up to humans eating fish from the contaminated water body. The tracking of PCB through the food chain will require the use of congener analysis because there will be slight changes in the PCB pattern through each step in the food chain. If ecological risk is a major pathway evaluation, the analysis of the organisms may have to be performed using congener analysis via gas chromatography with high-resolution mass spectrometry (GC/HRMS) to assess the risk from the World Health Organization (WHO) dioxin like PCBs. The fate and transformation of the PCBs through a project specific food chain such as was studied in New Bedford Harbor is an example. The common terns along the beaches adjacent to New Bedford Harbor were found to be acting erratically, having a very jerky step and jerky motion flying in the air and in some cases could no longer fly. The terns ate silverside fish that spawned in the area of the New Bedford Superfund Site Hot Spot and lived on food in the contaminated sediments. The common terns ate several times their weight of silversides each day. The biomagnifications of PCB up the food chain caused the terns to build up PCBs in their brain tissue to a point where their brain was drowning in PCB and the birds could not control their movements and could no longer fly. The terns eventually died of a PCB overdose. The changes in PCB congener pattern were tracked using full congener analysis and the analysis showed that each organism preferentially eliminated certain congeners and metabolized and retained other congeners in their tissue.

Determining the Presence of Colloidal Transport

Knowing if and how much the effects of colloidal transport are operating is important for the ground water remedial decision making process. The wells should be adequately constructed and developed and samples should be obtained following proper purging using the low flow/low stress technique (see Appendix) and *http://www.epa.gov/tio/tsp/download/gw_sampling_guide.pdf*). At one site the filtering of the groundwater samples had results as follows (NOTE, this is NOT sequential filtering):

Table 1. Data from Filtering of Groundwater Samples using multiple filter sizes

Well ID	Filter Size	Turbidity	Total PCBs (Homolog) in µg/L
L-1	None	2.37 NTU	1.03
L-1	2 micron	2.37 NTU	0.23
L-1	0.1 micron	2.37 NTU	non-detect
L-5	None	>1000 NTU	17.3
L-5	2 micron	>1000 NTU	3.37
L-5	0.1 micron	>1000 NTU	0.072

As the table above indicates, with a range of turbidity, filtering with both a 2 micron and 0.1 micron, the results show the presence of PCB's in groundwater. The unfiltered samples have the highest concentrations, then following the 2 micron filtration PCB remains in solution. For sample L-1 in Table 1, the concentration between 2 micron and 0.1 micron appears to be attached to particles within the colloid range since removal of colloids would be performed with the 0.1 micron filter. The sample L-5 has dissolved PCB too. A pertinent note here is that if a private well was installed at L-1 in Table 1, colloidal material would be coming out the tap because at 2.37 NTU there is no visible turbidity. EPA calls into question the need for filtration for this particular sample because the turbidity is already below the Region 4 criteria of 10 NTU's. In Region 4, any monitoring well sample with turbidity below 10 NTU's does not require any further purging or developing.

PCB PRODUCTION AND USES

Aroclor production involved the chlorination of biphenyl with anhydrous chlorine in the presence of a catalyst, such as iron filings or ferric chloride. From 1971-1974 two Aroclors, 1016 and 1254 (produced in a separate syntheses) (Frame, 2001), were produced differently. In these separate syntheses, commercial grade Aroclor 1242 was vacuum-distilled to produce a narrow boiling range PCB dubbed Aroclor 1016. Aroclor 1016 was produced for some small, specific capacitor applications that required very tight physical properties such as specific gravity and viscosity.

When Aroclor 1016 was separated by vacuum distillation, the remaining PCB in the reactor was composed of 41% chlorine. This remaining material was again reacted with anhydrous chlorine to create a second type of Aroclor 1254, that was composed of 54% chlorine but had specific congeners in higher concentration than the normal Aroclor 1254 (Frame, 1999; Kovanti et al, 2001). The second type of 1254 (sometimes referred to as "hot" or "heavy" 1254) had all the same physical properties except that it was later discovered that it contained a much higher content of dioxin-like PCB congeners and a larger amount of dioxin-like polychlorinated dibenzofurans (Burkhard and Lukasewycz, 2008). The specific gravity and pour point[2] were the same as commonly produced 1254 so it would meet the electrical specifications for high voltage capacitors.

In countries other than the US, PCB production included at least thirty types of PCBs [United States Department of Commerce (USDoC), 1976]. A few trade names include Aroclor B, Chlophen, Phenclor, Inerteen, Kanechlor, Phenoclor, Pyraleen, Pyranol, Santotherm, and Therminol. Most of the foreign PCBs were produced in Germany, Italy, Japan, France, and Great Britain.

In the Table 2, the types of operation and the Aroclor that was used in the production is provided so that PCB type and suspected source Aroclor can be established.

Table 2: Type of Operation Possible and PCB Aroclor used

Operation	Aroclor Used
Transformers	Aroclor 1260 and some 1254
Capacitors	Aroclor 1016, 1242, and 1254
Other electrical equipment including voltage regulators, switches, reclosers, bushings, and electromagnets	Aroclor 1248, 1254, and 1260
Oil used in motors and hydraulic systems	Aroclor 1248, 1254, and 1260
Fluorescent light ballasts	Aroclor 1254 and 1260
Cable insulation	Aroclor 1248 and 1254
Adhesives and tapes	Aroclor 1221, 1232, 1242, 1254, 1260
Oil-based paint and caulk	Aroclor 1242 and 1254
Plastics	Aroclor 1242, 1254, and 1262
Carbonless copy paper	Aroclor 1242
Floor finish	Aroclor 1254, 1260, and 1262
Lost wax casting	Aroclor 1254

Estimated percentage for various PCB uses:

- Closed system and heat transfer fluids (transformers, capacitors, fluorescent light ballasts, etc.): 60%
- Plasticizers: 25%
- Hydraulic fluids and lubricants: 10%
- Miscellaneous uses: 5%

PCB Aroclor used in each type of Transformer and Capacitor

High voltage AC transformers for large industrial uses	Aroclor 1260/TCB (Askarel 66.6% 1260, 33.3% TCB)
ower voltage AC transformers	Aroclor 1254
High voltage AC switches	Aroclor 1254
High voltage AC capacitors	Aroclor 1254
High voltage DC capacitors	Aroclor 1254 (70%)/TCB (30%)
Medium voltage AC capacitors	Aroclor 1242
Low voltage small can capacitors and light ballasts	Aroclor 1242 and 1016

List of Heat Transfer operations and the PCB used

Heat cells	Aroclor 1254
Rubber milling	Aroclor 1248, 1254
Plastics molding	Aroclor 1242, 1254
Plastics extrusions	Aroclor 1242, 1254
Metal molding	Aroclor 1254
Plastics calendaring and coating	Aroclor 1242

2 Pour point is the the lowest temperature at which PCB becomes semi solid and losses its flow characteristics

PCB hydraulic fluid Aroclor Type:

High pressure forming Presses	Aroclor 1248
Forging operations	Aroclor 1248, 1254
High temperature presses	Aroclor 1248, 1254
Construction equipment	Aroclor 1242, 1248

PCB ANALYTICAL ISSUES

In a soil sample analysis, Aroclor 1242 can degrade into a chromatogram that is a closer match to the Aroclor 1248 standard, and in ground water, to a chromatogram that is a closer match to the Aroclor 1221. The loss of some congeners and the altering of the concentration of other congeners can make quantitative analysis become only semi-quantitative, as the laboratory attempts to match the pattern to an Aroclor. Since Aroclors are mixtures, the closest match of the weathered chromatogram pattern to an Aroclor standard may not be to the standard of the Aroclor that was originally released. As the laboratory attempts to match the pattern to the closest Aroclor standard, likely some of the PCB material is not included at all in the quantitation. For example, if a tetra-substituted congener loses one chlorine atom due to biological action, then the corresponding remaining tri-substituted congener (trichlorbiphenyl) concentration is increased. Even when the five quantitative peaks do not change but other peaks do, the method of quantitation assumes that all peaks are present in the same ratio as those congeners in the Aroclor standard. Therefore, a congener or homolog analysis is preferred to get a true total PCB concentration, since these approaches allow for correct matching of individual compounds to their respective standards, rather than matching the pattern to the standard of an Aroclor/Aroclor mixture. Additionally, focusing the analysis on individual compounds allows for the use of more sensitive instrumentation and methodology, resulting in lower limits of detection.

Example Data from a Site showing the relationships between Aroclor and Homolog data for soils and ground-water:

In Figure 7 it is clear that for the same sample, the total PCB Homolog concentrations and Total PCB Aroclor concentrations are not the same. Note that the homolog analysis is the accurate total PCB concentration data. The total PCB homolog soil concentrations vary in that for some samples the total homolog concentration data is 2+ orders of magnitude higher than the total Aroclor concentrations. In other instances the total Aroclor data is up to an order of magnitude higher in concentrations than the total homolog concentration data. Noted above is that the concentration scale

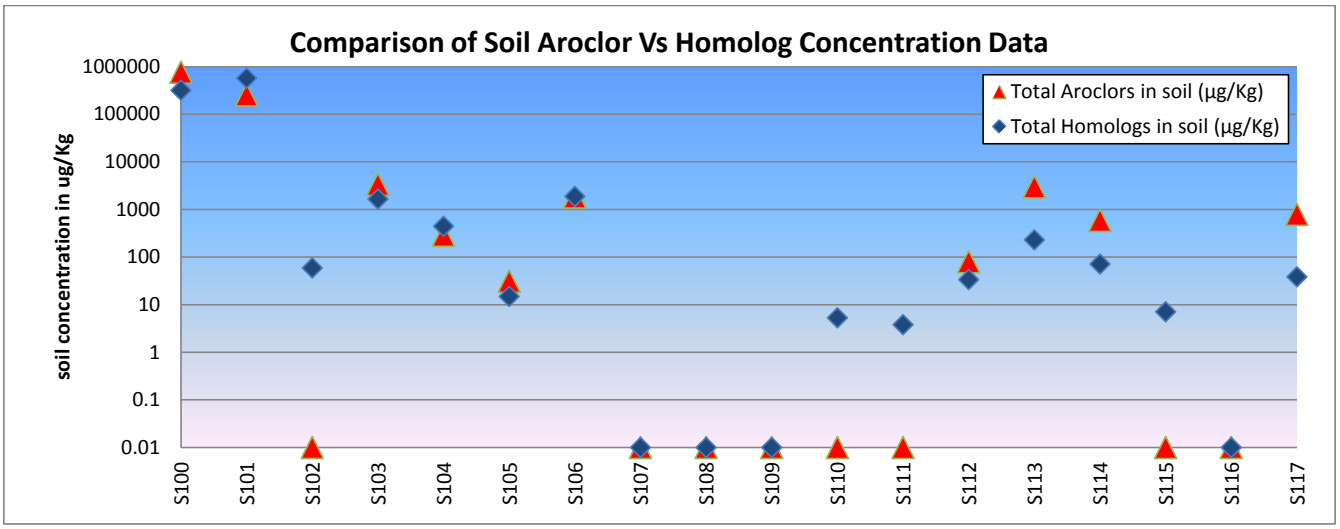

Figure 7: *Graphical Comparison of Total Aroclor and Homolog Soil Concentration Data. (Note: The log scale was chosen for concentration in order to represent all the data.)*

is logarithmic so the variation is significant for some of the samples. This site data shows that in some areas, if the total Aroclor soil concentration data is used there is the possibility that the soil treatment would be excessive, or in other instances if the total Aroclor data was used to inform soil treatment, an insufficient treatment area could occur. The take home here is that homolog total PCB concentration is the appropriate measure for determining total PCB soil and groundwater concentrations.

In looking at the same dataset shown in Figure 7, an additional point is pertinent. In the soil Aroclor data, some of the samples show higher concentrations for the Aroclor. Going back to a figure shown earlier (Figure 4), one can see that for example Aroclor 1016 has a subset of congeners that straddle the homolog groups of Mono, Di, Tri and Tetrachlorobiphenyl. Aroclor 1254 has a subset of congeners that straddle Tetra, Penta, and Hexachlorobiphenyl. With various weathering mechanisms and mixtures, there can be a double counting of congeners/homolog's so that under certain conditions total Aroclors PCBs can be greater than total congeners/homologs PCBs. On the other hand, weathering of PCB can create a chromatographic curve plot that is not possible to match to any Aroclor so the total Aroclor PCB concentrations could be a lot lower than the total homolog PCB concentration.

Table 4 is the data that informs Figure 7:

Table 4: Comparison of soil analytical results for Aroclors and Homologs

SampleID	Total Aroclors in soil (µg/Kg)	Total Homologs in soil (µg/Kg)
S100	765000	319530.0
S101	255500.0000	574450.0
S102	0.0100	59.1
S103	3370.0000	1652.0
S104	287.0000	445
S105	31.0000	14.9
S106	1837.0000	1887.0
S107	0.0100	0.0
S108	0.0100	0.0
S109	0.0100	0.01
S110	0.0100	5.3
S111	0.0100	3.8
S112	80.0000	33.6
S113	3000.0000	230.0
S114	590.0000	71.4
S115	0.0100	7.1
S116	0.0100	0.01
S117	790.0000	38.5

In another example, Figure 8, the soil concentrations were lower than the example shown in Figure 7 and the comparison is that 100% of the samples showed a Total PCB Homolog

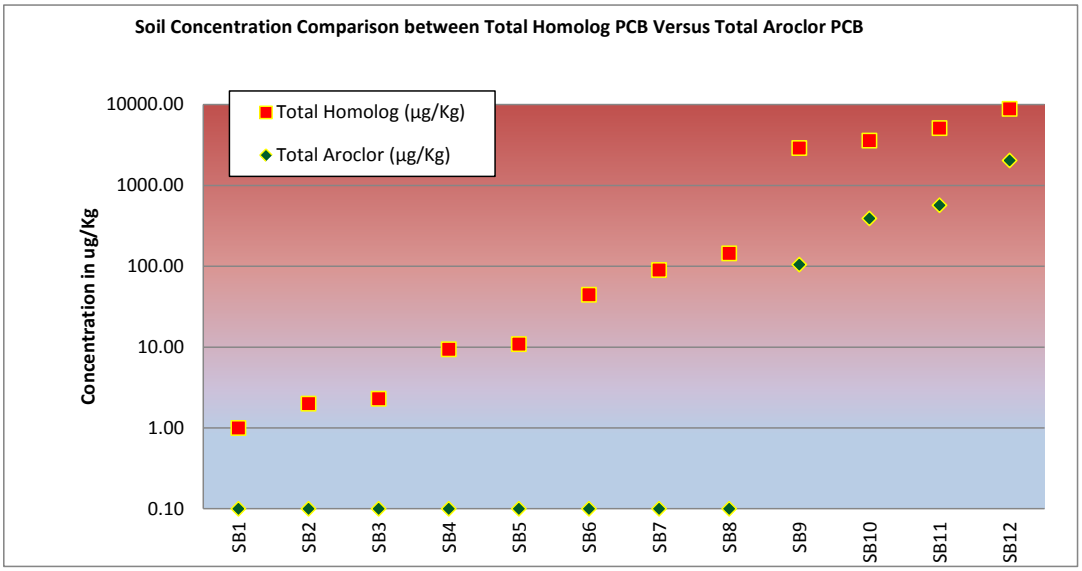

Figure 8: *Another comparison of Soil Total Homolog concentration versus Total Aroclor concentration.*

concentration greater than the Total PCB Aroclor concentration.

Table 5 is the data that informs Figure 8:

Table 5: Table of Data used to construct Figure 8

Location	Total Aroclor (µg/Kg)	Total Homolog (µg/Kg)
SB1	0.1	0.9
SB2	0.1	1.9
SB3	0.1	2.2
SB4	0.1	9.3
SB5	0.1	10.8
SB6	0.1	44.4
SB7	0.1	89.9
SB8	0.1	144.4
SB9	105.0	2802.0
SB10	391.0	3202.6
SB11	569.0	4557.6
SB12	2040.0	6838.0

Figure 9 illustrates two points. The first is that (1) high concentrations in soil do not necessarily migrate to ground water and cause highly contaminated ground water. The concentrations in groundwater from sample L-5 show that for lower soil concentrations, the resulting groundwater concentration is 17.3 ppb versus the highest concentration soil leaching 0.1 ppb. (2) The figure also demonstrates that if one PCB subsurface soil concentration (protective of groundwater) was chosen as a clean-up level for the facility it would not be appropriate for all scenarios. Further data analysis revealed the reason for this leaching pattern.

In Figure 10, the pie charts reveal that the homolog distribution is distinctive for L-1 and L-4 and represents one population of data; whereas, the homolog distribution for L-5 reveals it represents a different population. In the legend above the chart the homolog ID ranges from Monochlorobiphenyl (Mono - one chlorine atom) to Decachlorobiphenyl (Deca - 10 chlorine atoms). The more chlorine, the less soluble and more sorptive the PCB is. So the soil samples L-1 and L-4 show a distribution that is primarily Nonachlorobiphenyl (Nona) and Deca. In Sample L-5, the homologs are primarily Trichlorobiphenyl (Tri), Tetrachlorobiphenyl (Tetra) and Pentachlorobiphenyl (Penta) which is more soluble and less sorptive. The other piece of the story is that L-1 and L-4 sit in an upland area and L-5 sits down in the floodplain so this area receives repeated flooding which also flushes the PCB to groundwater.

The L-1 and L-4 data show that even if soil concentrations are high, the homolog distribution and the sampled area being in the uplands prevent migration of PCB, in large concentrations, to groundwater. The L-5 data shows that with the less chlorinated PCBs, in the presence of the periodic flooding, and with soil textures that include silt and sand (implying a higher hydraulic conductivity) leaching of PCB to ground water does occur.

SAMPLING RECOMMENDATIONS

It is important to note that sampling of waste solids such as concrete floors, pads, drains, chases etc. using the EPA Region I power impact drilling technique (pp. 53 - 58 of http://www.epa.gov/osw/hazard/tsd/pcbs/pubs/pcb-guid3-06.pdf) will yield a fine powder that can be easily extracted and analyzed using Aroclor analysis. All solid samples need to be thoroughly homogenized in the field and again in the laboratory to get representative samples. Surface soils need to be free of debris, grass and other vegetative matter. The soil must be thoroughly mixed. When collecting subsurface soils from various depths the sub samples can be homogenized in a bowl and individual samples from specific depths can be frozen for later analysis. The holding time starts at the point that the samples are collected.

Sediment samples (surface and subsurface) need to be thoroughly homogenized in the field. Samples can be collected, frozen (for congener analysis) and analyzed at a later date if necessary. It is particularly important to note that the percent moisture in sediments must be measured prior to weighing out the analytical sample so that extra sample can be added to the meet the dry weight sample criteria set in the method. This means that if the method requires 30 grams of dry solid then the amount of wet sample weighed must have a dry weight of thirty grams. Very low percent solids samples (<30% solids) should be considered

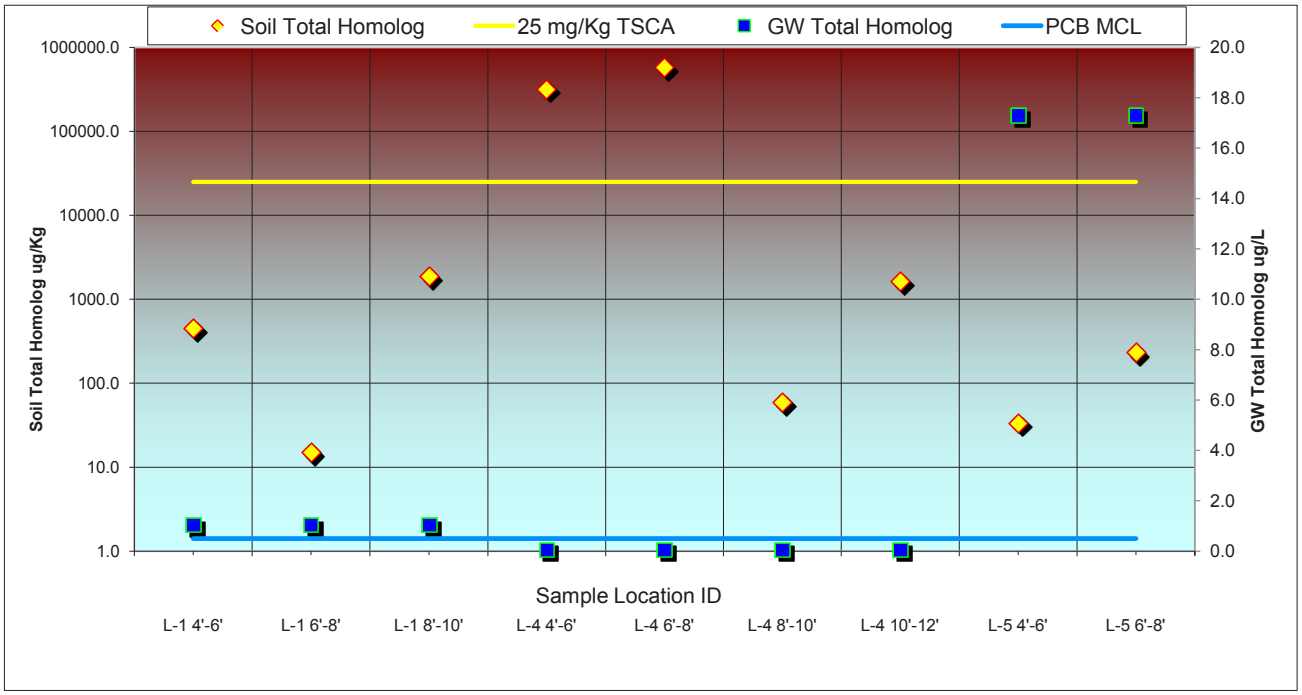

Figure 9. *Soil Concentration Total PCB (homolog) data with ground water Total PCB (homolog) concentration data.*

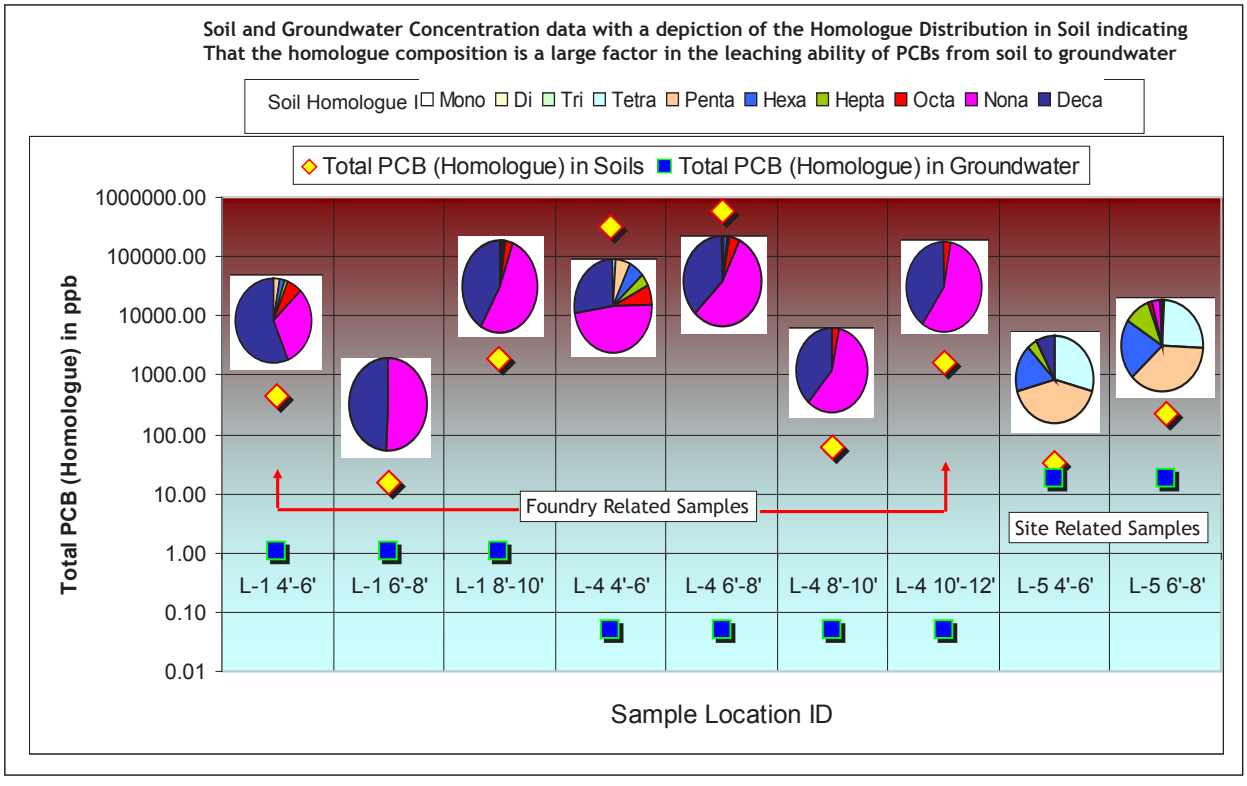

Figure 10. *A depiction of the soil and groundwater Total PCB (homolog) concentration data accompanied by the soil homolog distribution.*

for air drying or freeze drying prior to sample weighing, extraction and analysis. An alternate is to determine the percent solids (or percent moisture) on a small aliquot (e.g., 100 mg), and use the percent solids/moisture to determine the weight of sample that will yield 30 g of solids.

Sediment screening analysis using GC/ECD Aroclor analysis is acceptable if there are no major changes in the Aroclor pattern of the Aroclor known to be released. In most cases where fresh water sediments show changes in the Aroclor pattern, congener analysis is recommended for total PCBs. Aroclor analysis should be run for all data with no less than 10% (No less than 5 samples) of the samples also being analyzed for congeners. If weathering is revealed as an issue, the Site Team will need to make decisions about which held frozen samples or additional sample locations should be run for congeners.

Samples that exhibit oil droplets or an oil sheen should be handled as if they were pure PCB oil. These samples should be screened (see Appendix F) to determine how high the PCB concentration is prior to being sent to the laboratory for full quantitative analysis. Multi dilutions of these samples may be necessary to get the concentrations on scale. Landfill soils should be treated the same as surface and subsurface soils. Leachate should be analyzed as if it were water and either homolog or congener analysis used. Landfill leachate may require some special handling as it is a very reducing media and during extraction may precipitate solids that can clog extraction equipment. Landfill leachate may change as the water takes on oxygen and the sample may have a solid phase and a liquid phase.

Air samples that are collected on a filter or PUF may not indicate typical Aroclor patterns. High volume samples collected on the filter of a TO-4 apparatus may have the PCB stripped off the particles and all the PCB may be found in the PUF. The analysis of both the filter and the PUF together must be performed. Samples of air particulates caught on personnel air monitors may be analyzed by Aroclor analysis if enough particulate is present. In some cases congener analysis may be necessary to meet low detection limits need to show that personnel are protected. The bullets at the end of this section are the potential waste streams locations for manufacturing operations synthesizing PCBs, filling transformers and capacitors, transformer rework operations, and using PCBs for heat transfer and hydraulic fluids.

The following are a list of where to look for PCBs from the manufacturing process and primary use operations:

- Production floors (concrete) and floor drains
- Production piping and piping sumps
- Concrete floors and drains
- Sub floor concrete and soils under floors
- Air contamination/emissions within buildings with concrete contamination
- Uncontrolled floor drains, sumps and collection tanks
- Drainage ditches that go to water bodies
- Surface soils
- Subsurface soils
- Landfill soils
- Landfill leachate
- Groundwater near or under a production or PCB equipment manufacturing/filling facility
- Groundwater near to and under landfill soils
- Groundwater near saturated surface soils
- PCB Particulates in air at any site where PCB soils are being moved or remediated
- Painted surfaces containing PCB paint
- Caulking around windows, doors, between walls and floors

Sediment Sampling

The investigation of PCBs in highly wet sediments (less than 30% solids) usually creates difficulty in extracting the PCB from the wet sediment. The water must be removed first to get the best PCB extraction efficiency. Sediments found in fresh water rivers and streams that have a low percent solids may require processing using a low temperature oven drying (for higher chlorinated PCBs) or freeze drying to acquire the correct amount of dry solids required to perform analytical extraction to get quantitative results. It has been reported that extracting the very wet sediment

with water soluble solvents such as acetone or isopropanol first, to initially remove the water, and then extracting with the "method required" solvent (that will more efficiently remove the residual PCBs) is the best method developed to date. The sample extract must undergo clean up to remove sulfur and sulfur containing organics as well as other industrial interfering PAH compounds (see SW846 Method 3660B Sulfur Cleanup). Fresh water sediments having very small particle sizes will require rigorous extraction, clean-up and analytical procedures to get quantitative results. This will depend on the project data quality objectives (DQOs) and the final use of the data. PCB contaminated sediment remediation/clean-up is one of the largest remediation problems presently facing the EPA and the Army Corp of Engineers (ACOE) (see *http://www.epa.gov/region1/topics/water/rim/rimweblink.pdf*).

DEVELOPING A PCB SOIL AND WATER WORK PLAN

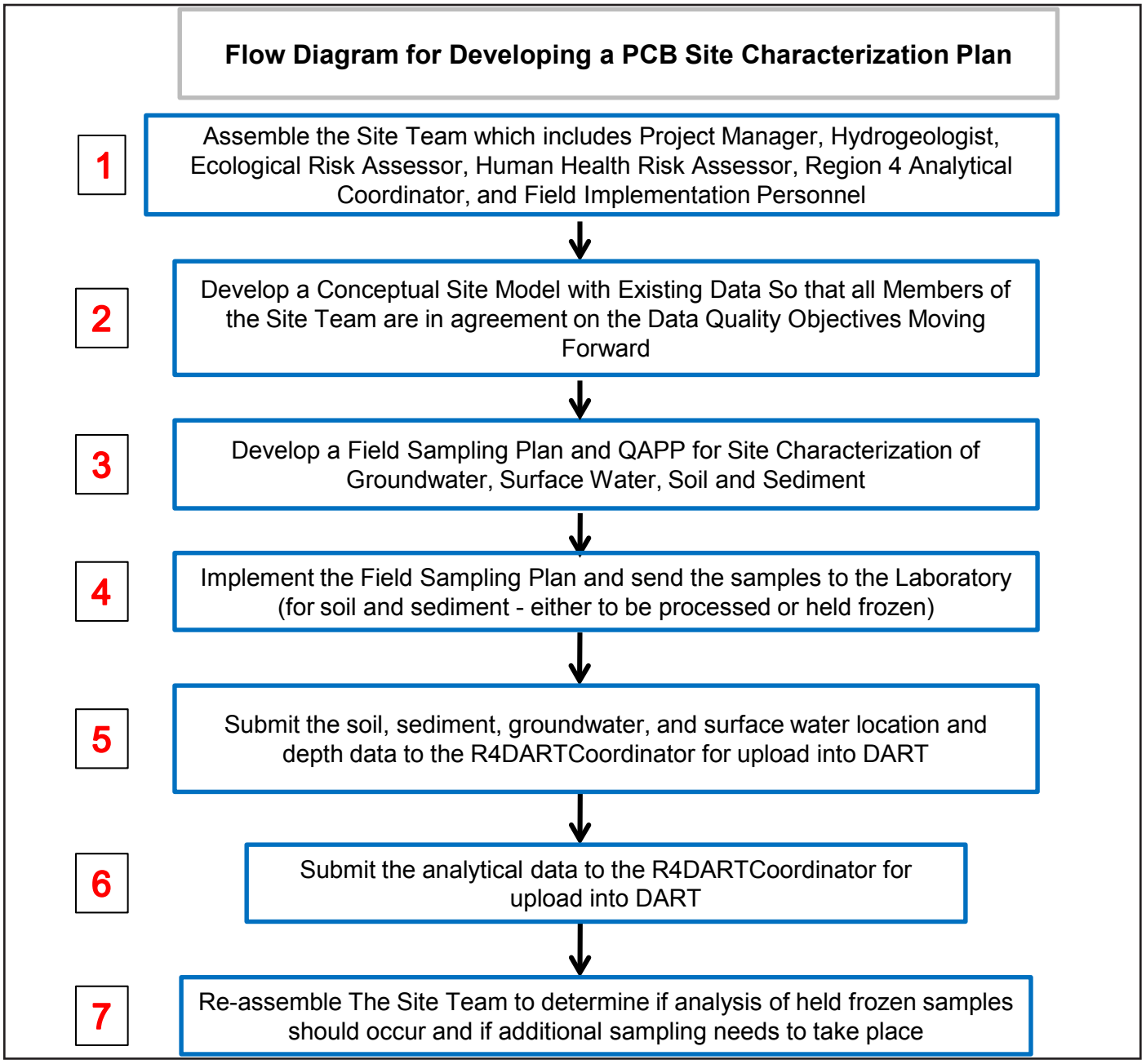

Figure 11: *Flow Diagram for Project Planning*

1 Assemble The Site Team

Assemble The Site Team composed of the Project Manager, Hydrogeologist, Ecological Risk Assessor, Human Health Risk Assessor, Region 4 Analytical Coordinator, and Field Implementation Personnel (from here on out the paper will call this "The Site Team"). Discuss the conceptual site model and how the field sampling plan needs to be written in order to be used in the field to characterize the PCB contaminant distribution.

2 Develop a Conceptual Site Model (CSM)

This initial CSM will allow all the parties on the Team to have a common understanding of the characterization concerns and solutions for field conditions that may pose difficulties during the sampling event. The CSM will also inform the type of sampling, the nature of the Field Sampling Plan (FSAP), and the budget for performing the characterization – an example is shown in the Figure 12 and the supporting text for the Figure.

Example Pathways:

- Leaching through
  - subsurface soil to groundwater
  - waste disposal units to subsurface soil
- Migration
  - from ground water to surface water features
  - from plumbing features to surface impoundments and surface water features
  - through plumbing features to subsurface piping/trenches
  - through plumbing features to ground surface
- Overland flow to surface water features
- Deposition by
  - particles blown onto the ground surface
  - Particles carried down to the ground surface during rainfall events

In looking at the CSM and Example Pathways above, several issues may need to be addressed:

- Aroclor (plus Aroclors 1262 and 1268) and congener analysis may be necessary in order to evaluate the weathering that may have occurred.
- If PCB NAPL is suspected then the lab should be notified so they can prepare to handle a highly contaminated sample.
- For characterization of subsurface soil and groundwater nature and extent, the recommended procedure is for a percentage (10% or no less than 5) of samples be subjected to congener analysis

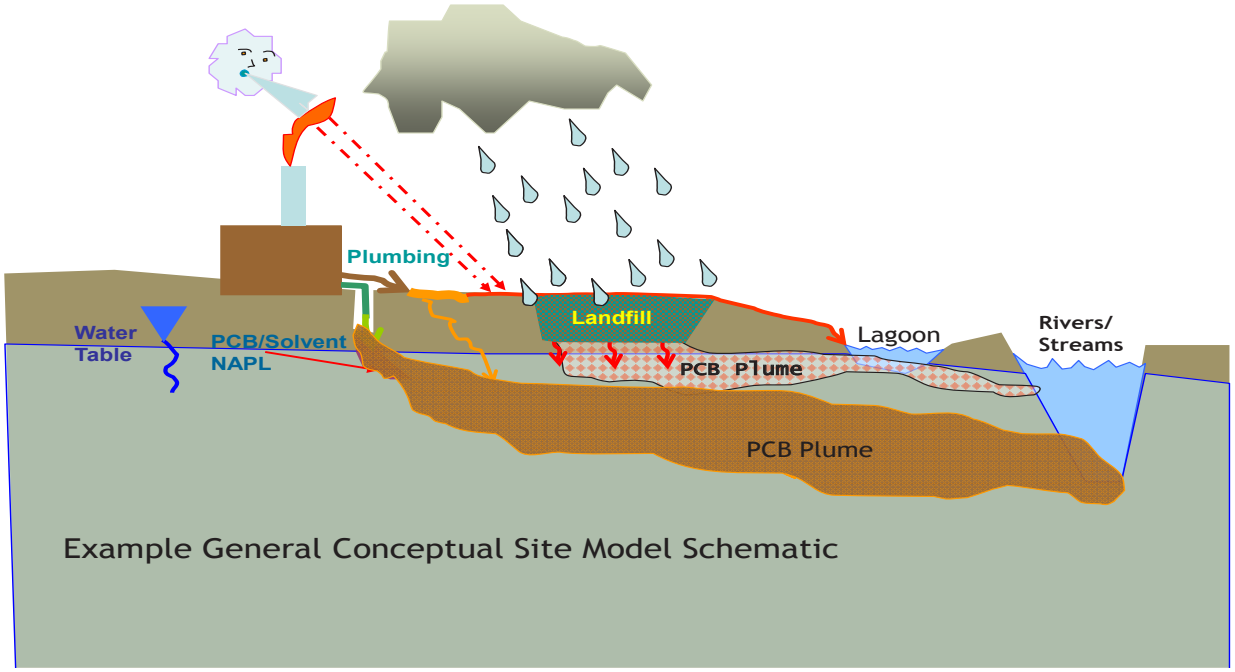

Figure 12: *Example of a General Conceptual Site*

- For the Risk Assessment 10% of the surface soil samples (but no less than 5) should be analyzed for congeners
- On a site specific or case by case basis, for the Ecological Risk Evaluation surface water and sediment samples may need to be analyzed for congeners 77, 123, 118, 114,1 05, 126, 153,167, 156, 157, 169, 189
- If a groundwater plume is known to be present, an evaluation for facilitated transport is highly recommended

3 *Develop the Field Sampling Plan and QAPP for the site work.*

In order to get the proper data for remedy selection several analyses need to be performed for various environmental media. Aroclor analysis is the least expensive method for analyzing samples for PCBs, so Aroclor data will generally be gathered for all media. In order to correlate the Aroclor data and determine where it is representative, congener data also should be obtained for nature and extent. There are exceptions to this suggestion. For example, in the instance where the site is an old landfill and removal has been called in to do a final action and no additional federal or state actions will take place, consideration should be given to what is known about the site at the time removal authority is in the execution planning stage. If one portion of the site is highly contaminated and aroclor data already indicate an action, then congener analysis may only be necessary for verifying the nature and extent of that portion of the site. If another portion of the site is contaminated but concentration data is borderline actionable, then congener analysis may be necessary to verify the definition of the actionable extent. The most important thing to do is **CONSULT WITH THE SITE TEAM** in order to develop a practical removal execution plan.

Though Aroclor was the original product, it weathers as it moves through the soil column or as it resides in sediment or sludges. The curve matching process used for Aroclor analysis can underestimate the total PCBs, if weathering has occurred. An evaluation of the correlation between the congener and Aroclor data is necessary so that total PCBs can be extrapolated over the entire site and for various environmental media. Region 4 TSS suggests that soil samples be obtained in suspected source (highly contaminated) areas, moderately contaminated areas and suspected clean areas and analyzed for both Aroclors and congeners so that the representativeness of the Aroclor data can be adequately evaluated. A curve produced by plotting congener total PCBs versus Aroclor total PCB data, can be used to provide correlation for the soil sampling data so that site managers can determine whether or not Aroclor data alone can be trusted at other locations to represent the total PCB concentrations in soil and water. Congener analysis may be necessary for surface soil and sediment so that the information can be incorporated into the ecological risk evaluations. The sections provided below include information that will inform the Field Sampling Plan and QAPP.

Soil and Sediment

- For subsurface soil leaching to groundwater and for nature and extent, Aroclor and congener analysis are recommended. A percentage (10% or no less than 5) of samples should be analyzed by congener analysis.
- For soil and sediment, it is recommended that if little is known about PCB distribution at the site, soil and/or sediment samples should be run using Aroclor analysis and then a subset of samples can be selected for congener analysis, once the Aroclor data are reviewed. For PRP lead sites, taking a greater number of samples during the initial field work and holding them in a frozen state should be considered so that if there is poor correlation between the Aroclor and congener analysis, the archived samples can be used to fill data gaps, as necessary. Note that soil and sediment samples can be held frozen for up to one year for congener analysis. If the site is Fund Lead and samples are being collected for the EPA Lab in Athens, or for an EPA contracted Non Routine Analytical Services, the labs may not be able to hold frozen samples (See Figure ES-1 on page ix for freezing requirements for samples).
- Typically for Ecological Risk evaluations congeners 81-TeCB, 77-TeCB, 123-PeCB, 118-PeCB, 114-PeCB, 105-PeCB, 126-PeCB, 153-HxCB, 167-HxCB, 156-HxCB, 157-HxCB, 169-HxCB, 189-HpCB are the most significant. 10%

of the sediment samples (no less than 5) should be analyzed for this list of congeners. Details of the ecological sampling strategy should be based on consultation with The Site Team.

Groundwater and Surface Water

- Groundwater samples should be collected using the low flow/low stress technique (See Yeskis and Zavala, 2002 - *http://www.epa.gov/tio/tsp/download/gw_sampling_guide.pdf* and the Appendix). This technique (versus the conventional low flow sampling) purges the well at the approximate rate that water enters the well so that if the well is productive, sampling can progress at a reasonable rate without invoking turbulent flow and turbidity. This also reduces the possibility of getting only stagnant water in the well casing. Both Aroclor and congener analyses are recommended for water samples. A percentage (10% or no less than 5) of samples should be run using congener analysis. A correlation analysis of the Aroclor and congener data is recommended.
- If turbidity is an issue, and in Region 4 that is > 10 Nephelometric Turbidity Units (NTU's), redevelop the well and resample. If turbidity remains an issue and is inherent in a low yield well, filtration with a 2 micron filter can be considered, NOT a 0.45 micron filter. Colloidal material can transport PCBs and removal of that material through filtration can provide a false negative sample result.
- Analysis for dissolved organic carbon (DOC) should be performed if facilitated transport is suspected (see FAQ).
- Surface water samples, obtained using conventional sample gathering methods for ecological assessments, may require sample analysis for Aroclor and congener's 81-TeCB, 77-TeCB, 123-PeCB, 118-PeCB, 114-PeCB, 105-PeCB, 126-PeCB, 153-HxCB, 167-HxCB, 156-HxCB, 157-HxCB, 169-HxCB, 189-HpCB. If ground water discharge to surface water is a pathway of interest, the detection limit of 0.014 ug/L should be used for surface water and groundwater analysis. **Consultation with The Site Team for the detection limits and congeners to be analyzed for is necessary.**

Analytical data requirements for full characterization

Table 6 provides details of the analysis methods, reporting limits and holding times for PCB analysis.

Aroclor Analysis for soil and groundwater – EPA Method 8082A (*http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/8082a.pdf*). Be sure and note that in addition to Method 8082A Aroclors, Aroclors 1262 and 1268 must be run in addition to the standard 8082A.

Congener Analysis for soil and groundwater – EPA Method 1668B

(*http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2009_01_07_methods_method_1668.pdf***)**

Congener Analysis for Dioxin like PCBs and Ecological PCBs – Use the same statement of work (SOW) as employed for the regular congener analysis and specify the individual congeners to be reported. There are 12 PCB congeners that have been designated by the World Health Organization (WHO) (Van-den Berg et al, 1998) as having "dioxin-like" (or non-ortho-substituted) toxicity. They are as follows: 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189. There are 18 PCB congeners that have been designated by the National Oceanic and Atmospheric Administration (NOAA) as always appearing in sediment and fish tissue and that do not readily degrade. This NOAA Congener List includes congener number: 8, 18, 28, 44, 52, 66, 77, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, and 206.

Initially homolog analyses was proposed by Region 4 because the analysis cost has typically been less than congener analysis, but because Method 680 is not an EPA promulgated method and because complications in executing Method 680 have emerged, the Region has reconsider advocating a wholesale recommendation for the homolog analysis. Region 4 has become aware that private sites have been running the congener analysis using EPA Method 1668B (the Congener Analysis method) and then summing the congeners into the homolog groups and presenting the data as a homolog analysis. This is fine, but the cost of the analysis is the same or higher than running the samples for congeners, so Region 4 is now simplifying our process approach to consider only Aroclor and congener analysis.

Table 6: Analytical Details for Sample Handling

Site Lead	Media	Analysis Objective	Recommended reporting limits based on MCLs, RSLs and AWQC	Recommended Analytical Method	Holding Times
EPA Region 4 Fund Lead	Ground Water/ Surface Water	Aroclor	0.014 ug/L for Groundwater/surface water issues; 0.5 ug/L for groundwater not influencing surface water	EPA Method 8082A (be sure and include 1262 and 1268)	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	For Athens - run EPA Method 1668B or Non-Routine Analytical Services for 1668A or B	If stored in the dark at less than 6 °C, aqueous samples may be stored for up to one year.
	Soil/ Sediment	Aroclor	33 ug/kg: 330 ug/kg max	**EPA** Method 8082A (be sure and include 1262 and 1268)	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	For Athens - run **EPA** Method 1668B or Non-Routine Analytical Services for 1668A or B	Up to 1 year frozen - Store in in the dark at less than -10 °C
PRP	Ground Water/ Surface Water	Aroclor	0.014 ug/L for Groundwater/surface water issues; 0.5 ug/L for groundwater not influencing surface water	EPA Method 8082A (be sure and include 1262 and 1268)	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	EPA Method 1668B	If stored in the dark at less than 6 °C, aqueous samples may be stored for up to one year.
	Soil/ Sediment	Aroclor	33 ug/kg: 330 ug/kg max	EPA Method 8082A	7 days until extraction and Extracts should be stored under refrigeration in the dark and should be analyzed within 40 days of extraction.
		Congener	Method Reporting Limit	EPA Method 1668B	Up to 1 year frozen - Store in in the dark at less than -10 °C

Note: consultation between the Region 4 Analytical Coordinator, the RPM/OSC, Human Health Risk Assessor, Hydrogeologist, and Ecological Risk Assessor are paramount since labs and analytical method details require clear direction

Regional Screening levels (RSL's) - http://www.epa.gov/region9/superfund/prg/

Maximum Contaminant LeveL (MCL's)

Ambient Water Quality Criteria (AWQC)

NOTE: Reporting levels can be customized to specific site needs to some extent for both the Regional laboratory and the CLP. In the absence of special requests, the routine approach for the Regional laboratory is to lower reporting levels to Maximum Contaminant Limits (MCLs) for only those contaminants which have an MCL. In the absence of special requests, the routine approach for the CLP, when the lowest reporting levels available from the contract are requested, provides the following results: Polychlorinated Biphenyls analyzed as Aroclor mixtures do not meet MCLs.
Reporting Limit: *Region 4 normally uses this term for the Sample-Specific Quantitation Limit, which has been adjusted for dilutions, moisture content, or other sample-specific factors. This value is the quantitation limit actually achieved in the analysis, and may be the same as the Quantitation Limit that was set as the goal for project planning. However, often, this value will be higher than the Quantitation Limit, since the goal of this Minimum Reporting Limit can only be achieved for relatively clean samples. This is the value that normally appears on the data sheet for data reporting. This is a data reporting value and will vary according to sample matrix of the specific sample.*

Perform Aroclor analysis:

- **For Region 4, Aroclor analysis should be run for all samples.**[3]
- When the Gas Chromatography/Electron Capture Detector (GC/ECD) pattern is unaltered and matches the standard pattern. For example the chromatogram represents peaks that are easily assigned to an Aroclor and there are a few "renegade" peaks, making the chromatogram noisy.
- When high concentrations of PCB is present in the soils due to DNAPL presence.
- When only one Aroclor is found or the Aroclor mixture has widely different chlorination levels. For example, a site where only 1016 or 1260 were disposed, the chlorination level between these Aroclors is significant so the chromatogram will clearly discern the peaks assigned to each of the Aroclors.
- When objectives include assignment of a specific responsible party to a specific Aroclor release.

Perform Congener analysis:

Congener analysis can be performed using High Resolution long column/long run time Gas Chromatography/Electron Capture Detection (HRGC/ECD), Gas Chromatography/Low Resolution Mass Spectrometry (GC/LRMS), or High Resolution Gas Chromatography/High Resolution Mass Spectrometry (HRGC/HRMS). Pesticide interferences can occur (Toxaphene) when using GC/ECD Analysis, whereas they do not occur with HRGC/ECD. Congener analysis using GC/ECD has been used predominantly for tissue and biological analysis. Congener analysis by GC/LRMS Selective Ion Monitoring (SIM) is used when:

- Aroclor patterns have been altered or when chlorinated species interferences are present. It is especially sensitive in the low chlorination range where mono-, di-, tri- and tetra- species are present.
- When the National Oceanic and Atmospheric Administration (NOAA) 18 congeners are to be analyzed and also needed to determine total PCB.
- When the data user desires to determine what congeners are present and which congeners have been lost due to weathering.
  - GC/LRMS may not be sensitive enough to quantitate congeners #77, #81, #126, and #169 the most toxic of the World Health Organization (WHO) high risk congeners due to their very low concentrations in manufactured Aroclors.
  - Gas Chromatography/High Resolution Mass Spectrometry (GC/HRMS) is used to determine the concentrations for the 12 WHO dioxin like congeners
  - Congener analysis is used over homolog analysis because there is a promulgated EPA Method, it is more sensitive, more selective, and more suited for risk assessment purposes. **GC/ECD is acceptable to analyze the NOAA 18 congeners, however, it cannot be used to determine all 209 congeners**.

Use in Risk Assessment: The use of congener data for risk assessment is different than with Aroclors. Slope factors for 4 PCB Aroclors (1016, 1242, 1254, 1260) have been developed but not for all Aroclors or all congeners. The Risk Assessor may use the total PCBs (sum of congeners) to calculate a total PCB risk and hazard. The dioxin-like PCB congeners will be assessed separately.

Note that when risk is calculated the provision for preventing double counting should be employed. Congener analysis for the dioxin like PCBs (WHO-12 and/or NOAA-18) may be necessary and this case by case determination should be determined by The Site Team as they establish the data needs (Data Quality Objectives) for the soil, groundwater, surface water, and sediment data.

4 Implement the Field Sampling Plan and QAPP.

5 Submit the soil, sediment, groundwater, and surface water location and depth data to the Region 4 DARTCoordinator for upload into DART.

3 **NOTE:** This paper will use the term Aroclor analysis which are the Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268. **Method 8082A does not include 1262 and 1268, so this analysis must be added in the Work Plan.** Region 4 SESD has incorporated Aroclor 1268 into their PCB Aroclor analysis process, but private CLP labs have not.)

6 Once the analytical data is returned, submit the analytical data to the Region 4 DART Coordinator for upload into DART.

7 Once the field work has been implemented and the analytical data is uploaded into the Region 4 DART data management system, convene The Site Team and review the data and determine if frozen, held samples need to be run and if additional samples need to be collected and analyzed.

EXAMPLE OF DATA EVALUATION

In the example depicted in Figure 12, soil leaching to groundwater was the concern. A sampling strategy was employed that sampled a variety of waste disposal settings related to the site. Sampling locations were determined in order to evaluate leaching in locations of current groundwater contamination and adjacent to a stream. The five sampling locations are presented below in the aerial photograph. The soil and groundwater samples were analyzed for both Aroclors and homologs so that a comparison of total PCBs for each sample could be compared. In addition to the comparison between samples, obtaining a distribution of the homologs was of interest in order to compare the homolog distribution to the groundwater concentrations and see what homologs were leaching versus those that were not.

The graphical depiction of soil concentration data is explained in the questions posed and answered for the data set.

Example Remedial analysis with regard to the outcome of the data analysis for a remedial path forward for subsurface soil:

The questions below are framed in order to develop this path forward for subsurface soil remediation to protect groundwater.

1. How is ground water responding to soil contamination?
2. How does the homolog distribution in soil affect the migration to ground water?
3. What soil concentration protective of groundwater should be considered for subsurface soil clean-up?

1. How is groundwater responding to soil contamination and how does the homolog distribution in soil affect migration to groundwater?

Subsurface soil is leaching to groundwater under certain conditions. When the soil is within the flood plain of a creek that runs adjacent to the Plant, and subject to routine flooding AND when the homolog distribution is represented by the lesser chlorinated homologs, leaching does occur. When the soil has the higher chlorinated homologs and is not adjacent to periodic flooding, the flux to groundwater either does not occur or occurs very slowly so that groundwater concentrations remain low.

In the past, NAPL has been present on the Plant site and appears to have influenced groundwater at a depth below 100 feet, but past removal activities appear to have removed NAPL and none appears in borings or monitoring wells.

2. How does the homolog distribution in soil affect the migration to ground water?

In conclusion, flux to groundwater from subsurface soil is occurring; however, when the homolog distribution is represented by the higher chlorinated PCB homologs (Nona and Deca), the area is not subject to routine flooding, the soil texture is a clay, and NAPL is not present, flux to groundwater is either not occurring or occurring at such a reduced rate that groundwater concentrations remain either below or very close to the MCL for PCBs.

3. What soil concentration protective of groundwater should be considered for subsurface soil clean-up?

A strategy would be to take all the soils data that exists for the unit in question and determine what the homolog distribution is for the soil. In the case of old data for which there is only Aroclor analysis, see if there are assumptions that can be made to assign a distribution. Those assumptions could be, if the soil concentration is high (greater than 10 mg/kg) and Aroclor 1268 is the primary Aroclor, understand that it may not be Aroclor 1268, it may be just weathered out, indeterminate PCB. One note is that there was not a lot of Aroclor 1268 produced so finding it is specific to the site. For instance, there are chlor-alkali facilities that had real Aroclor 1268 because the process

involved anodes coated with Aroclor 1268. Also understand that the concentrations for the Aroclor data may be much lower than the actual homolog analysis. Determine areas where going back and doing some confirmatory sampling congenors or homolog analysis, is appropriate. Pick test areas for installation of monitoring wells, keeping those wells in areas of periodic flooding, to test drive the hypothesis that migration to groundwater is dependent on periodic flooding, higher hydraulic conductivity soil, and lesser chlorinated homologs.

In the case presented in Figure 13, the data establishes that in upland areas where the homolog distribution is either primarily Aroclor 1268 or the Nona and Deca homologs, there will be a unique subsurface soil concentration protective of groundwater that is higher. In areas where the homolog distribution is in the lowest to mid chlorinated level and the Aroclors are 1254 and 1260, the area is within a stream flood plain and the soil textures include a silt or sand (higher hydraulic conductivity) the subsurface soil concentration protective of groundwater will be a lower concentration.

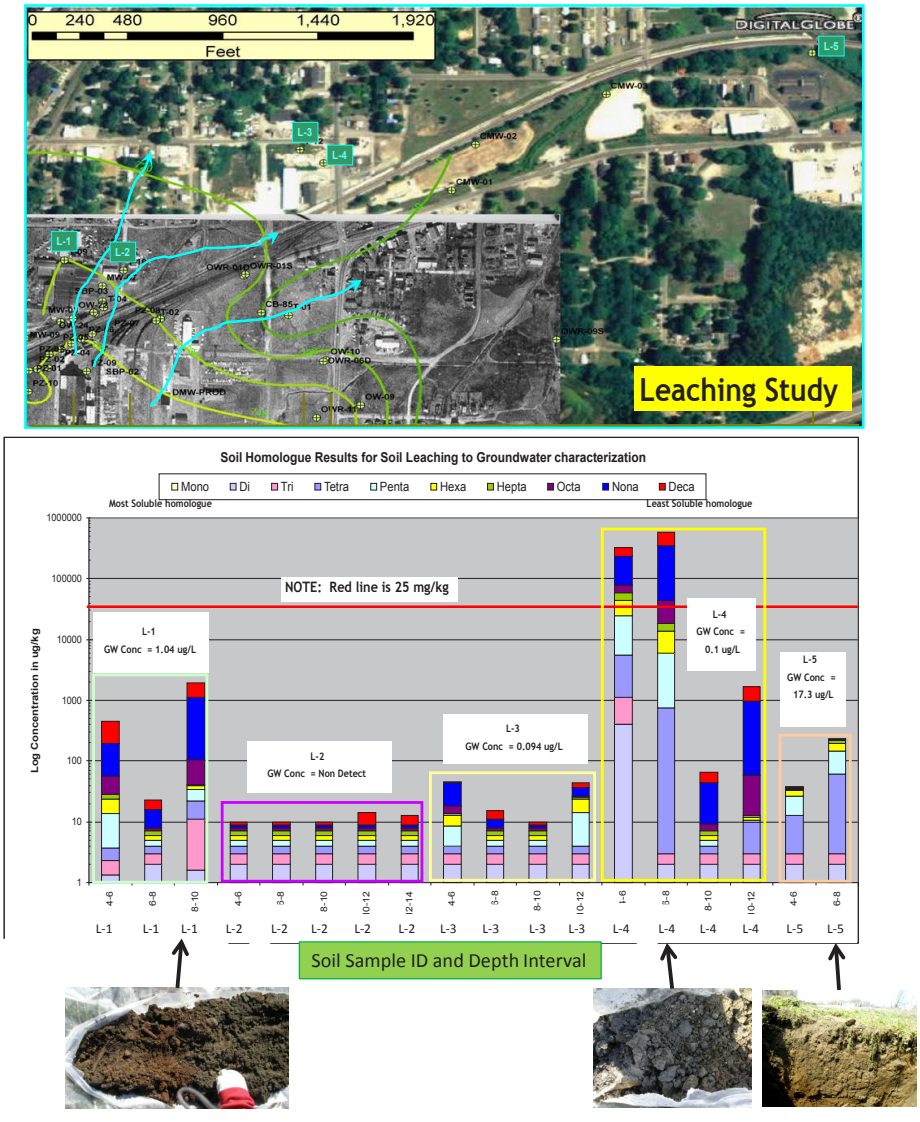

Figure 13: *Soils Data for use in evaluating PCB leaching to groundwater. Photographs of the most contaminated soil intervals are featured in the figure.*

FREQUENTLY ASKED QUESTIONS

Should Dissolved Organic Carbon analysis (DOC) be run for every sample?

This will depend on the nature of the soils surrounding the well. If the soils have high Total Organic Carbon (TOC) and larger concentrations of PCB in the 10 to 100+ mg/L range, then each water sample should have DOC analyzed. If facilitated transport is suspected due to PCB concentrations in the water above the equilibrium solubility then DOC analysis must be performed. If only a few wells fall into the above cases only those wells need to have DOC analysis. The DOC samples cannot be held for extended periods of time like frozen soil sample can, so the DOC analysis must be run within the required holding time (14 Days).

In the presence of DNAPL, how should the well sampling be performed?

If dense non-aqueous phase liquid (DNAPL) is discovered during the initial well inspection or the sounding of the well, low stress/low flow sample collection should not be performed. If DNAPL is in the well, the odor of the air above the water may have an organic odor and testing the air above the water will a photo-ionization detector (PID) may be necessary. Use of a dual phase water level probe will show whether or not DNAPL is present and at what depth. If either of these methods indicates an organic phase, a bailer should be used to collect a sample. The bailer should be retrieved very carefully and should be emptied from the bottom to try and capture the DNAPL or emulsion phase separately from the water. A DNAPL sample must not be sent to the laboratory without the laboratory being warned ahead of time. In many cases the laboratory will not accept PCB DNAPL samples and a separate laboratory equipped to perform waste dilution methods needs to be contacted. If the concentration of PCB is as high as 1000 milligrams per kilogram (mg/kg or ppm) in the soils surrounding the well, DNAPL or a PCB emulsion can be expected. The use of a dual phase water level probe will indicate at what depth the emulsion or DNAPL is present.

Do PCBs form colloids and how should the sampling be conducted to handle the eventuality?

PCBs form colloids in several ways. If the PCB is in the presence of a water soluble solvent or liquid organic phase along with the released PCB, this mixture will enhance PCB colloid formation. Natural surface active agents in the surrounding organic soils can act on the PCB to disperse the PCB into tiny colloidal particles in the ground water. The level of chlorination of the PCB can control whether the PCB will form a colloid. The nature of the PCB mixture initially released to the ground and the nature of the soils as well as the condition of the percolating water through the soils will determine if a colloid will form. The nature of the colloid formed is controlled by the environment and the condition of the PCB released. If turbidity is an issue and the wells have been reconditioned with turbidity continuing to persist, samples should be analyzed unfiltered and also a sample should be collected and filtered with a 2 micron filter.

How are low flow/low stress groundwater samples collected?

Refer to Ground-Water Sampling Guidelines for Superfund and Resource Conservation and Recovery Act (RCRA) Project Managers attached in *http://www.epa.gov/tio/tsp/download/gw_sampling_guide.pdf*

Why should a team be assembled to develop work plans?

Project planning is typically recommended for the successful investigation of all sites. However, for PCB sites both complicated analytical and complicated contaminant migration issues make developing this team is essential. The team should consist of Quality Control (QC) chemists, experienced sample collection personnel, human health risk assessors, ecological risk assessors, hydrogeologists and an experienced environmental laboratory to determine the nature and risk of those chemicals. In addition, team should include hydrologists, geologists, hydrogeologists, soil scientists, and civil engineers to look at the physical characteristics of the site. The team together will design the project from the initial surface soil sampling, soil boring design, well installation

and sample collection through analysis and data validation. The QC chemists, risk assessors, and hydrogeologists will meet to prepare a quality assurance project plan (QAPP) that will include where the samples will be collected, how they will be collected (Standard Operating Procedures [SOPs]), how the sample will be analyzed (SOPs), the QA/QC criteria that will be met by the laboratory for all the analyses of each sample media collected, and how the data will be evaluated after all these processes are completed. Only a diverse team that meets and designs the entire project will be successful in investigating a PCB site properly.

What is the relationship between TSCA regulations and migration of PCBs to groundwater?

The Toxic Substances Control Act (TSCA) regulation always plays a part in PCB remedy consideration. In the context of site remediation, CERCLA considers TSCA an ARAR and the data necessary to support the option captured in the portion of the regulation, known as 40 C.F.R. § 761.61(c), is provided in this Issue Paper in order to provide site specific data that informs site specific clean-up criteria appropriate for protection of human health and the environment. The Issue Paper is focused on data needs for site characterization for the nature and extent of PCB contamination in water, sediment, and soil in support of evaluating migration pathways and risk and for determining remedial strategies in Superfund and Resource Conservation and Recovery Act (RCRA) Remedial Investigations and Remedial Facility Investigations, respectively.

What is auto fluff?

When a whole discarded or wrecked automobile, truck, or other vehicle is crushed everything inside the car is compressed into a block of metal. This means that if there are any residual fluids such as crankcase oil, brake fluid, automatic transmission fluid, engine coolant, or small capacitor fluids, they will either be drained out or will absorb to the foam making up the car seats and other upholstery. White goods (e.g. fluorescent lights, stove, refrigerators, air conditioners, freezers, etc) were also placed in the cars before crushing to get denser metal blocks. The solid block formed during crushing and compressing is then chipped up into small pieces. The foam that was compressed in the block will expand during chipping and come out looking like softball or cantaloupe sized chucks. These chunks are called auto fluff and may contain absorbed fluids left in the car before crushing. Older cars contained small capacitors containing pure Aroclor 1242 and when these capacitors were crushed they leaked out the fluid. These PCBs ended up in the auto fluff. The auto seat foams/ fluff also had flame retardant placed in them during manufacture so the foam would meet Underwriter's Laboratory (UL) standards for flame retardant requirements. Chlorinated biphenyls, brominated biphenyls and more recently polybrominated diphenyl ethers were used as flame retardants. Clean auto fluff/top-soil was found to be a very good cover for closed landfills and hazardous waste closure cells. Some PCB contaminated auto fluff ended up being used to cover landfills and thus had to be remediated as a hazardous waste site.

What issues arise around the presence of Aroclor 1016 and 1242?

Laboratories now possess capillary columns with stationary phases that can distinguish between Aroclor 1242 and Aroclor 1016. This is especially true when a second column with a different stationary phase is used as a confirmation column and is run simultaneously. Method SW846 8082A requires confirmation via secondary column or Gas Chromatography/Mass Spectrometry (GC/MS).

What are the NOAA Congeners?

The National Oceanic and Atmospheric Administration (NOAA) Congener List by National Status and Trends Programs are listed by Congener Number: 8, 18, 28, 44, 52, 66, 77, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, and 206. An evaluation of sediment and fish tissue was assembled and NOAA realized that there were 18 congeners that always appeared and this list is the outcome of that evaluation. This list represents congeners that are persistent in sediment and do not readily degrade.

What are the WHO 12 Congeners?

The World Health Organization (WHO) has provided a list of 12 dioxin-like congeners which are PCB-77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189

Does Aroclor Analysis get Aroclor 1242 and 1268?

No it does not. Our Region 4 EPA SESD Lab does analyze for Aroclors 1242 and 1268 if you ask for Aroclor Analysis, but all labs otherwise only capture analysis down to Aroclor 1260. Be sure and ask for the additional Aroclor 1242 and 1268 analysis.

What congeners should be run for ecological evaluations?

81-TeCB, 77-TeCB, 123-PeCB, 118-PeCB, 114-PeCB, 105-PeCB, 126-PeCB, 153-HxCB, 167-HxCB, 156-HxCB, 157-HxCB, 169-HxCB, 189-HpCB

What is "hot" or "heavy" 1254?

Only 2 Aroclors, 1016 and 1254 (produced in a separate syntheses) (Frame, 2001), were produced differently, from 1971-1974. Raw Aroclor 1242 was vacuum-distilled to produce a narrow boiling range PCB dubbed Aroclor 1016. Aroclor 1016 was produced for some small, specific capacitor applications that required very tight physical properties such as specific gravity and viscosity. When Aroclor 1016 was separated by vacuum distillation, the remaining PCB in the reactor was composed of 51% chlorine. This remaining material was again reacted with anhydrous chlorine to create a second type of Aroclor 1254, that was composed of 54% chlorine but had specific congeners in higher concentration than the normal Aroclor 1254 (Frame, 1999; Kovanti et al, 2001). The second type of 1254 (sometimes referred to as Hot 1254) had all the same physical properties except that it was later discovered that it contained a much higher content of dioxin-like PCB congeners and a larger amount of dioxin-like polychlorinated dibenzofurans (Burkhard and Lukasewycz, 2008). The specific gravity and pour point[4] were the same as commonly produced 1254 so it would meet the electrical specifications for high voltage capacitors.

What detection limit should be used?

The detection limit for PCB analysis of a specific medium with depend on the regulatory clean-up standard that is applied to that media or a risk based limit set to determine if there is human health or ecological risk. Table ES-1 is a reference for use in determining the proper detection limits. In the case of surface waters we are using the Ambient Water Quality Criteria (AWQC) of 0.014 micrograms per liter (µg/L). Because groundwater will usually impact surface water at some point along the groundwater path, the AWQC can also be applied to ground water. The AWQC can be achieved as a detection limit using GC/ECD or congener analysis, but the project team will have to collect 2-3 liters of water and the laboratory will have to extract the larger volume, concentrate the extract to a lower volume (1.0 milliliters [ml] to 0.2 ml) and shoot more extract on the GC column (0.2 microliter [µL]). The Site Team will also have to meet a detection limit 3-5 times lower than the AWQC to prove that there is no blank contamination (this is a regional data validation requirement in most regions). If the project needs to attain the national recommended water quality standard (NRWQC) at 0.000064 µg/L then only GC/HRMS can be used and many liters of water will need to be extracted.

The detection limits for soils should be in the 100 micrograms per kilogram (µg/kg) range up to 2 mg/kg in contaminated soils. The detection limit will depend on the use of the data. If the data were used to confirm that the soil was remediated to below some risk based level the detection limit stated above would be appropriate. In some cases where the soils are heavily contaminated, a detection limit in the mg/Kg range is appropriate. For soils that will be compared to the Remedial Screening Level (RSL - http://www.epa.gov/region9/superfund/prg/) concentrations, the RSL concentration will inform the detection limit needed.

When is Aroclor analysis appropriate?

- When the Gas Chromatography/Electron Capture Detector (GC/ECD) pattern is unaltered and matches the standard pattern. For example the chromatogram represents peaks that are easily assigned to an Aroclor and there are not a lot of "renegade" peaks, making the chromatogram noisy.
- When high concentrations of PCB is present in the soils due to DNAPL presence.
- When only one Aroclor is found or the Aroclor mixture has widely different chlorination levels. For example, if there is a site where only 1016

4 Pour point is the lowest temperature at which PCB becomes semi solid and losses its flow characteristics

or 1260 were disposed of, the chlorination level between these Aroclors is significant so the chromatogram will clearly discern the peaks assigned to each of the Aroclors.

- When the project needs to assign a responsible party to a specific Aroclor release.
- When there are fresh spills from industrial or electrical equipment.

When is congener analysis used?

Congener analysis can be performed using long column/long time run GC/ECD or can be run in a similar manner as homologs using GC/LRMS. GC/ECD analysis of congeners has similar problems with pesticide interferences as Aroclor analysis. Congener analysis using GC/ECD has been used predominantly for tissue and biological analysis. Congener analysis by GC/LRMS SIM is used when

- Aroclor patterns have been altered or when chlorinated species interferences are present. It is especially sensitive in the low chlorination range where mono-, di-, tri- and tetra- species are present.
- When the National Oceanic and Atmospheric Administration (NOAA) 18 congeners are to be analyzed and thus used to determine total PCB.
- When the data user needs to determine what congeners are present and which congeners have been lost due to weathering.
  - GC/LRMS may not be sensitive enough to quantitate congeners #77, #81, #126, and #169 the most toxic of the World Health Organization (WHO) high risk congeners due to their very low concentrations in manufactured Aroclors.
  - Gas Chromatography/High Resolution Mass Spectrometry (GC/HRMS) is used to determine the list of 12 WHO congeners that risk assessors especially need to know for dioxin-like carcinogenic risk measurements.
  - Congener analysis is used over homolog analysis because it is more sensitive, more selective, and more suited for risk assessment purposes. **GC/ECD is acceptable to analyze the NOAA 18 congeners, however, it cannot be used to determine all 209 congeners.**
- Aroclor analysis should be run for all data with no less than 10% (or a minimum of 5 samples) of the samples also being analyzed for congeners. Total Aroclor results should be compared to total congener results to help determine if weathering is an issue. If weathering is revealed as an issue, the Site Team will need to make decisions about what samples should be run for congeners. Note that when risk is calculated the provision for preventing double counting should be employed. Congener analysis for the dioxin like PCBs (WHO-12 and/or NOAA-18) may be necessary and this case by case determination should be determined by the Site Team as they establish the data needs (Data Quality Objectives) for the soil, groundwater, surface water, and sediment data.

How is Fish PCB data considered and what analysis should be performed?

Consult The Site Team so this can be determined on a case by case basis.

DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

Aroclor - A common trade name for mixtures of PCBs. The mixtures have been widely used as coolants and lubricants in transformers, insulators, and other electrical equipment because of their highly stable properties. Because of their stability in the environment together with the toxicity and their propensity to biomagnify up the food chain, Aroclor mixtures can cause severe impacts to human and ecological systems.

Askarel - Askarel is a PCB/chlorobenzene mixture produced for filling transformers. The PCBs were diluted in a mix of tri- and tetrachlorobenzene solvent in concentrations of 30% to 70% or 300,000 to 700,000 ppm PCBs.

Colloid – In environmental fate and transport, colloids are considered a mobile (carrier) particle to which a hydrophobic compound, like PCBs, attach. A colloid is termed a “mobile solid” that has a particle size that ranges from 10 – 10,000 angstroms or less than or equal to 1 micrometer in diameter. Colloids include humic and fulvic acids, clay minerals, and iron/aluminum oxides.

Colloidal Transport –A colloidal system is one in which finely divided particles, which are

approximately 10 to 10,000 angstroms in size, are dispersed within a continuous medium in a manner that prevents them from being filtered easily or settled rapidly. Colloids can be created in the natural environment. During the process of migrating through the soil along with rainwater, PCBs can become colloids due to the natural surface active agents and humic substances contained in natural soils. This allows the PCB to form very small particles that are in the colloidal particle range. The PCB colloid particles that are surrounded by some surface-active material can move through the ground water and can migrate through small soil pores as well as the water does. When the water containing the colloids is analyzed, the pattern found is usually that of the original Aroclor with little environmental weathering and congener losses. The amount of pure PCB liquid released and the organic nature of the soils may have a great deal to do with how and why colloids are formed.

At the same time, humic and fulvic acids in the organic soils can complex with the PCB forming a water soluble chelate that will move with the percolating water or ground water. The actual chelating action is not well characterized at this time but is being researched. Colloid-facilitated transport of contaminants are transported because (1) there is a source of colloids (mobilization), (2) contaminants bind extensively and essentially irreversibly to the colloids, and (3) colloids move with the groundwater (transport).

Congener - Any single, unique, well-defined chemical compound in the PCB category is called a “congener.” The name of a congener specifies the total number of chlorine substitutes and the position of each chlorine. There are a total of 209 congeners.

Facilitated Transport - Any process that has the potential to speed the transport of a pollutant beyond what is expected based solely on considerations of idealized Darcian flow and equilibrium sorptive interactions with an immobile solid phase, has been broadly termed, “facilitated transport”. For the purpose of PCBs, a hydrophobic compound, facilitation of transport occurs when solvents are mixed with the PCB, PCBs attach to colloids and move, and PCBs are entrained in an emulsion and move.

Homolog - Subcategories of PCB congeners having equal numbers of chlorine substituents. For example, the “Tetrachlorobiphenyls” (or “Tetra-PCBs” or “Tetra-CBs” or just “Tetras”) are all PCB congeners with exactly 4 chlorine substituent’s that may be in any arrangement.

K_{ow} - Octanol-Water Partition Coefficient - A coefficient representing the ratio of the solubility of a compound in octanol (a non-polar solvent) to its solubility in water (a polar solvent). The higher the K_{OW}, the more non-polar the compound is. Log K_{OW} is generally used as a relative indicator of the tendency of an organic compound to adsorb to soil. Log K_{OW} values are generally inversely related to aqueous solubility and directly proportional to molecular weight

Hydrophobic – A compound that has a very low solubility and in some instances repels water.

Sorption - The process in which one substance takes up or holds another (by either absorption or adsorption).

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APPENDICES

APPENDIX A: GROUNDWATER SAMPLING

Low Stress Approach shown in page 8 of Ground-Water Sampling: Guidelines for Superfund and RCRA Project Managers (2002):

PURGE CRITERIA

"Low-Stress Approach"

The first technique for purging a well, known as the low stress approach, requires the use of a variable-speed, low-flow sampling pump. This method offers the advantage that the amount of water to be containerized, treated, or stored will be minimized. The low-stress method is based on the assumption that pumping at a low rate within the screened zone will not draw stagnant water down, as long as drawdown is minimized during pumping. Drawdown should not exceed 0.33 feet (0.1 meters) (Puls and Barcelona, 1996). The pump is turned on at a low flow rate approximating the recovery rate (based on the drawdown within the monitoring well during sampling). This technique requires the location of the pump intake to be within the saturated-screened interval during purging and sampling.

The water-quality indicator parameters (purge parameters), pH, specific electrical conductance, dissolved oxygen concentration, oxidation-reduction potential, temperature and turbidity, should be monitored at specific intervals. The specific intervals will depend on the volume within the tubing (include pump and flow-through cell volumes), pump rate and drawdown; commonly every three to five minutes. These parameters should be recorded after a minimum of one tubing volume (include pump and flow-through-cell volumes) has been purged from the well. These water-quality-indicator parameters should be collected by a method or device which prevents air from contacting the sample prior to the reading, such as a flow-through cell (Barcelona et al., 1985; Garske and Schock, 1986; Wilde et al., 1998). Once three successive readings of the water-quality indicator parameters listed in Table 1 have stabilized, the sampling may begin.

Table A-1: Stabilization Parameters and Criteria

Parameter	Stabilization Criteria	Reference
pH	+/- 0.1	Puls and Barcelona, 1996; Wilde et al., 1998
specific electrical conductance (SEC)	+/- 3%	Puls and Barcelona, 1996
oxidation-reduction potential (ORP)	+/- 10 millivolts	Puls and Barcelona, 1996
turbidity	+/- 10% (when turbidity is greater than 10 NTUs)	Puls and Barcelona, 1996; Wilde et al., 1998
dissolved oxygen (DO)	+/- 0.3 milligrams per liter	Wilde et al., 1998

The water-quality indicator parameters that are recommended include pH and temperature, but these are generally insensitive to indicate completion of purging since they tend to stabilize rapidly (Puls and Barcelona, 1996).

Oxidation-reduction potential may not always be an appropriate stabilization parameter, and will depend on site-specific conditions. However, readings should be recorded because of their value as a double check for oxidizing conditions, and for some fate and transport issues. When possible, especially when sampling for contaminants that may be biased by the presence of turbidity, the turbidity reading is desired to stabilize at a value below 10 Nephelometric Turbidity Units (NTUs). For final dissolved oxygen measurements, if the readings are less than 1 milligram per liter, they should be collected with the pectrophotometric method (Wilde et al., 1998, Wilkin et al., 2001), colorimetric or Winkler titration (Wilkin et al., 2001). All of these water-quality-indicator parameters should be evaluated against the specifications of the accuracy and resolution of the instruments used. During purging, water-level measurements must be taken regularly at 30-second to five-minute intervals (depending on the hydraulic conductivity of the aquifer, diameter of the well, and pumping rate) to document the amount of drawdown during purging. The water-level measurements will allow the sampler to control pumping rates to minimize drawdown in the well.

APPENDIX B: TABLE OF THE DIOXIN-LIKE CONGENERS IN AROCLORS

Table B – 1: Dioxin-like PCB Congener Concentrations in Commercial Aroclors
(All concentrations in ug/g or ppm)

PCB Congener	WHO TEF	Aroclor 1221	Aroclor 1232	Aroclor 1016	Aroclor 1242	Aroclor 1248	Aroclor 1254	Arodor 1260	Aroclor 1262	Aroclor 1268
77	0.0001	12.6	2150	40.9	2590	4440	174	33.8	84.6	36.1
81	0.0003	0.51	111	1.96	156	221	16.4	3.33	4.63	1.35
105	0.00003	55.9	3030	69.5	4840	17300	33800	434	764	107
114	0.00003	4.04	248	6.03	443	1320	1930	17	46	5.86
118	0.00003	88.1	4460	110	6980	24200	78900	5610	1980	101
123	0.00003	3.33	164	4.72	277	806	1150	5.02	27.8	3.24
126	0.1	0.28	21	0.56	33.6	98	37.3	2.13	2.28	1.76
156	0.00003	7.49	90.7	3.72	255	654	8440	4860	946	17.6
157	0.00003	1.46	22	1.03	70.9	171	1870	252	63.8	7.92
167	0.00003	2.52	32.4	1.1	80.7	207	3100	1990	278	4.96
169	0.03	0.08	0.17	0.13	0.11	0.21	0.81	0.82	0.4	0.32
189	0.0003	1.17	4.36	0.12	4.53	11	246	1290	451	4.4

The table is adapted from Rushneck et al with modification based on updated WHO TEFs added from Van Den Berg et al, 2006.

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APPENDIX C: PCB AROCLOR/HOMOLOG PROPERTIES

Table C-1: PCB Aroclor/Homolog Properties

Aroclor	A1221	A1232	A1016	A1242	A1248	A1254	A1260	A1268	Homo-logue Solubility
Homologue Group	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	Wt%	ug\L
Monochlorobiphenyl	47.88	22.27	1.31	0.95	0	0	0	0	4000.000
Dichlorobiphenyl	35.94	21.19	19.4	15.15	2.03	0.49	0.1	0	1600.000
Trichlorobiphenyl	6.52	23.47	45.36	36.53	24.9	1.31	0.27	0	650.000
Tetrachlorobiphenyl	1.69	23.37	32.82	36.07	51.36	26.81	4.39	0.51	260.000
Pentachlorobiphenyl	0.65	4.78	1.16	8.73	18.45	44.32	10.56	2.75	99.000
Hexachlorobiphenyl	1.09	0.61	0	1.11	2.07	21.85	40.68	2.08	38.000
Heptachlorobiphenyl	0.43	0.5	0	0.79	1.48	4.68	33.37	8.32	14.000
Octachlorobiphenyl	0.06	0.12	0	0.28	0.45	0.54	9.4	40.93	5.500
Nonachlorobiphenyl	0	0.02	0	0.03	0.06	0.03	1.21	37.29	2.000
Decachlorobiphenyl	0.01	0.01	0.01	0	0	0.02	0.02	8.12	0.760
Aroclor Solubility (ug/L)	15000.00	1450.00	420.00	240.00	54.00	12.00	0.30	<0.3	
Aroclor Kow (cm^3/g)	12000	35000	24000	380000	1300000	1070000	14000000	>140000000	
Guidance on Remedial Actions for Superfund Sites with PCB Contamination, EPA/540/G-90/007									

APPENDIX D: FLOW DIAGRAM FOR EVALUATING FACILITATED TRANSPORT

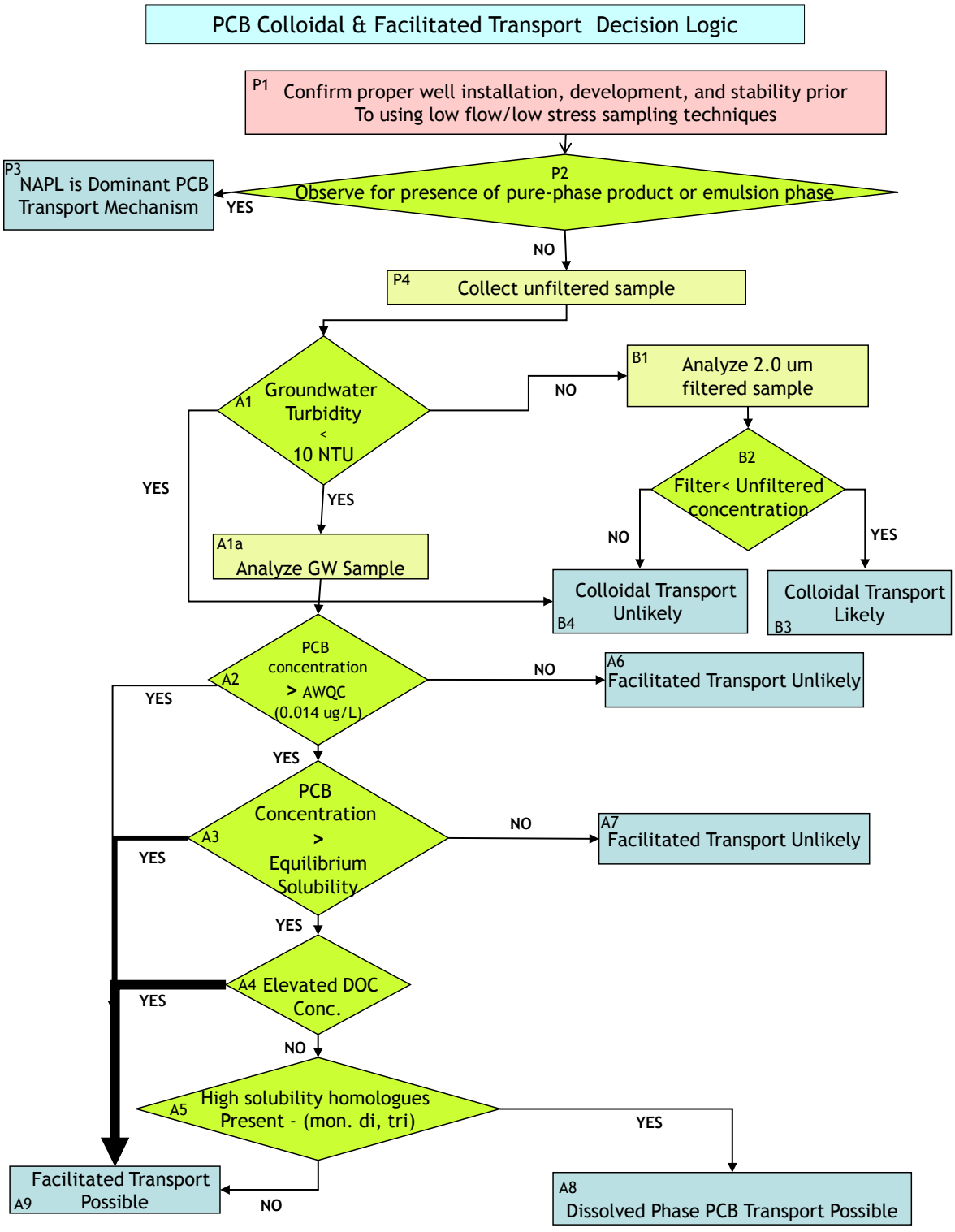

Figure D-1: *Flow Diagram from evaluating facilitated/colloidal transport in Groundwater*

The Flow diagram outlines a general screening procedure to help the project manager initially determine if PCBs are being transported via colloidal or facilitated transport in a ground water environment. The low flow/low stress collection technique (See Appendix A) is the suggested technique to use for sampling groundwater. In this flow diagram, the authors are defining facilitated transport, as the transport that takes place in the presence of chlorobenzenes or other solvents (that increase PCB solubility); or, when there are chelating agents present that will complex the PCB into a more soluble form.

Note on project planning: The project manager along with the project team must develop a conceptual site model prior to developing a project QAPP and field investigation plans. With sites where PCBs have been found in surface and subsurface soils in excess of 50 mg/Kg the possibility of finding PCBs in the ground water is high especially when soil borings indicate that the elevated concentrations of PCB are at depths near or at the top of groundwater, or in areas co-located with chlorobenzenes, or in wash down areas. The presence of chlorobenzenes will lower the viscosity of the PCB fluid and allow the PCB to move downward at a more rapid rate than expected. Depending on the type of PCB (lower chlorinated/higher solubility Aroclor versus higher chlorinated/lower solubility Aroclor) present and the nature of the soils (sandy versus clay rich) the threshold concentration of the PCBs in soil may be as low as 2 mg/Kg and as high as 100 mg/Kg. Project personnel must review the analytical and soils analysis data to make a decision on a ground water sampling strategy. The placement of wells must be determined using the known operational activities during the life of the site and soils data and groundwater flow data in order to successfully determine if groundwater has been impacted by PCBs found in the soils. The project manager, with the assistance of technical experts (e.g., hydrogeologist/hydrologist), must ensure that the wells to be sampled are installed, developed and purged properly prior to sampling.

Diamond P2: The decision tree commences during the time when the sample is being collected using the low flow/low stress procedure. It is assumed that before the well is sampled that the bottom of the well has been sounded out. During the initial investigation of the measurement of well depth, the investigators must determine if DNAPL is present or whether an organic emulsion at the bottom or near bottom of the well is present. If non-aqueous phase liquid (DNAPL or LNAPL) is found during well inspection we must assume that the presence of a pure phase product means that the dominant transport mechanism is the movement of that pure phase PCB/Solvent mixture (P3) and not facilitated or colloidal transport.

Note on proper sampling procedure: The object of using the Low flow/Low Stress procedure is to collect samples that are low in turbidity and represent the water flowing through the aquifer. If the well is installed and developed properly, the water collected will generally have very little solids content, and the turbidity will be as low as 1.0 NTU. Noted here is that each EPA Region or State may have already established limits for turbidity prior to collecting a sample for analysis. Turbidity guidelines from 1.0 NTU to 20 NTU are documented in the literature as indicators of a stabilized well ready for sampling. The decision tree uses 10.0 NTU as a turbidity guideline so that a distinction can be made as to whether possible colloidal transport or co-solvency is causing the groundwater contamination. Sampling data at a large PCB site, with turbidity issues and a low permeability aquifer, indicate that colloidal transport can exist in wells with turbidity as low as 2.7 NTU's. Colloidal transport of PCBs is less likely with lowered turbidity. In some cases the geology of the soils or bedrock surrounding the well will be such that, 10 NTU is not attainable. In those cases the project hydrologist must determine whether the groundwater is stabilized enough at an NTU turbidity level low enough to be representative of the groundwater in the aquifer. If the turbidity of the sample is stabilized and is < 10.0 NTU, then the sample can be collected and analyzed in the normal manner. In this case, the left flow path of the decision tree is used to determine whether facilitated transport is possible. In some cases the water in the well may have turbidity > 10.0 NTU during pumping; and possibly particulate matter, or an emulsion may be included in the water sample. Elevated solids content may be encountered using low-flow/low stress techniques and is mainly due to

the behavior of the surrounding geologic material. At this time, the sampling team must determine if the well needs further development, or the groundwater is exhibiting this condition due to the type of soil surrounding the well at that depth. If the turbidity of the water stabilizes at greater than 1.0 NTU (How much above is up to the project team), and all other testing parameters are stable as well, the sample may be collected. In these cases colloidal transport is a possibility and the right hand side portion of the decision tree is used for colloidal transport. In Region 4, SESD has a guideline of 10 NTUs and any water below that is considered adequate for sampling, provided other parameters stabilize. However, as noted above, sampling data at a large PCB site, with turbidity issues and a low permeability aquifer, indicate that colloidal transport can exist in wells with turbidity as low as 2.7 NTU's. Filtering with both a 2.0 micron and 0.1 micron filters showed results that colloidal material goes through both the 2.0 and 0.1 micron filters (See Table 1 in the main text).

If the sample is collected via bailers due to very low recharge of the well, then the ground water may have high solids content due to the natural behavior of the geologic formation or the collection method. Any description of unusual field conditions should be noted on the chain-of-custody sheets to be used by the analytical lab. The laboratory must be notified if method modifications need to be made or aid in the interpretation of the eventual analytical results. If solids are encountered the laboratory must be informed as to how the project wants to handle the type of sample. In most cases the laboratory will homogenize the sample and include the particulate portion to quantitate total PCB.

Block P4: After the sample has been collected (above or below 1.0 NTU) and analyzed (A1) and the results show that the water has a PCB concentration below the Ambient Water Quality Standard (AWQC = 0.014 µg/L) (A2), then there may be little justification for an evaluation of colloidal or facilitated transport (A6). Note: In groundwater, the AWQC is chosen as the trigger level so that projects will then be directed to begin to evaluate the presence of PCBs in groundwater and whether their presence is due to facilitated transport. When the groundwater PCB concentration exceeds the maximum contaminant level (MCL) of 0.5 µg/L, an evaluation of human health risk is performed. Most PCB congeners and all of the Aroclor mixtures have equilibrium solubility's exceeding the MCL concentration. It is very important at this time in the project to evaluate the PCB concentrations above, at, and below the MCL but to also understand which PCB congeners are present and what mechanism is causing them to be present in groundwater.

In some cases the ground water analytical results will indicate that only mono, di and tri substituted PCB congeners, the more water soluble species, are present in low concentrations. In some cases the concentration of these congeners may exceed the AWQC. If the concentration of the total PCB is above the AWQC we proceed to the next diamond of the decision tree (A3).

Next the PCB concentration is compared to the equilibrium solubility[5] (A3) of the average molecular weight range of PCBs found using either the closest characteristic Aroclor, homolog (level of chlorination analysis) or congener analyses (See Appendices C and E). If the sample PCB concentration is below the equilibrium concentration then facilitated transport is unlikely but may still be possible (A7). If the concentration of PCB is above the equilibrium solubility, an evaluation of the soil and groundwater data may need to be performed to determine why the concentration is elevated. The volume of water collected using low flow/low stress is usually one liter. In cases where either facilitated transport or colloidal transport is suspected from previous site data, then several liters of water may need to be collected for other analyses that will have to be performed to determine either facilitated transport or colloidal transport. If the extra water is not collected during the initial sample collection, then a second sampling episode will be required and the initial volume and extra volume of water needs to be collected for all analysis.

When the < 10.0 NTU water has PCB concentrations greater than the equilibrium solubility then we can suspect that the transport may be facilitated due to the presence of dissolved organic carbon or elevated concentrations of VOCs and SVOCs. At this point in the decision tree the concentration of dissolved organic carbon (DOC)

5 See Appendix C and E

(A4) originating from water soluble humic, or fulvic acids, or other soluble organic acids that may complex (chelation) the PCBs must be determined. The concentrations of other organic solvents such as TCE; 1,1,1-Trichloroethane; BTEX, or water soluble ketones and alcohols should also be determined. If either DOC or organic solvents are present, there may be strong indications that the PCBs in solution are present via co-solvency facilitated transport or by chelation due humic substances. Facilitated transport under these conditions is possible (A9). If there is low DOC and no appreciable solvent concentration the PCBs may be dissolved (As stated above). In this case, the PCBs present are the soluble mono, di, or tri chlorinated biphenyls (A5). If the original analysis of the < 1.0 NTU ground water indicates only the mono, di, and tri substituted biphenyls and their concentrations are above the AWQC and the equilibrium solubility, this should be enough evidence to indicate dissolved phase PCB transport (A8).

Diamond A1 to diamond B1: When the groundwater has a turbidity above 10 NTU, and the turbidity and other Low Flow/Low Stress Procedure measurement parameters are stable, a sample is collected (B1). An aliquot of the groundwater is then filtered through a 2.0 µm pore size filter and both unfiltered and filtered samples are sent to the laboratory for analysis. The filtered and unfiltered concentrations are compared (B2) to determine if colloidal particles passed through the filter. If the filtered water contains PCB that is less than the non-filtered water concentration, then there may be reason to believe that colloidal transport is happening (B3). If filtered detects no PCB there is no reason to believe that colloidal transport is happening and the PCB present is attached to fine particles (B4).

Note, on filter pore size and procedures: Groundwater with turbidity greater than 10.0 NTU (or greater than the regionally established turbidity requirement for sample collection) may possibly contain colloidally transported PCB. In this case, two volumes of water must be collected for analysis (one filtered and one not filtered). The pore size of the filter suggested by this guidance is 2.0 µm (micron). The pore size of the filter may vary from 0.2 µm up to 10.0 µm depending on what is known about the geologic formation, the other contaminants in the surrounding soil, and the state of the PCB that was initially released because PCB colloids will form in different sizes due to different physical conditions. If colloidal transport is suspected, then a second volume of the groundwater will need to be filtered in the field through a 2.0 µm filter. Do not do multiple sequential filtering of raw groundwater, simply filter the sample in the field one time and then send the filter to the lab along with the water sample. Sequential multiple filtering of a groundwater sample will alter the sample quality and the results will not be representative. If there are solid particles in the groundwater, some of the solid particles will be caught on the filter. If a cellulosic filter is used, the project personnel must determine if the PCBs are adsorbed to the filter material and how much PCB can be absorbed or whether rinsing will remove the PCB. In the case where PCB is adsorbed to the filter then the filter itself will have to be analyzed as well to get a mass balance between what has passed through the filter and what has been retained. It is recommended that an inert filter material be used such as a Teflon or glass fiber filter so that PCBs will not be adsorbed to the filter material.

Note on filter/filtrate analysis: It is important to have the laboratory analyze the filter after the field filtration process along with the filtrate and the unfiltered water aliquot. Using these three analyses, one can determine a mass balance between total PCB, PCB attached to solid particulates, and colloidal/soluble PCBs.

If appreciable solids are detected in the sample during the low flow procedure, then the project manager must decide whether to inform the laboratory to separate the water from the solids and analyze both separately in the unfiltered sample. This will depend on how much solids are present and how well the PCBs can be removed from the solids during the extraction procedure used for the groundwater sample. If there is only a small amount of solids present, then the normal liquid/liquid extraction procedures can be used. The solids portion of the sample may also be considered mobile when using the low flow technique and colloidal transport is still a viable option for consideration.

Note on SPE analysis: If the laboratory is using Solid Phase Extraction procedures to remove PCB from the water, any particles or larger colloids will end up on or adsorbed to the Solid Phase Media along with soluble and colloidal PCB. The laboratory must be made aware of this fact before analysis proceeds. It may be necessary to analyze the PCBs via liquid/liquid/separatory funnel or continuous liquid/liquid extraction after filtration of the solid particulate to achieve Total PCB concentrations in the groundwater.

This decision tree is only a screening tool and an outline for a project team to use to determine why PCBs are present in groundwater. The actual chlorination level of the PCBs present may have more to do with its solubility or is propensity to attach to fine particles in solution or the PCB propensity to complex with water soluble natural organics in the water. Knowing the chlorination level of the PCB present via Aroclor, congener analysis is essential when using this decision tree and for determining if there is colloidal transport or facilitated transport.

Further, more definitive work may need to be performed by the project team to determine how much facilitated/colloidal or soluble PCB transport is happening to be able to characterize the actual PCB quantities for use in risk assessment.

APPENDIX E: SOLUBILITY'S OF AROCLORS, HOMOLOGS AND CONGENERS

Table D-1 Aroclor, Homolog and Congener Solubility

Aroclors	*Solubility*	*Units*	*Reference*
1268	7.7	µg/L	
1260	2.7	µg/L	
1254	12	µg/L	
1242	240	µg/L	
1221	590	µg/L	
1016	420	µg/L	
Homolog Group	**Solubility**	**Units**	
Monochlorobiphenyl	4000	µg/L	
Dichlorobiphenyl	1600	µg/L	Description: This spreadsheet calculates physical properties for Aroclors by weighting the properties of each Aroclors constituent congeners. The weight percents for four Aroclors (1016, 1242, 1254 and 1260) are taken from work by Frame, et al (December, 1996). These weight percents are used to calculate the Aroclors molecular weight and to derive congener mole fractions used to weight the physical properties of the congeners.
Trichlorobiphenyl	650	µg/L	
Tetrachlorobiphenyl	260	µg/L	
Pentachlorobiphenyl	99	µg/L	
Hexachlorobiphenyl	38	µg/L	
Heptachlorobiphenyl	14	µg/L	
Octachlorobiphenyl	5.5	µg/L	
Nonachlorobiphenyl	2	µg/L	
Decachlorobiphenyl	0.76	µg/L	
Congener	**Solubility**	**Units**	
1	5697	µg/L	
2	4738	µg/L	
3	768	µg/L	
4	1283	µg/L	
5	1344	µg/L	
6	N/A	µg/L	
7	1067	µg/L	
8	643	µg/L	
9	1508	µg/L	
10	2561	µg/L	
11	705	µg/L	
12	396	µg/L	
13	N/A	µg/L	
14	643	µg/L	
15	23	µg/L	
16	589	µg/L	
17	N/A	µg/L	
18	447	µg/L	
19	N/A	µg/L	
20	N/A	µg/L	
21	47	µg/L	
22	69	µg/L	

Congener	Solubility	Units
23	224	µg/L
24	N/A	µg/L
25	N/A	µg/L
26	257	µg/L
27	N/A	µg/L
28	83	µg/L
30	204	µg/L
31	95	µg/L
32	N/A	µg/L
33	151	µg/L
34	N/A	µg/L
35	N/A	µg/L
36	N/A	µg/L
37	28	µg/L
38	N/A	µg/L
39	30	µg/L
40	12	µg/L
41	N/A	µg/L
42	33	µg/L
43	N/A	µg/L
44	76	µg/L
45	N/A	µg/L
46	27	µg/L
47	49	µg/L
48	N/A	µg/L
49	41	µg/L
50	N/A	µg/L
51	N/A	µg/L
52	33	µg/L
53	47	µg/L
54	14	µg/L
55	N/A	µg/L
56	11	µg/L
57	N/A	µg/L
58	5.	µg/L
59	N/A	µg/L
60	2.	µg/L
61	18.	µg/L
62	N/A	µg/L
63	7	µg/L
64	N/A	µg/L
65	43	µg/L
66	4	µg/L

Congener	Solubility	Units
67	N/A	µg/L
68	N/A	µg/L
69	N/A	µg/L
70	11	µg/L
71	N/A	µg/L
72	11	µg/L
73	N/A	µg/L
74	4	µg/L
75	N/A	µg/L
76	N/A	µg/L
77	1	µg/L
78	N/A	µg/L
79	3	µg/L
81	N/A	µg/L
82	2	µg/L
83	N/A	µg/L
84	N/A	µg/L
85	N/A	µg/L
86	N/A	µg/L
87	3	µg/L
88	N/A	µg/L
89	N/A	µg/L
90	N/A	µg/L
91	N/A	µg/L
92	N/A	µg/L
93	N/A	µg/L
94	N/A	µg/L
95	10	µg/L
96	N/A	µg/L
97	8	µg/L
98	N/A	µg/L
99	N/A	µg/L
100	N/A	µg/L
101	9	µg/L
102	N/A	µg/L
103	N/A	µg/L
104	N/A	µg/L
105	1	µg/L
106	N/A	µg/L
107	N/A	µg/L
108	N/A	µg/L
109	N/A	µg/L
110	N/A	µg/L
111	N/A	µg/L

Congener	Solubility	Units
112	N/A	µg/L
113	N/A	µg/L
114	2	µg/L
115	N/A	µg/L
116	4	µg/L
117	N/A	µg/L
118	1	µg/L
119	N/A	µg/L
120	N/A	µg/L
121	N/A	µg/L
122	N/A	µg/L
123	N/A	µg/L
124	N/A	µg/L
125	N/A	µg/L
126	N/A	µg/L
127	N/A	µg/L
128	0.3	µg/L
129	N/A	µg/L
130	N/A	µg/L
132	N/A	µg/L
133	0.4	µg/L
134	N/A	µg/L
135	N/A	µg/L
136	3	µg/L
137	1	µg/L
138	1	µg/L
139	N/A	µg/L
140	3	µg/L
141	N/A	µg/L
142	1	µg/L
143	N/A	µg/L
144	N/A	µg/L
145	N/A	µg/L
146	N/A	µg/L
147	N/A	µg/L
148	N/A	µg/L
149	N/A	µg/L
150	N/A	µg/L
151	2	µg/L
152	N/A	µg/L
153	0	µg/L
154	N/A	µg/L
155	2	µg/L
156	N/A	µg/L

Congener	Solubility	Units
157	N/A	µg/L
158	N/A	µg/L
159	N/A	µg/L
160	1	µg/L
161	N/A	µg/L
162	N/A	µg/L
163	N/A	µg/L
164	N/A	µg/L
165	N/A	µg/L
166	0.2	µg/L
167	N/A	µg/L
168	0.9	µg/L
169	0.04	µg/L
170	0.1	µg/L
171	N/A	µg/L
172	N/A	µg/L
173	N/A	µg/L
174	0.3	µg/L
175	N/A	µg/L
176	N/A	µg/L
177	N/A	µg/L
178	N/A	µg/L
179	N/A	µg/L
180	0.2	µg/L
181	N/A	µg/L
183	N/A	µg/L
184	N/A	µg/L
185	0.2	µg/L
186	N/A	µg/L
187	N/A	µg/L
188	N/A	µg/L
189	0.04	µg/L
190	0.2	µg/L
191	N/A	µg/L
192	N/A	µg/L
193	N/A	µg/L
194	0.02	µg/L
195	N/A	µg/L
196	N/A	µg/L
197	0.1	µg/L
198	N/A	µg/L
199	N/A	µg/L
200	N/A	µg/L
201	N/A	µg/L

Congener	Solubility	Units
202	0.04	µg/L
203	N/A	µg/L
204	N/A	µg/L
205	N/A	µg/L
206	0.003	µg/L
207	N/A	µg/L
208	N/A	µg/L
209	0.000	µg/L

APPENDIX F: PCB FIELD DETECTION AND IMMUNOASSAY METHODS FOR PCB SCREENING

Various screening methods are available for determining the presence or absence of chlorinated organics that could denote the existence of PCBs in various matrices. Chemical test kits such as Chlor-N-Oil or Chlor-N-Soil, so-called hazardous characterization techniques such as the Beilstein copper wire test, Total Organic Halides (TOX), and immunoassay methods are an important step in the delineation of site contamination, as they can provide a cost effective method of determining the possible presence or absence of PCBs in soils, wastes, solids, and ground or surface waters. The methods discussed in this section (with the exception of TOX) can be performed quickly, with real time answers provided in minutes.

It should be noted here the importance of a good project QAPP and clear data quality objectives, prior to utilizing any of these methods. Whenever possible, the delineation scheme should be reviewed and performed by both a chemist familiar with these methods, and by the laboratory chosen to perform the confirmation samples, to ensure all goals are achievable and performed in the most economical manner.

Screening methods for PCBs are techniques for the determination of the presence or absence of halogenated organics and must be confirmed by analytical methods performed in a fixed laboratory. Screening methods are useful for informing the laboratory of high-level contamination. While applicable regulations may require the majority of a site to be delineated with methods that achieve detection limits (DLs) in the low ppb range, other materials encountered on a site may be handled with tests that determine the presence or absence of halogenated molecules in order to avoid extra costs associated with performing laboratory analysis on multiple samples. Depending on the number of samples, at times it may be more cost effective to use an on-site GC/ECD. A good example of this is the disposal of investigative-derived wastes created during a field assessment. Wastes to be sent off-site for disposal may be segregated into various waste streams, and these may be further

subdivided into wastes that appear to contain halogenated organics and those that do not.

Beilstein

The Beilstein screening method (developed by Friedrich Konrad Beilstein in the 1800s) is a common field screening method utilized primarily by persons performing hazardous waste characterization in the field. Once soil and groundwater samples are obtained they should be transported to a central field testing area such as a folding table or the tail-gate of a pick-up. The test is performed by inserting a thin gauge (approximately 18 gauge) clean copper wire into a flame (typically a hand-held propane torch) to form copper oxide. After the wire cools, it is inserted into the material to be tested and then reinserted into the flame. After the petroleum based organics have burned off (yellow flames), the halogen that is present along with the copper will give off a distinctive green flame that lasts for only a few seconds. If halogens are present, copper halides are formed and the flame will take on distinctive colors such as green for chlorides, blue green for bromides, and blue for iodides. (The test does not react to fluorides). The Beilstein method is sensitive to compounds that contain 1% or more (e.g. DNAPL) chlorinated organics (10,000 ppm) and should not be used as a screening tool for compounds where PCBs are expected in low ppm ranges. The test is very effective for the screening of Aroclors or Askarels found in transformers and capacitors.

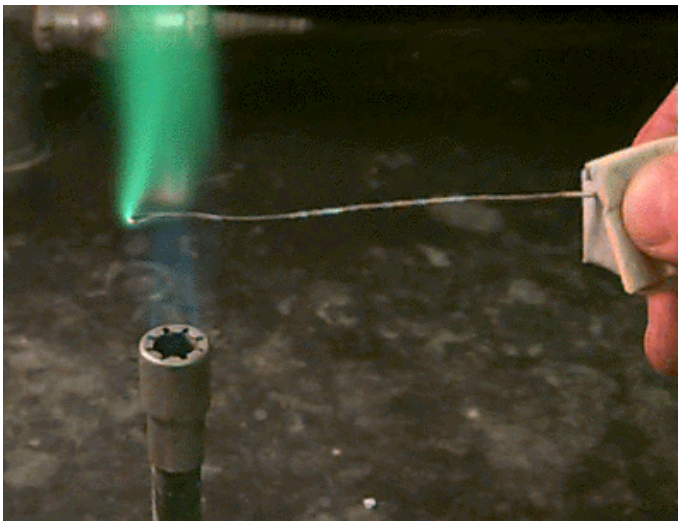

Figure F-1: *A Positive Beilstein Reaction to Chlorides*

There are several precautions to be taken when performing this (or any other screening method).

- Using an approved method, always send samples that have yielded positive halogen color results to the laboratory for confirmation of PCBs, their homolog's, or congeners. The confirmatory test should use an approved method.
- At least 10% of all samples (positive or negative) should be sent to the laboratory for confirmation.
- Always perform the Beilstein test in an area with proper ventilation and with appropriate personal protective equipment (PPE).
- Whenever possible, Beilstein tests should be performed in a shaded area, as bright sunlight can mask the very subtle halogen flame color.

The following procedure for performing a Beilstein flame test is a fairly standard representation of the method.

Materials

- Propane torch (preferably one that has its own integral igniter).
- Copper wire, 18 gauge or smaller (purchase locally), approximately 6 inches in length (wire should be uninsulated; if insulated wire is used, all insulation should be stripped from the wire and wire should be inserted into the flame for 30 seconds before use). Bend over about 2 inches of one end of the wire and twist it around itself. Continue twisting until a small loop exists at the twisted end of the wire.

NOTE: DO NOT USE COPPER TUBING; MATERIAL ON THE INSIDE WILL NOT BURN CLEAN AND CARRY OVER WILL OCCUR.

- Container of distilled water.
- 1:1 Hexane/Methylene Chloride (DCM) mixture to be used as a QC check.
- Fire extinguisher (dry chemical type for A, B, and C fires).

Procedure

- At the start of every shift, check the wire by testing it with a 1:1 hexane/DCM mixture to ensure a green flame is produced when heated. Also, check the wire with distilled water for carry over and record the results on the Compatibility Quality Control Log of that shift. Always

remember to date and initial your QC checks. If you cannot obtain a positive test result with the hexane/DCM mixture or a negative result with the distilled water, recheck the cleaned copper wire with the solvent mixture, water, and copper wire and repeat or:

- Clean the copper wire loop and twists by holding the wire in the flame from the propane torch until the copper glows orange. Cool by submerging the wire in a beaker of clean distilled water.
- Retrieve some sample on the cooled, looped end of the copper wire. Place the sample on the loop in the flame of the propane torch, let the hydrocarbons burn off, and observe the color of the final flame from the sample.
- Hold the loop in the flame until the wire glows orange to clean the loop for the next sample to be tested. Be sure to cool wire in water before proceeding to the next sample.

Interpreting the results

The appearance of any green flame indicates the possible presence of chlorinated compounds and a positive Bielstein result. All positive Bielstein results should be confirmed with appropriate laboratory analysis. Any other color observed in the flame is a negative Bielstein result, but the color of the flame should be noted in the logbook, as other colors may indicate the presence of other ions or metals.

Interferences

A false negative result may occur due to very volatile compounds that evaporate completely before they can be heated sufficiently to cause decomposition. False positives may occur on acidic compounds, quinoline and pyridine derivatives, organic acids, urea, and copper cyanide.

***Chlor-N-Oil*® / *Chlor-N-Soil*®**

These screening methods use a reaction of metallic sodium to strip the attached chlorine atoms off of their parent molecules. The sodium chloride formed in this initial reaction is then colorimetrically titrated to determine the presence of the organic PCBs. These tests are available as kits for performing the tests on soils/solids or transformer oils. Their sensitivity is in the 20 - 50 ppm range (50 ppm being the TSCA regulatory limit). While both of the kits discussed here are commercially available from a variety of vendors, the kits used in this document are from Strategic Diagnostics (formerly Dexsil Corporation).

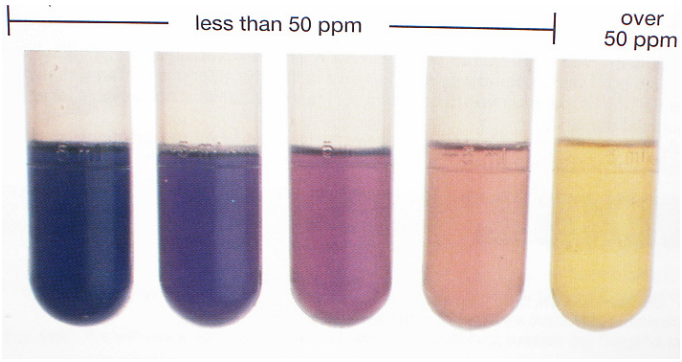

Figure F-2: *Chlor-N-Oil Results Photograph*

The methodology for both the Chlor-N-Oil and Chlor-N-Soil are essentially the same, the only difference being that the Chlor-N-Soil involves an extraction step for the soil. To see the complete methodology navigate to the following link:

http://www.dexsil.com/technical_info/

Methodologies for the Chlor-N-Oil or Chlor-N-Soil may also be found in Appendix C.

These methods are useful in demonstrating the absence of PCBs. While the kits claim to detect PCBs, they actually measure the presence of organo chlorine compounds. The method uses the aforementioned sodium reaction, and will not fail to convert any of the organo chlorine atoms found in any PCB to inorganic chloride. The tests cannot determine the difference between inorganic chlorides or organic chlorines; it also cannot determine if the organic chlorides are due to the presence of PCBs or chlorinated solvents that may be present at the site. Any samples that test positive for the presence of chloride/chlorine must be sent to the laboratory for an approved PCB analysis. As noted previously, at least 10% of all negative samples should be sent to the laboratory for confirmation as well.

Total Organic Halides

Total Organic Halides (TOX) determines organic chlorides present in a surface water or ground water sample. This method is a laboratory screening technique. A similar method, Extractable Organic Halides (EOX), is used for the determination of

organic halides in solids, soils, or wastes. With TOX, the water sample is passed through granular activated carbon (GAC) and any organic halides are adsorbed onto the GAC. The GAC is then heated in a pyrolysis chamber to approximately 800 °C to convert the adsorbed organic halides to HX (hydrogen halides), that are subsequently measured through coulometric titration. The EOX method extracts organic halides into an ethyl acetate solution via sonification from a small portion of the solid or waste. Then a micro liter portion of the sample is introduced into the pyrolysis cell and measured through coulometric titration.

These methods measure all organic halogens except for fluorine. Therefore, their primary usefulness is as a screening tool. As in the other screening methods previously addressed in this appendix, all positive results must be verified for PCBs with Aroclor, homolog, or congener analysis. As in the case of the Chlor-N-Oil methods, the primary usefulness comes from negative results. The methods can provide sensitivity into the 10 ppb range for waters, and 10 ppm range for wastes or solids. At least 10 % of all samples with negative results should be verified with Aroclor, homolog, or congener analysis.

Immunoassay

In the mid 1990s, the EPA began to promulgate immunoassay methodologies for screening PCBs. While EPA SW846 4020 is a procedure intended for screening soils and non-aqueous wastes, the technique may also be applied to surface and ground waters, wipe samples, concrete, and wood chips. Immunoassays can provide a very cost effective method of screening as long as users are well informed of its limitations and the potential for positive or negative interferences.

The Enzyme-Linked Immunosorbent Assay (ELISA) immunoassays work by using antibodies that are developed specifically to bind with PCBs. Selective response is used to confirm the presence of the PCBs in the samples. Typically, the walls of a test tube are coated with specific PCB antibodies. The quantity of antibodies is known, and a limited number of antibody binding sites are available for the sample. A developer in the test kit developer couples some of the contaminant, or antigen, with an enzyme that will react with a colorimetric agent to produce a color change but will not interfere with the antigen's ability to bind with the antibodies. The enzyme is referred to as the label because it allows detection of the antigen's presence, creating a labeled antigen. A solution that contains the enzyme conjugate (the antigen labeled for analysis) is then prepared. There is also a colorimetric agent, or chromogen, that will react with the enzyme on the labeled antigen and cause a color to form. In the case of the PCB chromogens, a lack of color indicates the presence of PCBs. The solutions are then read with a spectrophotometer to achieve semi-quantitative results.

Most manufacturers of PCB immunoassay kits have either sold their products to or have merged with the company Strategic Diagnostics Inc. Therefore, the methodologies treated in this chapter will be those for the products of Strategic Diagnostics Inc.

To view the methodologies, navigate to the following link:

http://www.sdix.com/TechSupport.asp?sSupportType=Technical%20Bulletins

All of the methods, except those for water, involve an extraction step prior to the actual performance of the immunoassay. The immunoassay steps of the methodologies are similar for both the EnSys® and RapidAssay® kits. There are various caveats that must be understood prior to utilizing any of the commercially available kits. These practitioners have found that radical temperature changes, below 50° F and above 85° F, will cause the kits to perform poorly. A temperature controlled environment, such as an on-site trailer with heating and cooling, should be employed whenever possible.

Costs of various analytical methods available from commercial laboratories should be carefully compared to the costs of the immunoassay kits. Often there is a "break even" point in the number of immunoassay kits purchased versus the costs of standard Aroclor analysis. Typically this is around 50 tests for the Ensys® kits and 100 tests for the RapidAssay® kits. If fewer than these are to be performed, it is frequently more cost effective to utilize a commercial laboratory (on-site mobile laboratory may be cost effective as well depending on the number of analysis to be performed).

The major advantage of immunoassay kits is the ability to provide results in under an hour.

Because immunoassay kits use a chromogen that is colored for negative results and becomes clear as positive results are obtained, care must be taken with waters that contain blue or yellow compounds. Ferric iron present in the sample will yield false negatives, as will cupric or permanganate salts. Although there is a filtering step in the procedures, these will often not eliminate these interferences. Raising the pH of the water to 9.5 and then re-filtering it will often eliminate this problem, **but care should be taken to perform this on spiked and un-spiked trial samples prior to actually using this in the field.** Trial samples for practice runs on immunoassays should be prepared with waters or soils that contain known concentrations from the site, whenever possible.

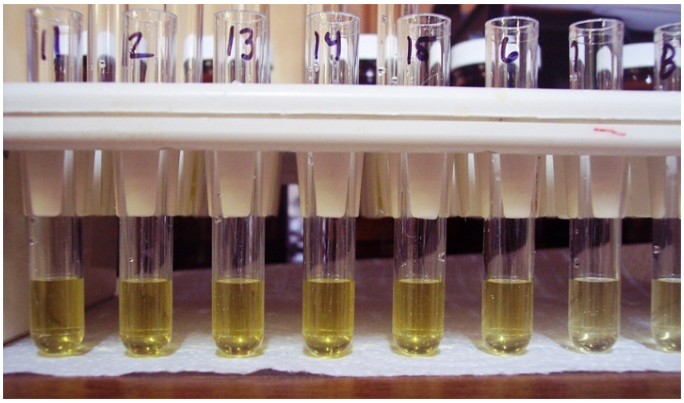

Figure F-3. *Typical Immunoassay Run (Note the Subtle Color Difference)*

The immunoassay kits provide the maximum sensitivity with Aroclors 1260 and 1254. Lesser chlorinated Aroclors will have higher detection limits, with Aroclor 1221 being two orders of magnitude higher. If the actual contaminant Aroclor PCB at the site is known to be less chlorinated than the Aroclor kit standards, then that Aroclor should be used as the standard in measuring samples.

Table F-1. Aroclor Typical Soil Detection Limits

Compound	MDL (ppm)	LOQ (ppm)	IC50 (ppm)
Aroclor 1254	0.20	0.5	3.60
Aroclor 1260	0.20	0.3	2.30
Aroclor 1248	0.22	0.6	4.22
Aroclor 1242	0.34	1.2	8.80
Aroclor 1262	0.36	0.7	4.74
Aroclor 1232	0.84	2.6	18.76
Aroclor 1268	0.92	3.0	21.80
Aroclor 1016	0.94	3.6	25.60
Aroclor 1221	13.54	22.6	162.6

Table F-2. Aroclor Typical Water Detection Limits

Compound	MDL (ppb)	LOQ (ppb)	IC50 (ppb)
Aroclor 1254	0.20	0.50	3.60
Aroclor 1260	0.20	0.32	2.30
Aroclor 1248	0.22	0.59	4.22
Aroclor 1242	0.34	1.22	8.80
Aroclor 1262	0.36	0.66	4.74
Aroclor 1232	0.84	2.61	18.76
Aroclor 1268	0.92	3.03	21.80
Aroclor 1016	0.94	3.56	25.60
Aroclor 1221	13.54	22.58	162.60

A Standard Operation Procedure (SOP) for the method should be developed prior to the start of a project. All analysts performing the method should read and sign the SOP. If an analyst typically performs immunoassays on a routine basis but is unavailable for a project, then the analyst to be utilized should demonstrate proficiency with the method whenever possible by using blind prepared samples. Recoveries should be within ranges specified in EPA SW846 4020. Prior to using the kits, all materials should be read and thoroughly understood before attempting to perform the tests. The need for laying out all materials specified in the method, well in advance to performing the test, cannot be overstated. As some of the chemicals used in the method are hazardous, proper safety equipment should be utilized at all times. Sample extractions should be performed in a different area than where the actual immunoassays are performed whenever possible. It is extremely advisable to perform at least one practice run on several trial

samples of known concentration and on standards before attempting to perform the immunoassays on real-world samples. Once an analyst has performed the trial run, the analyst should carefully note where "bottlenecks" can occur that slow down the analytical process, and allow space and time for them. **It is most important to develop a rhythm in the performance of a well planned and timed routine for these analyses, and for this reason, the same analyst should perform all immunoassays at a site or location whenever possible to achieve the best data quality.**

The most accurate approach to calibration of an immunoassay screening test for PCB contamination is to utilize a known amount of the contaminant itself, taken from the project site. This is applicable to surface waters, ground waters, or solids. This can be achieved by using well homogenized samples that have been previously analyzed for the appropriate Aroclor(s), according to EPA method SW846 8082.

Screening Method Summary

- Beilstein tests should be utilized whenever oily or semi solid wastes are encountered that may be combined to form one or more wastes in streams. These can also be used to check transformer oils or other high voltage electrical equipment coolants, as typically these will contain PCBs in the percentage concentration range. But the tests cannot be used to determine whether samples are hazardous or non hazardous, as the Toxic Substances Control Act (TSCA) regulatory limit is 50 ppm and this is too low to be determined by this method.
- Chlor-N-Oil/Chlor-N-Soil tests should be utilized to determine soils or oils for disposal or TSCA purposes. They do not detect below 1 part per million, and as such are not generally applicable to risk-based assessments. They provide their main usefulness in determining whether or not a sample is negative. All positive samples should be analyzed by approved PCB methods.
- TOX analysis (for oils and soils) is useful to determine waste oils that fall under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulations. As in other screening methods, they can eliminate further analysis by showing that a sample is negative. Positive results must be confirmed by an approved PCB method. TOX can be used to screen other types of samples as long as project detection limits are not below 10 ppm for soils, or 10 ppb for waters. (The cost for a TOX analysis for a particular laboratory should be compared to the same laboratory's cost for an Aroclor analysis, prior to utilization).
- Immunoassays (for soils, sediments, surface water, and groundwater) provide quick (less than an hour) turnaround time, and that is their primary usefulness. It should be noted that they are semi-quantitative at best, and do not differentiate between Aroclors. They can provide rapid assessment but costs should be compared with Aroclor analysis if time is not a critical factor. Typically, 100 or more Aroclor analyses will need to performed before a "break even" point occurs in costs when compared to standard Aroclor analysis.

Passive Sample Deployment for Pore Water Detection

Another tool for evaluating PCB distribution in sediments has been demonstrated in EPA Region 10. This method involves the placement of passive sampling devices for determining the PCB concentrations in pore water. Below is a trip report of this method that has been successfully implemented at the Duamish River site in Washington state.

Figure F-4. *Passive Sampling Device*

Figure F-5. *Deployment of passive sampling device*

Duwamish River Passive Sampler Retrieval, January, 2013

EPA divers demonstrate a passive sampling technique in the Duwamish River. We know that porewater relates to fish tissue data, so sampling techniques that target this area are very useful in gauging a site cleanup. EPA divers have deployed a variety of passive samplers to support Superfund work. This technique has the capability of integrating data over a longer period of time--making it more likely that a contaminated groundwater plume discharging to a river like this one will be captured, vs. other techniques that might produce more of a snapshot. The sampling technique being tested by Principal Investigator Philip Gschwend, MIT gauges the effectiveness of carbon in sediment in binding PCBs. This aspect could demonstrate the effectiveness of sediment amendments to lower available PCBs. For more information, see: http://www.epa.gov/region10/pdf/diveteam/duwamish_passive_sampling_2013.pdf

APPENDIX G: DATA QUALITY REQUIREMENTS FOR ANALYSIS OF SOILS AND GROUNDWATER

Developing data quality objectives (DQOs) (EPA QA/G-4HW, Data Quality Objectives Process for Hazardous Waste Site Investigations, 1/2000)

If the project is a new investigation and the parties that released the PCB are unknown then the identification of the specific Aroclor PCB released may be very important to finding the origin(s) of the PCB. The initial DQO is to identify the Potential Responsible Party (PRP). Given the many uses of PCBs (Section 2) PRPs may not be aware that they were using or releasing PCBs to the environment. Inadvertent uses of PCB in machinery, in white goods, and lighting do not usually create gross contamination as is found at sites where PCBs were produced in bulk or were used in a specific industrial process such as heat transfer/heat cell use. Investigating the specific PCB used at a site will help in determining the Aroclor used, the possible migration in soils, and whether the PCBs would be expected in the groundwater. If the PCB Aroclor is known then the DQO for the data will be data that will support a remedial decision or risk evaluation. If the PCB has been identified as a contaminant of concern (COC) and the range of concentrations of the PCB across the site are known, then the investigator can evaluate what analytical detection levels will be needed to get usable data to make decisions, and data of known quality to meet human health and ecological risk assessment requirements; in addition, data quality to inform leaching to groundwater evaluation should be obtained. As the investigation goes farther away from the source of the PCB contamination the concentration of the PCB will become less and less requiring more analytical sensitivity and lower detection limits.

A site specific QAPP must be generated describing the reason for the project and the overall project data quality needed to get data usable for making remedial decisions and for human health and ecological based decisions. DQOs[6] must be supported by tight project measurement performance criteria (MPCs) that include overall precision, accuracy, representativeness,

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completeness, comparability, and most importantly, sensitivity (PARCCS). The tables in the QAPP should conform to the Uniform Federal Policy for Quality Assurance Project Plans (UFPQAPP). Note here that if an alternative is proposed to UFPQAPP, careful scrutiny must be performed by a qualified Quality Assurance (QA) professional. For PCB investigations that will be used to make risk based decisions the sensitivity MPC is very important when analyzing sediments, surface waters and groundwater, but the MPCs that make up the remaining PARCCS are also very important to the usability of the data. The risk based PCB concentration (MCL) for drinking water is 0.5 µg/L and it can be achieved using normal Aroclor analysis as long as the PCB pattern can be recognized. The detection limit that must be met, that includes the uncertainty due to blank contamination, is 3-10 times lower than 0.5 µg/L or 0.05 µg/L. **Getting greater sensitivity for the analysis of surface waters, while trying to achieve the detection limit of 0.014 µg/L (the ambient water quality standard), may mean collecting more water (2 to 5 liters), extracting the water using solid phase extraction (SPE) techniques, extracting the SPE membrane, concentrating the extract to lower volumes than stated in the method, and finally injecting more extract on column into the GC.** To be able to overcome the possible blank contamination uncertainty, the actual detection limit would have to be 0.004 µg/L. It will take a very clean sampling and analytical system to achieve usable data at the concentration of the ambient water quality standard. The need to control the sampling and analytical system and achieve ±20-30% precision, 50-150% recovery for accuracy, 95% completeness, ±50% comparability will be a challenge for the project at low detection limits required by some projects. Overall project accuracy will require using equipment blanks, reagent blanks, matrix spikes, and matrix spike duplicates, and standard reference materials. Overall project precision will use field duplicates and matrix spike/matrix spike duplicates (MS/MSD), and continuing calibrations.

The overall project DQOs/ MPCs and the laboratory QC criteria must be documented in a project specific QAPP that spells out all of these criteria. The QAPP must also spell out the sample collection, sample handling and custody procedures, sample extract and clean-up procedures, and the analytical methods to be used for PCB analysis. The QAPP tables are derived from worksheets that are found and follow the UFPQAPP. These worksheets need to be completed for each matrix to be analyzed for PCBs (or any other parameter) for the project. These worksheets will be incorporated into the QAPP as tables and must be agreed upon and followed by the sample collection personnel and the analytical laboratory of record. T**he final QAPP must have attached all the SOPs for sampling and analysis that will be used.**

All of the PARCCS criteria add up to getting usable data for remedial decisions, human health risk decisions and ecological risk decisions. In most cases with PCBs, the regulatory limit must be achieved to be able to make those decisions. As stated earlier the actual detection limit must be 3-10 times lower than the regulatory limit to account for any blank contamination that may result from sampling procedures and laboratory analysis. The lower limits of detection needed may require further concentration procedures and tighter analytical controls to be able to meet the MPCs and laboratory QC criteria for a project. Tighter project DQOs don't allow a lot of leeway in the sample collection and analysis, but when you have to deal with other problems that can arise in the nature of the sample such as:

- Sulfur and sulfur containing organics,
- Pesticide interferences,
- Other chlorinated organic species, and
- High moisture content in freshwater sediments

Meeting the MPCs/QC criteria may be a challenge. Each of the above phenomena can cause an elevation in the already lower detection limits. When the detection limit gets elevated, then the data may not be of adequate quality to indicate a PCB contamination above a specific human health risk or ecological risk required limit.

Soils and Sediment data quality

Aroclor analysis by GC/ECD and resolving problems to get better data quality.

Is only one Aroclor present? The project investigators must determine this fact from previous data or must find this out during an initial sampling

phase. If one Aroclor is present in an un-weathered state, then straight forward Aroclor analysis by GC/ECD should result in quantitative results.

If the chromatographic pattern indicates that there is more than one Aroclor present, the analyst must determine which peaks used for quantitation are representative for each Aroclor present. Many Aroclors of similar chlorination level share peaks that represent neither Aroclor. If the mix were Aroclor 1016 and Aroclor 1260, there are no chromatographic overlaps. If the mix were Aroclor 1242 and Aroclor 1248, then there is major overlapping of representative peaks and actual quantitation may be very difficult.

The analyst must also be cognizant of chlorinated pesticides that may be present and may co-elute with major PCB peaks used for quantitation of specific Aroclors. If other chlorinated species such as Polychlorinated naphthalenes or toxaphene are present the analyst may need to send the extract back to the preparation laboratory for further clean-up. The analytical instrument program may also need to change the run time or temperature program to be able to separate the interfering material.

Clean-up procedures for soils and contaminated solids must include acid clean-up to remove hydrocarbons, PAHs, and some pesticides/ herbicides. If the soils come from wetlands or landfills, then removal of sulfur and organic sulfur species is required using gel permeation chromatography (GPC) to get acceptable quantitation and meet QC criteria. Further extract clean-up may be required if the chromatography is unacceptable or the PCB pattern is obscured by other organic species not removed during ordinary sample preparation. In some cases silica gel fractionation may be required to separate PCBs from other chlorinated organic species or other interfering organic species. Dilution of the sample extract is not the solution as it may compromise reaching the project specific quantitation limits. Every effort must be made to meet project QC criteria for the project.

PCB ANALYTICAL METHOD DECISION TREE

If the chromatography indicates that there are mixtures that cannot be resolved by extract clean-up or that the Aroclor pattern has indications of moderate to severe weathering the chromatographer in conjunction with the laboratory manage may contact the project manager and suggest that the laboratory re-extract the sample and analyze the sample using homolog or congener analysis. The need for a new extraction is because the internal standards and surrogate spikes added for homolog or congener analyses are different than those added to Aroclor analyses to get a complete and accurate quantitation of total PCBs. When the Aroclor cannot be identified, there may be problems meeting the first Project DQO of determining the origin of the PCB and identifying the PRP. When the Aroclor cannot be identified, then LOC analysis of congener analysis is required. The LOC (homolog) analysis can narrow down the original released Aroclor identification simply by comparing the sample LOC results to Aroclor standards run as LOC analysis as well as getting the total PCB concentration.

When the project has determined that the DQOs are to meet human health and/or ecological risk assessment the sensitivity of the methods chosen will require detection limits to be decreased and be at least 3-10 times lower than the risk based regulatory limit. This will ensure that the data will meet the risk decision points.

Many times the MPCs will be set during the project planning stage by the project personnel for the PARCCS (precision, accuracy, representativeness, completeness, comparability, and sensitivity) parameters but the planners didn't include the laboratory in the discussion. The laboratory can suggest the use of standard reference materials (National Institute of Standards and Technology [NIST] or Canadian reference standards) for soils or sediment to make sure the Accuracy MPC is met for the project. As stated earlier the QAPP tables must take the form of the UFPQAPP for all PCB analyses in soils. If Aroclor analysis is deemed unusable for the project, then congener or homolog analyses are required to meet the project DQOs.

Total Congener Analysis

When Aroclor analysis is deemed unusable for the project congener analysis is most applicable. Total congener analysis means identifying and

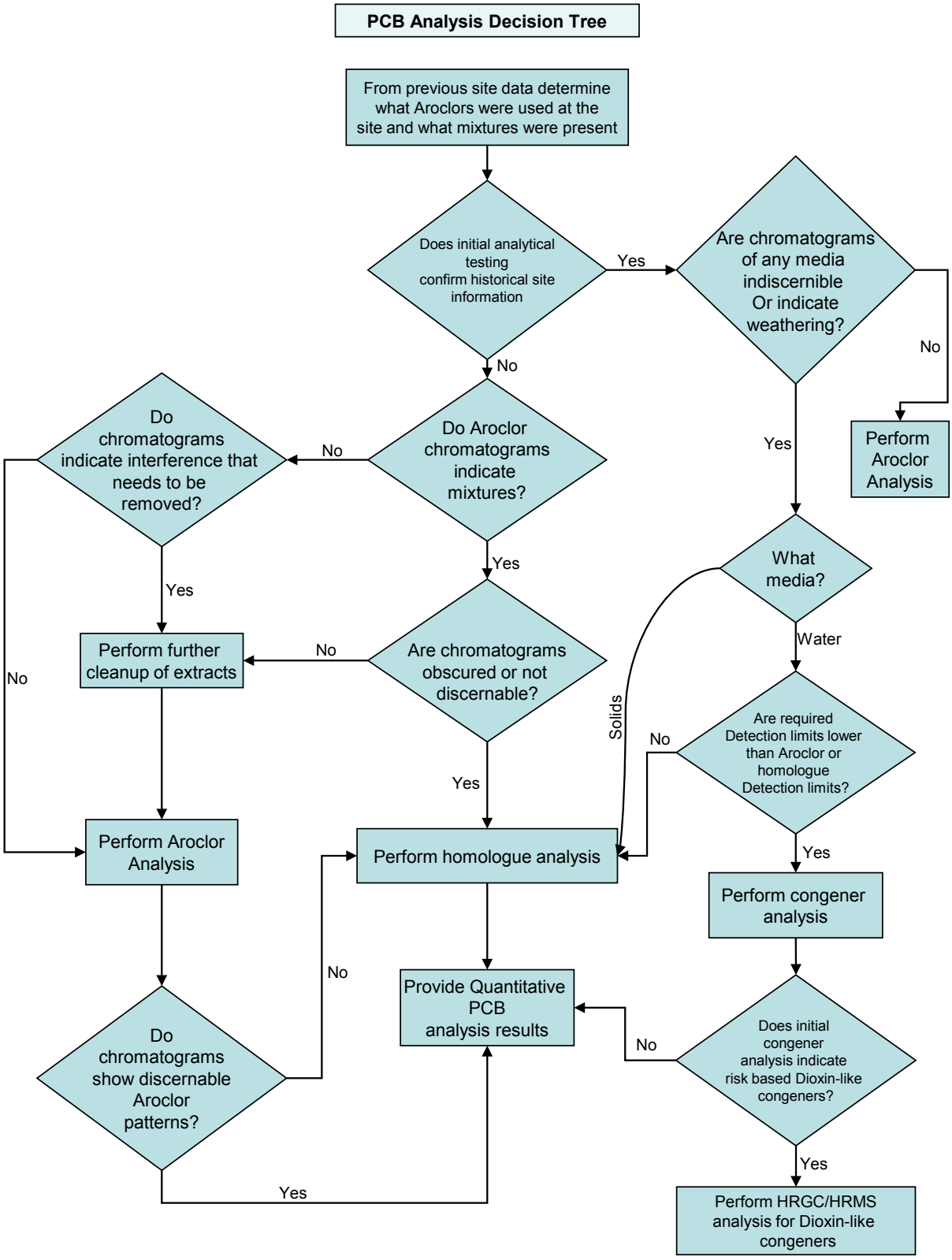

Figure G-1: *PCB Analytical Method Decision Tree*

quantifying all the PCB congeners above the limit of detection. In most cases this means quantifying 120-130 congeners unless the initial Aroclor released was Aroclor 1016, Aroclor 1221, or Aroclor 1268 that have much smaller numbers of total congeners. Calibrations of congener analyses can contain only these 120-130 congeners[7] that could exist in soil samples or some labs actually calibrate for all 209 PCB congeners. Calibrating and testing for all 209 congeners means that data must be gathered and records maintained for all 209 congeners. This is unnecessary as many of the congeners will not exist in a native sample (120-130 congeners are typically found in a native sample). The analysis can be performed either by GC/ECD, GC/LRMS, or if very low detection limits are required to quantify the dioxin-like congeners then GC/HRMS is required.

Congener analysis for soils is usually reserved for detection of low quantities of total PCB where there is significant weathering or dioxin-like PCB congeners are suspected. Congener analysis of 120-130 congeners will be able to nominally detect PCBs at or below 0.5 to 1.0 µg/kg in soils. If GC/ECD or GC/LRMS are used the column used must be able to resolve the co-planer/dioxin like PCBs from the planer PCBs. In most lab situations the lab will include a separate analysis after Carbon/Cellite separation of the co-planer congeners. This will allow the quantification of congeners #77, #81, #126, and #169, the most toxic of the co-planer congeners.

Full congener analysis is the analysis of all 209 possible congeners. This means that the instrument calibration will include all 209 congeners. Full congener analysis is different from looking for only the 120+ naturally occurring congeners described above. Full congener analysis will detect and quantify all congeners including congeners that are the result of, industrial breakdown, biodegradation, or metabolism by organisms. Frame et al discovered a number of congeners that are not found in un-weathered Aroclor mixes that appear to be generated in nature from Aroclor breakdown.

Method 1668B (GC/HRMS) is capable of quantifying very low concentrations of dioxin-like congeners or all congeners. To measure all congeners the method will have to be run on several different GC columns to separate each congener from other co-eluting congeners. Normally this is not necessary as the co-eluting congeners are not high enough in concentration to change the total PCB concentration. The SPB-octyl column recommended generates the best results for most common soil sample extracts. The method has the capability of quantifying the very high concentration congeners (found in percent levels in pure Aroclors) such as congeners #105 and #118; as well as, the very low concentration congeners such as congeners #126 and #169 (in the low ppm levels in pure Aroclors) in one analytical run. The analysis of the co-planer dioxin-like congeners are only performed on soils when human health or ecological risk decisions need to be made at the perimeter of the site being investigated. In these cases, at least 10% or more of the samples collected at the perimeter need to be analyzed by Method 1668B.

No matter which PCB analytical method is chosen for a site investigation there must be a project QAPP generated that must have the UFPQAPP tables completed for the PCB analysis as well as the SOPs to be used by the laboratory for the sample extraction, clean-up and analysis.

Groundwater PCB data quality

When to use what analysis for groundwater or surface water?

Groundwater PCB analysis has been performed for many years and in most cases there have been no PCBs detected using Aroclor analysis. This has usually been due to not having an Aroclor chromatographic pattern found or the detection limits were too high to actually detect the soluble PCB. In most cases where PCBs have been found in ground water analyses the concentration of the PCB was relatively high and above the solubility of PCBs in water. The complete chromatographic pattern of an Aroclor is found in the presence of DNAPL PCB, emulsified PCB, colloidal PCB, or PCB in solution due to the presence of a co-solvent. Where the above situations are not present in groundwater or surface water, Aroclor analysis is not recommended. In scenarios where the surrounding soils are grossly contaminated and there is a strong possibility of having colloidal PCB or PCB in the DNAPL form, Aroclor analysis of the

7 Congeners will be laboratory specific depending on the standards used by the laboratory.

groundwater is recommended. At sites known to have large concentrations of solvents that could act as a co-solvent with PCBs, then Aroclor analysis is recommended. When the soil contamination is significantly less than the soil screening level (SSL) (0.2 mg/kg) up to 10.00 mg/kg, PCBs will probably not be in the colloidal or DNAPL form. Initial testing of the groundwater for total PCBs by GC/ECD may indicate whether there are dissolved PCBs when only the lower chlorinated congeners are found in the chromatographic pattern of the groundwater. This will depend on the nature and chlorination level of the PCB in the surrounding soils. If all the chlorination levels of the surrounding soil Aroclors are found in the water then there is a good possibility that there is colloidal PCB, emulsified PCB, DNAPL, or PCBs that are present due to a co-solvent. The initial GC/ECD test on groundwater or surface water may help in deciding the appropriate analytical method to be used for all quantitative testing (**an analyst with experience in evaluating the presence of these low chlorination level congeners is necessary to make this judgment**). If the initial GC/ECD test indicates that there is no Aroclor pattern or the peaks found are very small but are in the retention time window of PCB congeners, then a more sensitive, lower detection level method is warranted. The drinking water MCL of 0.5 µg/L for water is relatively high and should be attainable with Aroclor analysis if there is a complete Aroclor pattern to quantitate. The ambient water quality standard of 0.014 µg/L is normally not attainable using a standard Aroclor method without enhancement modifications (discussed in the next section).

The type of PCB found in the soil column can dictate what analysis to use for water and what detection limits to strive for. If the PCB released was 1016, 1221, 1232, or 1242, one can expect some of the lower chlorinated congeners (mono-, di-, and tri- substituted) to be in solution if the surrounding soils have Aroclor 1254 or 1260 the amount of soluble congeners present in the un-weathered Aroclor is very small. Weathering of the soil Aroclors will affect the amount of the lower chlorinated congeners that may be found in the groundwater or surface waters.

If the concentration of PCB in the surrounding soils is >500 mg/kg, then field tests (using a test kit that changes color when in contact with organic solvents or fluids or a dual phase water level indicator) for DNAPL or DNAPL emulsion must be performed prior to choosing a sample collection method or analytical method. If the initial screening analytical tests indicate the entire spectrum of peaks found in the soil Aroclor chromatogram then the PCB may be present in the dissolved, colloidal, or DNAPL forms.

The initial testing of the surrounding soils may indicate what sample collection and analytical method to be used for the groundwater.

PCBs found in groundwater as a result of soil contamination are usually found in a dissolved phase. This means that the original Aroclor pattern of the PCB in the soil has changed or only indicates those congeners that are soluble. The concentration of the soluble congeners is usually very low and will require enhancements to the analytical method. Such enhancements include:

- Extracting multiple liters of water using solid phase extraction or multiple separatory funnel extractions or by combining multiple extracts from liquid-liquid extractors,
- Clean-up of the extract to remove color and interfering compounds,
- Concentrating the extract 2 to 5 times or more than the method requires,
- And injecting a larger extract volume on column.

These analytical enhancements may be necessary to get detection limits in the parts per trillion (ppt) or parts per quadrillion range needed for ecological risk assessment purposes. The analytical method, whether using GC/ECD, GC/LRMS, or GC/HRMS requires that the sample collection procedures be performed using highly decontaminated and clean pumps, tubing, glassware, and sample containers to prevent any cross contamination or blank contamination that could overshadow the actual results. The laboratory performing the analysis must prove that they have very low background contamination by performing reagent blanks and instrument blanks and showing the least amount of PCB lab related contamination. If the water has low levels of mono-, di- or tri- substituted chlorinated biphenyl and the laboratory is using GC/ECD these lower chlorinated species have much lower sensitivity to the ECD detector, but higher sensitivity using GC/LRMS. In this case there needs to be a

lower calibration point for these congeners to prove that they can be detected and quantitated.

Figure G-2 provides a process for determining how to handle soil samples and water samples and which analysis is most appropriate.

Field and Lab based process to determine soil and water analytical techniques

The detection limit for groundwater used for drinking is controlled by the maximum contaminant level (MCL) of 0.5 µg/L. To achieve 0.5 µg/L the analytical system must have a detection limit of 0.1 - 0.05 µg/L to account for any blank contamination introduced in the sample collection or analysis. As stated earlier, to achieve detection limits of 0.014 µg/L, the AWQC, the method must have enhancements to achieve a detection limit/ sensitivity 3 to 10 times lower. In some states there may be a lower regulated drinking water limit for PCBs than the national limit of 0.5 µg/L. In most cases where the PCB is in the dissolved form, there will be no distinguishable Aroclor pattern and congener analysis will be warranted.

If there is evidence of DNAPL from field testing the well, then the use of Aroclor analysis must be performed. In these cases the analytical laboratory may need to have an instrument set up to screen the sample extract to determine the approximate concentration prior to analyzing the sample on the analytical system. If the sample is very concentrated it may need to be diluted into the calibration range of the instrument. In these cases the detection limit that is proposed to be achieved that is documented in the QAPP will not be achieved, but that is not a problem considering the concentration of the sample. If actual DNAPL liquids are recovered from the well, the laboratory must evaluate how they will analyze this sample. Waste dilution methods are most applicable for analysis of DNAPL. First the sample is diluted and cleaned-up using acid clean-up procedures and then screened on a GC/ECD set up for high

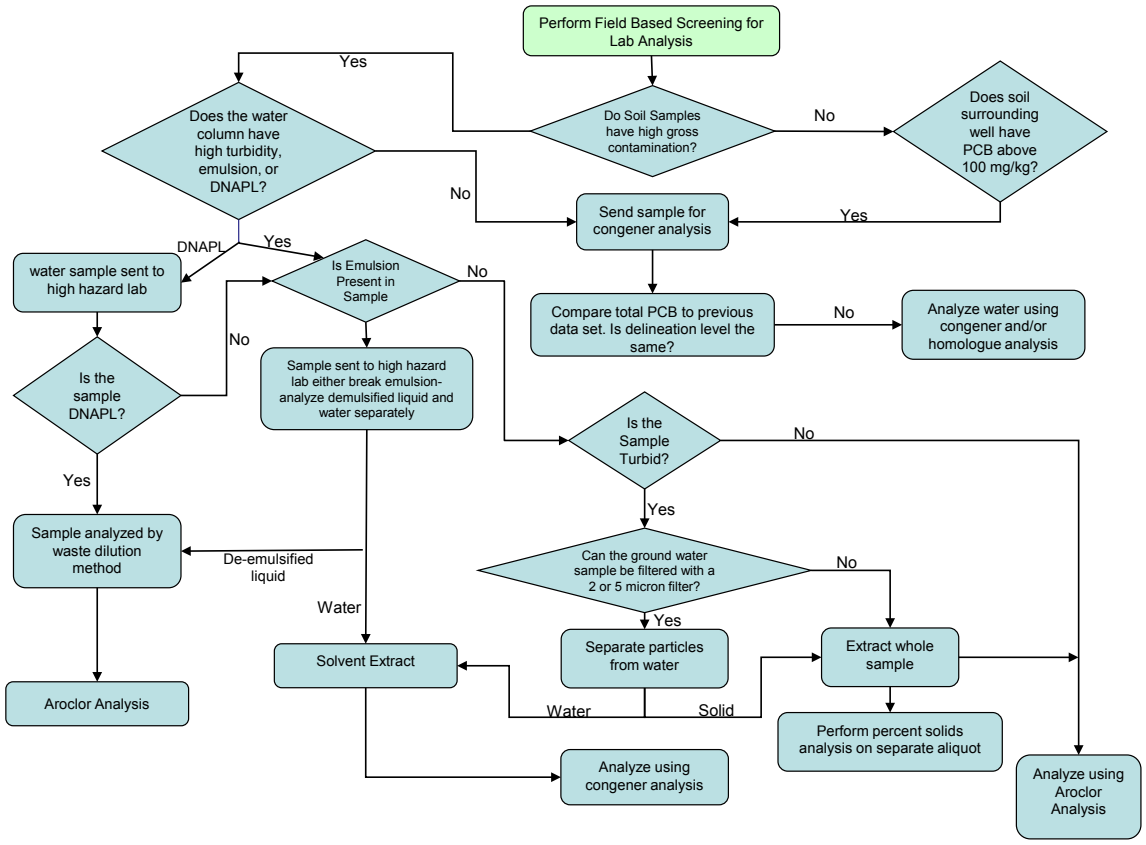

Figure G-2: *Flow Diagram for handling Soil and Water Samples and which analysis to run*

concentration samples to determine the actual concentration range. The sample may need further dilution before it is analyzed on the regular analytical system. Any attempt to analyze DNAPL liquids must be performed in an area that does not contaminate other samples. In some cases a special laboratory that handles this type of sample should be sought out to do the analysis.

Of all the PCB analyses performed on groundwater, the most uncertain for the laboratory is the case where PCBs are in the colloidal form or are present in a dissolved state due to co-solvency. If the surrounding soils have considerable concentrations of a solvent that is water miscible or has some solubility in water, then the water sample should be treated as a high concentration sample. The only indication that PCB colloids may be present is the turbidity of the sample measured during the low flow monitoring procedure. If the colloids have very small particle size, they may not exhibit any elevated turbidity. PCBs that are in an emulsion above a DNAPL phase will have high turbidity and should be treated as very high concentration samples.

The sample collection personnel must be aware of these possible conditions and measure the turbidity carefully as part of the low flow process. In Region 4, having water above the 10 NTU turbidity low flow requirement and also not seeing any solid particles may be an indication of colloidal PCB and/or colloidally transported PCB. In the case of co-solvency there may be no visual indication in the sample.

Any observations made in the field need to be communicated to the laboratory doing the work. There should be contingency plans made with the laboratory and documented in the QAPP for times when unusual field observations are made. Any field notes including low flow monitoring measurements need to be transmitted to the laboratory along with the sample chains of custody. There may be a need to do an initial screening of the sample extracts if colloidal PCBs are suspected so that the sample extract will not be injected into a clean analytical instrument. If initial screening indicates a chromatographic pattern for a highly chlorinated Aroclor then colloidal PCBs or PCBs dissolved due to co-solvents are present. The screened extract can then be diluted and the analysis can be performed for Aroclors or congeners.

If the soil concentrations are less than 100 mg/kg of a highly chlorinated Aroclor, the concentration of PCB in groundwater may be low and is there in the dissolved form. This will depend on the specific PCB in the soil. If the PCB in the soil has been identified as Aroclor 1016, 1221, 1232, or 1242 then there is a propensity for the mono-, di-, and tri- substituted congeners to dissolve in the water leaving the higher chlorinated species attached to the organic phase of the soil.

As stated earlier if there are only the lower chlorinated species in water the use of GC/ECD may result in a less sensitive analysis. It will be important for these analyses to be accompanied by MS/MSD analysis using only Aroclor 1221 in the MS/MSD spike or a laboratory calibration having Aroclor 1221. When only the lower chlorinated species (mono-tri substituted) biphenyls are found, it is unlikely that there would be any dioxin-like risks. Dioxin–like risks congeners start with tetra congeners #77 and #81. No mono-, di-, or tri-substituted congeners are dioxin-like but would still have to be evaluated as a human health risk.

Aroclor QA and QC criteria must be met to have valid data. The retention times and retention time windows for the five peaks or more, chosen for quantitation of a specific Aroclor, must be identical to the retention times and windows of the peaks in the Aroclor standard. If the peaks chosen for quantitation have changed in shape or ratio to other peaks, these peaks may not be quantitative and other peaks need to be chosen for quantitation. In the EPA, Aroclor methods for water analysis there is a requirement that a secondary method for confirmation be used (i.e. second column, GC/MS, etc) to identify and confirm each peak in a chromatogram within some specific criteria. It is important when using a GC/ECD that this be followed. If many samples have been analyzed at a site and the primary column data is found to be valid, this requirement may be waived.

Congener analysis of PCBs in water

Congener analysis has been traditionally performed by GC/ECD for many years. To be able to identify 120 -130 congeners in a single run the analysis run time had to be lengthened to 90-120 minutes to

separate most of the congeners. Depending on the column packing used there will still be many co-eluting congeners. In some case several different columns have had to be used to quantify all of the peaks in a chromatogram.

If the co-eluting peaks are very small in concentration so the actual total PCB concentration will be small. Second column confirmation may be required if there are unknown peaks in the chromatogram. Because most laboratories have performed the congener method many times, all at long run times, they have confidence in each peak's identification and no second column confirmation is required. Full congener analysis of all 209 congeners can be performed using GC/LRMS and GC/HRMS.

The use of a mass spectrometer allows the laboratory to discern whether two co-eluting peaks are from the same or different chlorination levels. This advantage allows the laboratory to not have to run a second column confirmation analysis on each sample. GC/MS sensitivity is increased when the instrument is run in the selected ion monitoring (SIM) mode. The chromatographer programs the instrument to look for primary and secondary ion for all ten levels of chlorination. When a peak elutes from the GC, the instrument uses these ions to quantify the peak. It is important to the final data quality of the GC/LRMS or GC/HRMS analysis that the instrument be properly tuned and calibrated with at least 5 levels of PCB calibration solutions containing all the peaks that are of environmental interest (120-130 for normal analyses or 209 when all peaks need to be quantified). The QAPP for LRMS or HRMS analysis must have a detailed SOP for the analytical method and all QC control criteria. The QAPP must also detail how the data will be validated and reported.

GC/HRMS is the most sensitive analysis for PCBs in any media. Method 1668B has some of the most stringent QA/QC criteria of any EPA method. The method requires that the water be extracted by liquid/liquid or solid phase extraction methods. The extract is put through a stringent series of clean-up steps prior to being concentrated for injection and analysis. The quality control criterion for Method1668B analysis requires the laboratory to have the HRMS in a highly clean area where there are no outside environmental influences. The area where the samples are extracted, cleaned up, and prepared for analysis must also be very clean but must be separated from the instrumental area. The QC criteria that must be met are detailed in the method and used to validate the resulting data. The project QAPP must detail in the UFPQAPP table that criteria detailed in Method 1668B.

The use of LOC, partial congener, full congener, and HRMS congener analysis requires that the project QAPP have more detailed UFPQAPP tables and worksheets. The degree of quality control for these methods is much greater that the QC related to Aroclor analysis. The tables must detail not only the ability of the method to meet the DQO defined detection limits but to generate data that satisfies the MPCs set down in the QAPP. The PARCCS criteria should be met to produce data of known quality but more importantly the data must be usable for making decisions for remedial action or for human health or ecological risks.

Analytical techniques to achieve lower detection limits and their effect on Data Quality

Any of the analytical enhancements that have been discussed in earlier sections, and that are performed to lower the method defined detection limits for soils, solids, surface water or for groundwater, will to some degree create more work to achieve the QA/QC desired to meet project DQOs. There will need to be QC samples, spikes, and internal standards that will need to be monitored through sample preparation, sample extraction, sample extract clean-up, sample concentration, and sample instrumental analysis. Each step must be performed precisely and quantitatively to ensure that the final answer is precise, accurate and sensitive enough to meet the project DQOs, MPCs, and laboratory QC criteria. Each step must have a documented standard operating procedure that is documented as an attachment to the QAPP, and is followed by the laboratory or the sample collection personnel. Lowering detection limits comes with a price in time and money and extensive QC. The steps that must be performed properly are:

- Sample collection- Collecting water samples for low level PCB congener analysis requires extensively cleaned and decontaminated sampling equipment (any material that come in contact with the water sample), and documented

ultra-clean sample containers. In some cases there will be the need to collect samples using the Clean hands/Dirty hands technique.

- Collecting extra volumes of groundwater or surface water will require longer sampling periods especially when using the Low Flow sampling technique. In some cases that may mean collecting a sample over a 4-8 hour period with a low flow pump. It is important to collect equipment blanks during the process.
- Large volumes of water handling issues will arise at the sample extraction phase. If samples are extracted using separatory funnel or liquid/liquid extraction techniques, they may have to be extracted in several aliquots and each aliquot extract combined at the end of the process. When the extraction is performed using solid phase extraction (SPE) techniques the glassware must be ultra clean and the SPE media/filter pretreated with ultra-clean solvents. The removal of the PCB from the SPE material will require the proper clean techniques and enough rinses to ensure that all the PCB has been removed. QC samples may include several solvent reagent blanks before and after the extraction process.
- When the samples are put through acid/base, gel permeation chromatography (GPC), or silica gel column clean-up, all reagents must be certified clean and free of PCBs. The procedure may need to have specific monitoring congeners (non Aroclor congeners) to monitor the clean-up process and ensure that all the PCB has made it through the process.
- The concentration steps to get to a final extract volume must be performed with the greatest care and manual dexterity if the final volume of

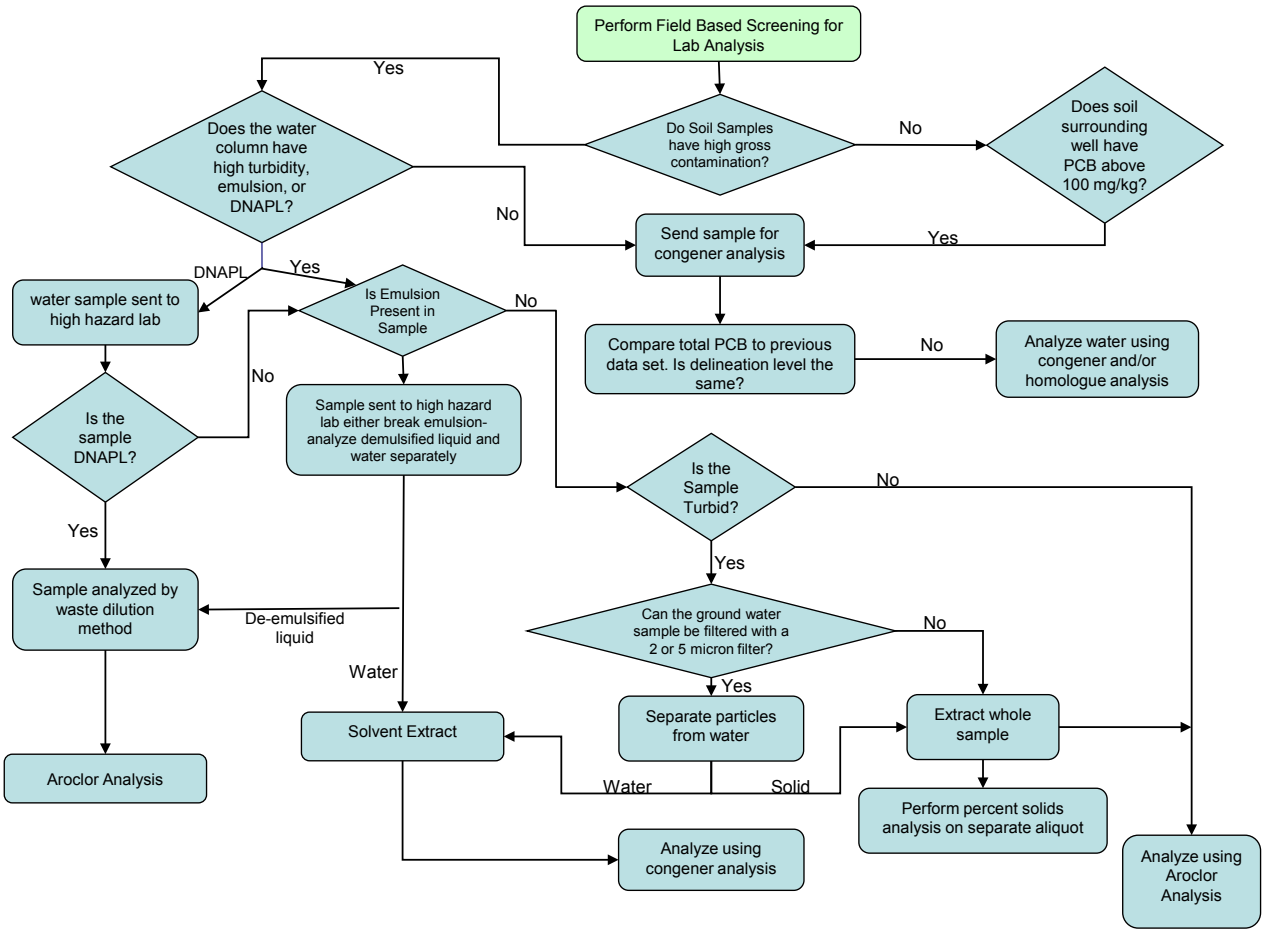

Figure G-3: *Decision Tree for Characterization and Analysis of Samples for PCB Contamination*

the extract is concentrated below one milliliter. In some cases laboratories have to concentrate the sample volume to 0.2 milliliters (mL) or to 20 microliters (uL). There must be documented SOPs for each of the concentration steps.

- The analytical instrument must be monitored first using very strict tuning criteria checked periodically after each sample run of 20 samples. The peak retention times, peak width and shape must also be examined during this process. The calibration and, continuing calibration criteria for each of the congeners or for a specific set of congeners must be checked before running samples and after each sample run. Periodic checks of instrument blanks, and reagent blanks must be monitored, and be in control prior to the initial analysis and after each continuing calibration. If the instrument is calibrated internally the recovery of the internal calibration standards must monitored and meet criteria. If GC/MS SIM is used there will be a monitoring of the ion ratios and other MS criteria. The criteria must also be met for surrogate PCBs that are added to monitor whether the PCBs have made it through all of the sample extraction, clean-up, and concentration processes. The peak shape and shoulders, as well as the baseline between peaks, may need to be manually integrated and must meet SOP criteria. All of the instrument checks must be compiled in the analytical SOP.
- Laboratory must internally validate their data and sign off that it meets QC criteria. If any QC criteria are not met then the sample extract must be rerun or, in some cases the sample must be re-extracted and rerun.

As the final check on data quality the project must have a data validation process performed by a third party. This process must be documented in and SOP that is attached to the project QAPP. The criteria used for validation must be detailed in the QAPP.

APPENDIX H: TABLE OF PCB CONGENER AND AROCLOR PROPERTIES CALCULATED BY EPA KERR LAB

Congener weight percents from Frame Dec. 1996
Frame, G., et al. (1996) Complete PCB Congener Distributions for 17 Aroclor Mixtures Determined by 3 HRGC Systems Optimized for Comprehensive, Quantitative, Congener-Specific Analysis. *Journal of High Resolution Chromatography.* December.
Henry's Law Constant and Solubility data are from Dunnivant 1992
Dunnivant, Frank, et al. 1992. Quantitative Structure - Property Relationships for Aqueous Solubilities and Henry's Law Constants of Polychlorinated Biphenyls. *Environ. Sci. Technol.*, 26(8):1567-1573.
log Kow data are from Hawker and Connell, 1998
Hawker, D.W., and D.W. Connell. 1988. Octanol-water partition coefficients of polychlorinated biphenyl congeners. Environ. Sci. Technol., 1988, 22, 382-387.
Vapor Pressure data are from Burkhard, et al., 1985 (as reported in Mann, 2000)
Burkhard, L.P., D.E. Armstrong and A.W. Andren. 1985. Henry's law constants for the polychlorinated biphenyls. Environ. Sci. Technol., 19:590-596.
Mann, Craig. 2000. Physo-chemical properties for Four PCB Aroclors (Revised) Environmental Quality Management Inc. May 4.

PCB Congener	Congener No.	Congener Weight Percents					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
		Frame December 1996 and Anderson, 1991					Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
2-Monochlorobiphenyl	1	0.53	0.54	0.01	0.02	0	188.65		5.70E+00	4.46	2.95E-04
3-Monochlorobiphenyl	2	0.025	0.03	0	0	0	188.65		4.74E+00	4.69	2.88E-04
4-Monochlorobiphenyl	3	0.155	0.18	0	0	0	188.65		7.69E-01	4.69	2.75E-04
2,2'-Dichlorobiphenyl	4	3.64	3.08	0.04	0.02	0	223.09	418	1.28E+00	4.65	3.31E-04
2,3-Dichlorobiphenyl	5	0.16	0.14	0	0	0	223.09		1.34E+00	4.97	2.40E-04
2,3'-Dichlorobiphenyl	6	1.665	1.43	0.01	0.01	0	223.09	163		5.06	3.27E-04
2,4-Dichlorobiphenyl	7	0.295	0.26	0	0	0	223.09		1.07E+00	5.07	3.80E-04
2,4'-Dichlorobiphenyl	8	8.3	7.05	0.09	0.04	0	223.09	145	6.43E-01	5.07	3.02E-04
2,5-Dichlorobiphenyl	9	0.585	0.5	0	0	0	223.09	195	1.51E+00	5.06	3.24E-04
2,6-Dichlorobiphenyl	10	0.115	0.20	0	0	0	223.09		2.56E+00	4.84	4.27E-04
3,3'-Dichlorobiphenyl	11	0	0	0	0	0	223.09		7.05E-01	5.28	2.88E-04
3,4-Dichlorobiphenyl	12	0.07	0.06	0	0	0	223.09		3.97E-01	5.22	2.34E-04
3,4'-Dichlorobiphenyl	13	0.245	0.21	0	0	0	223.09			5.29	2.51E-04
3,5-Dichlorobiphenyl	14	0	0	0	0	0	223.09		6.43E-01	5.28	4.17E-04
4,4'-Dichlorobiphenyl	15	2.445	2.11	0.02	0.01	0	223.09		2.39E-02	5.3	2.24E-04
2,2',3-Trichlorobiphenyl	16	3.88	3.14	0.055	0.01	0	257.53	681	5.90E-01	5.16	2.51E-04
2,2',4-Trichlorobiphenyl	17	3.98	3.13	0.05	0.01	0	257.53	79		5.25	3.72E-04
2,2',5-Trichlorobiphenyl	18	10.805	8.53	0.165	0.05	0	257.53	892	4.48E-01	5.24	3.16E-04
2,2',6-Trichlorobiphenyl	19	1	0.79	0	0	0	257.53	165		5.02	4.37E-04
2,3,3'-Trichlorobiphenyl	20	0.885	0.72	0	0	0	257.53			5.57	2.19E-04
2,3,4-Trichlorobiphenyl	21	0	0	0	0	0	257.53		4.80E-02	5.51	2.29E-04
2,3,4'-Trichlorobiphenyl	22	3.505	2.84	0.03	0.01	0	257.53	236	6.93E-02	5.58	1.91E-04
2,3,5-Trichlorobiphenyl	23	0.015	0.01	0	0	0	257.53		2.24E-01	5.57	3.16E-04
2,3,6-Trichlorobiphenyl	24	0.165	0.13	0	0	0	257.53			5.35	3.09E-04
2,3',4-Trichlorobiphenyl	25	0.72	0.59	0	0	0	257.53	309		5.67	3.16E-04

PCB Congener	Congener No.	Congener Weight Percents (Frame December 1996 and Anderson, 1991)					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
							Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
2,3',5-Trichlorobiphenyl	26	1.58	1.28	0.015	0	0	257.53	348	2.58E-01	5.66	2.95E-04
2,3',6-Trichlorobiphenyl	27	0.505	0.41	0	0	0	257.53	644		5.44	3.98E-04
2,4,4'-Trichlorobiphenyl	28	8.535	6.86	0.125	0.03	0	257.53	273	8.33E-02	5.67	2.88E-04
2,4,5-Trichlorobiphenyl	29	0.1	0.08	0	0	0	257.53			5.6	2.95E-04
2,4,6-Trichlorobiphenyl	30	0	0	0	0	0	257.53		2.05E-01	5.44	5.75E-04
2,4',5-Trichlorobiphenyl	31	9.29	7.34	0.195	0.04	0	257.53	309	9.57E-02	5.67	2.74E-04
2,4',6-Trichlorobiphenyl	32	2.37	1.90	0.03	0.01	0	257.53			5.44	3.89E-04
2',3,4-Trichlorobiphenyl	33	6.2	5.01	0.105	0.03	0	257.53	24	1.52E-01	5.6	2.40E-04
2',3,5-Trichlorobiphenyl	34	0.03	0.02	0	0	0	257.53			5.66	4.17E-04
3,3',4-Trichlorobiphenyl	35	0.055	0.08	0	0	0	257.53			5.82	1.78E-04
3,3',5-Trichlorobiphenyl	36	0	0	0	0	0	257.53			5.88	3.39E-04
3,4,4'-Trichlorobiphenyl	37	1.015	2.03	0.04	0.00	0	257.53	83	2.89E-02	5.83	1.52E-04
3,4,5-Trichlorobiphenyl	38	0	0	0	0	0	257.53			5.76	2.34E-04
3,4',5-Trichlorobiphenyl	39	0	0	0	0	0	257.53		3.10E-02	5.89	3.02E-04
2,2',3,3'-Tetrachlorobiphenyl	40	0.58	0.76	0.135	0	0	291.97	111	1.27E-02	5.66	1.82E-04
2,2',3,4-Tetrachlorobiphenyl	41	0.76	0.68	0.015	0	0	291.97			5.69	2.44E-04
2,2',3,4'-Tetrachlorobiphenyl	42	1.59	1.18	0.12	0	0	291.97	129	3.35E-02	5.76	2.51E-04
2,2',3,5-Tetrachlorobiphenyl	43	0.265	0.18	0	0	0	291.97			5.75	3.31E-04
2,2',3,5'-Tetrachlorobiphenyl	44	4.475	3.55	1.49	0.04	0	291.97	145	7.68E-02	5.75	2.29E-04
2,2',3,6-Tetrachlorobiphenyl	45	1.225	0.89	0.035	0	0	291.97	393		5.53	3.55E-04
2,2',3,6'-Tetrachlorobiphenyl	46	0.485	0.36	0	0	0	291.97	268	2.79E-02	5.53	3.39E-04
2,2',3,4'-Tetrachlorobiphenyl	47	1.25	0.93	0.105	0	0	291.97	149	4.96E-02	5.85	3.72E-04
2,2',4,5-Tetrachlorobiphenyl	48	1.6	1.18	0.085	0	0	291.97	165		5.78	3.02E-04
2,2',4,5'-Tetrachlorobiphenyl	49	3.375	2.52	0.68	0.01	0	291.97	168	4.12E-02	5.85	3.55E-04
2,2',4,6-Tetrachlorobiphenyl	50	0.01	0	0	0	0	291.97			5.63	6.03E-04
2,2',4,6'-Tetrachlorobiphenyl	51	0.32	0.23	0	0	0	291.97			5.63	5.13E-04

PCB Congener	Congener No.	Congener Weight Percents (Frame December 1996 and Anderson, 1991)					Erickson, 1997 Molecular Wt	Burkhard, 1985 Vapor Pressure	Conversion using Dunnivant, 1992 Congener Solubility	Hawker & Connell, 1988 Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
2,2',5,5'-Tetrachlorobiphenyl	52	4.62	3.53	3.105	0.24	0	291.97	19	3.35E-02	5.84	3.16E-04
2,2',5,6'-Tetrachlorobiphenyl	53	0.945	0.71	0.08	0	0	291.97		4.74E-02	5.62	4.27E-04
2,2',6,6'-Tetrachlorobiphenyl	54	0.015	0.00	0	0	0	291.97		1.46E-02	5.21	5.75E-04
2,3,3',4'-Tetrachlorobiphenyl	55	0	0.1	0	0	0	291.97			6.11	1.82E-04
2,3,3',4'-Tetrachlorobiphenyl	56	0.065	1.82	1.125	0.01	0	291.97		1.16E-02	6.11	1.51E-04
2,3,3',5-Tetrachlorobiphenyl	57	0.01	0.02	0	0	0	291.97			6.17	2.69E-04
2,3,3',5'-Tetrachlorobiphenyl	58	0	0	0	0	0	291.97		5.56E-03	6.17	2.51E-04
2,3,3',6-Tetrachlorobiphenyl	59	0.395	0.32	0.01	0	0	291.97			5.95	3.02E-04
2,3,4,4'-Tetrachlorobiphenyl	60	0.035	1.18	0.565	0.04	0	291.97	421	2.72E-03	6.11	1.51E-04
2,3,4,5-Tetrachlorobiphenyl	61	0	0	0	0	0	291.97		1.80E-02	6.04	2.40E-04
2,3,4,6-Tetrachlorobiphenyl	62	0	0	0	0	0	291.97			5.89	3.72E-04
2,3,4',5-Tetrachlorobiphenyl	63	0.055	0.12	0.045	0	0	291.97		7.33E-03	6.17	2.40E-04
2,3,4',6-Tetrachlorobiphenyl	64	1.855	1.70	0.475	0.01	0	291.97	136		5.95	2.69E-04
2,3,5,6-Tetrachlorobiphenyl	65	0	0	0	0	0	291.97		4.32E-02	5.86	3.39E-04
2,3',4,4'-Tetrachlorobiphenyl	66	0.375	3.39	2.285	0.02	0	291.97	453	4.52E-03	6.2	2.04E-04
2,3',4,5-Tetrachlorobiphenyl	67	0.06	0.16	0	0	0	291.97			6.2	2.34E-04
2,3',4,5'-Tetrachlorobiphenyl	68	0	0	0	0	0	291.97			6.26	3.80E-04
2,3',4,6-Tetrachlorobiphenyl	69	0	0	0	0	0	291.97			6.04	5.01E-04
2,3',4',5-Tetrachlorobiphenyl	70	0.575	3.73	5.16	0.04	0	291.97	512	1.11E-02	6.2	2.04E-04
2,3',4',6-Tetrachlorobiphenyl	71	1.165	1.03	0.13	0	0	291.97			5.98	3.16E-04
2,3',5,5'-Tetrachlorobiphenyl	72	0	0.01	0	0	0	291.97		1.16E-02	6.26	3.63E-04
2,3',5',6-Tetrachlorobiphenyl	73	0	0	0	0	0	291.97			6.04	5.25E-04
2,4,4',5-Tetrachlorobiphenyl	74	0.33	1.81	1.515	0.05	0	291.97	572	4.52E-03	6.2	2.14E-04
2,4,4',6-Tetrachlorobiphenyl	75	0.06	0.04	0	0	0	291.97			6.05	4.68E-04
2',3,4',5-Tetrachlorobiphenyl	76	0	0.08	0.025	0	0	291.97			6.13	2.39E-04

PCB Congener	Congener No.	Congener Weight Percents					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
		Frame December 1996 and Anderson, 1991					Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
3,3',4,4'-Tetrachlorobiphenyl	77	0	0.31	0.115	0	0	291.97		9.67E-04	6.36	1.03E-04
3,3',4,5-Tetrachlorobiphenyl	78	0	0	0	0	0	291.97			6.35	1.63E-04
3,3',4,5'-Tetrachlorobiphenyl	79	0	0	0	0	0	291.97		3.59E-03	6.42	1.95E-04
3,3',5,5'-Tetrachlorobiphenyl	80	0	0	0	0	0	291.97		1.21E-03	6.48	3.75E-04
3,4,4',5-Tetrachlorobiphenyl	81	0	0.01	0	0	0	291.97			6.36	1.43E-04
2,2',3,3',4-Pentachlorobiphenyl	82	0	0.26	1.32	0	0	326.41	198	2.78E-03	6.2	1.45E-04
2,2',3,3',5-Pentachlorobiphenyl	83	0	0.11	0.52	0	0	326.41	295		6.26	2.14E-04
2,2',3,3',6-Pentachlorobiphenyl	84	0.05	0.41	1.95	0.11	0	326.41	64		6.04	2.51E-04
2,2',3,4,4'-Pentachlorobiphenyl	85	0	0.31	1.885	0.01	0	326.41	23		6.3	1.91E-04
2,2',3,4,5-Pentachlorobiphenyl	86	0	0.02	0.08	0	0	326.41			6.23	2.40E-04
2,2',3,4,5'-Pentachlorobiphenyl	87	0	0.46	3.7	0.41	0	326.41	259	3.52E-03	6.29	1.84E-04
2,2',3,4,6-Pentachlorobiphenyl	88	0	0	0	0	0	326.41			6.07	3.80E-04
2,2',3,4,6'-Pentachlorobiphenyl	89	0	0.09	0.1	0	0	326.41			6.07	2.95E-04
2,2',3,4',5-Pentachlorobiphenyl	90	0	0	0	0	0	326.41			6.36	2.95E-04
2,2',3,4',6-Pentachlorobiphenyl	91	0.06	0.21	0.73	0.00	0	326.41	742		6.13	3.47E-04
2,2',3,5,5'-Pentachlorobiphenyl	92	0	0.09	0.93	0.30	0	326.41			6.35	2.60E-04
2,2',3,5,6-Pentachlorobiphenyl	93	0	0	0	0	0	326.41			6.04	3.39E-04
2,2',3,5,6'-Pentachlorobiphenyl	94	0	0.00	0.01	0	0	326.41			6.13	3.89E-04
2,2',3,5',6-Pentachlorobiphenyl	95	0.305	0.61	4.045	2.46	0	326.41	838	1.10E-02	6.13	3.00E-04
2,2',3,6,6'-Pentachlorobiphenyl	96	0.04	0.03	0.025	0	0	326.41			5.71	4.07E-04
2,2',3',4,5-Pentachlorobiphenyl	97	0.02	0.38	2.7	0.09	0	326.41	269	8.39E-03	6.29	1.78E-04
2,2',3',4,6-Pentachlorobiphenyl	98	0	0	0	0	0	326.41			6.13	3.89E-04
2,2',4,4',5-Pentachlorobiphenyl	99	0.01	0.46	3.775	0.04	0	326.41	312		6.39	2.51E-04
2,2',4,4',6-Pentachlorobiphenyl	100	0	0	0	0	0	326.41			6.23	0.00E+00
2,2',4,5,5'-Pentachlorobiphenyl	101	0.17	0.69	6.755	3.13	0	326.41	353	9.41E-03	6.38	2.45E-04

PCB Congener	Congener No.	Congener Weight Percents (Frame December 1996 and Anderson, 1991)					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
							Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
2,2',4,5,6'-Pentachlorobiphenyl	102	0.22	0.07	0.12	0	0	326.41			6.16	3.72E-04
2,2',4,5,6'-Pentachlorobiphenyl	103	0	0	0.015	0	0	326.41			6.22	5.01E-04
2,2',4,6,6'-Pentachlorobiphenyl	104	0	0	0	0	0	326.41			5.81	7.41E-04
2,3,3'4,4'-Pentachlorobiphenyl	105	0	0.47	5.18	0.22	0	326.41	698	1.88E-03	6.65	9.93E+14
2,3,3',4,5-Pentachlorobiphenyl	106	0	0	0	0	0	326.41			6.64	1.66E-04
2,3,3',4',5-Pentachlorobiphenyl	107	0	0	0	0	0	326.41			6.71	1.58E-04
2,3,3',4,5'-Pentachlorobiphenyl	108	0	0	0	0	0	326.41			6.71	1.78E-04
2,3,3',4,6-Pentachlorobiphenyl	109	0	0.06	0.575	0	0	326.41	622		6.48	2.82E-04
2,3,3',4',6-Pentachlorobiphenyl	*110*	*0*	*0.83*	*8.855*	*1.33*	*0*	*326.41*	*225*		*6.48*	*1.96E-04*
2,3,3',5,5'-Pentachlorobiphenyl	*111*	*0*	*0*	*0*	*0*	*0*	*326.41*			*6.76*	*2.69E-04*
2,3,3',5,6-Pentachlorobiphenyl	*112*	*0*	*0*	*0*	*0*	*0*	*326.41*			*6.45*	*2.69E-04*
2,3,3',5',6-Pentachlorobiphenyl	*113*	*0*	*0*	*0.005*	*0*	*0*	*326.41*			*6.54*	*3.24E-04*
2,3,4,4',5-Pentachlorobiphenyl	114	0	0.04	0.34	0	0	326.41		2.48E-03	6.65	1.43E-04
2,3,4,4',6-Pentachlorobiphenyl	115	0	0.04	0.285	0	0	326.41			6.49	2.45E-04
2,3,4,5,6-Pentachlorobiphenyl	116	0	0	0	0	0	326.41		4.30E-03	6.33	2.95E-04
2,3,4',5,6-Pentachlorobiphenyl	117	0	0.03	0.21	0	0	326.41			6.46	2.40E-04
2,3',4,4',5-Pentachlorobiphenyl	118	0	0.66	10.47	0.49	0	326.41	949	1.97E-03	6.74	1.26E-04
2,3',4,4',6-Pentachlorobiphenyl	119	0	0	0.1	0	0	326.41			6.58	3.09E-04
2,3',4,5,5'-Pentachlorobiphenyl	120	0	0	0	0	0	326.41			6.79	2.45E-04
2,3',4,5,6-Pentachlorobiphenyl	121	0	0	0	0	0	326.41			6.64	5.62E-04
2',3,3',4,5-Pentachlorobiphenyl	122	0	0.01	0.175	0	0	326.41			6.64	1.26E-04
2',3,4,4',5-Pentachlorobiphenyl	123	0	0.03	0.235	0	0	326.41			6.74	1.74E-04
2',3,4,5,5'-Pentachlorobiphenyl	124	0	0.03	0.38	0	0	326.41			6.73	1.70E-04
2',3,4,5,6'-Pentachlorobiphenyl	125	0	0.02	0.025	0	0	326.41			6.51	2.88E-04
3,3',4,4',5-Pentachlorobiphenyl	126	0	0	0.01	0	0	326.41			6.89	8.13E+14

PCB Congener	Congener No.	Congener Weight Percents					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
		Frame December 1996 and Anderson, 1991					Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
3,3',4,5,5'-Pentachlorobiphenyl	127	0	0	0	0	0	326.41			6.95	1.55E-04
2,2',3,3',4,4'-Hexachlorobiphenyl	128	0	0.02	1.565	0.54	0	360.85	354	2.93E-04	6.74	1.05E-04
2,2',3,3',4,5-Hexachlorobiphenyl	129	0	0	0.385	0.14	0	360.85	205		6.73	1.41E-04
2,2',3,3',4,5'-Hexachlorobiphenyl	130	0	0	0.55	0.22	0	360.85	528		6.8	1.51E-04
2,2',3,3',4,6-Hexachlorobiphenyl	131	0	0	0.165	0.07	0	360.85			6.58	2.40E-04
2,2',3,3',4,6'-Hexachlorobiphenyl	132	0	0.04	1.895	2.90	0	360.85	114		6.58	2.04E-04
2,2',3,3',5,5'-Hexachlorobiphenyl	133	0	0	0.055	0.07	0	360.85		4.34E-04	6.86	2.04E-04
2,2',3,3',5,6-Hexachlorobiphenyl	134	0	0	0.285	0.34	0	360.85	243		6.55	2.29E-04
2,2',3,3',5,6'-Hexachlorobiphenyl	135	0	0	0.445	1.08	0	360.85	171		6.64	2.69E-04
2,2',3,3',6,6'-Hexachlorobiphenyl	136	0	0	0.47	1.46	0	360.85	369	3.78E-03	6.22	3.24E-04
2,2',3,4,4',5-Hexachlorobiphenyl	137	0	0	0.47	0.02	0	360.85	238	1.73E-03	6.83	1.86E-04
2,2',3,4,4',5'-Hexachlorobiphenyl	138	0	0.10	5.875	6.54	0	360.85	481	1.51E-03	6.83	1.29E-04
2,2',3,4,4',6-Hexachlorobiphenyl	139	0	0	0.145	0	0	360.85			6.67	3.31E-04
2,2',3,4,4',6'-Hexachlorobiphenyl	140	0	0	0	0	0	360.85		3.22E-03	6.67	3.09E-04
2,2',3,4,5,5'-Hexachlorobiphenyl	141	0	0.00	0.835	2.62	0	360.85	269		6.82	1.74E-04
2,2',3,4,5,6-Hexachlorobiphenyl	142	0	0	0	0	0	360.85		1.37E-03	6.51	3.16E-04
2,2',3,4,5,6'-Hexachlorobiphenyl	143	0	0	0	0	0	360.85			6.6	2.95E-04
2,2',3,4,5',6-Hexachlorobiphenyl	144	0	0	0.18	0.61	0	360.85	34		6.67	2.95E-04
2,2',3,4,6,6'-Hexachlorobiphenyl	145	0	0	0	0	0	360.85			6.25	4.68E-04
2,2',3,4',5,5'-Hexachlorobiphenyl	146	0	0	0.56	1.15	0	360.85	718		6.89	1.86E-04
2,2',3,4',5,6-Hexachlorobiphenyl	147	0	0	0.06	0	0	360.85			6.64	3.16E-04
2,2',3,4',5,6'-Hexachlorobiphenyl	148	0	0	0	0	0	360.85			6.73	4.27E-04
2,2',3,4',5',6-Hexachlorobiphenyl	149	0	0.06	2.735	8.75	0	360.85	155		6.67	2.34E-04
2,2',3,4',6,6'-Hexachlorobiphenyl	150	0	0	0	0	0	360.85			6.32	5.01E-04
2,2',3,5,5',6-Hexachlorobiphenyl	151	0	0	0.455	3.04	0	360.85	318	2.23E-03	6.64	2.82E-04

PCB Congener	Congener No.	Congener Weight Percents					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
		Frame December 1996 and Anderson, 1991					Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
2,2',3,5,6,6'-Hexachlorobiphenyl	152	0	0	0	0	0	360.85			6.22	4.27E-04
2,2',4,4',5,5'-Hexachlorobiphenyl	153	0	0.06	3.53	9.39	0	360.85	654	8.84E-04	6.92	1.66E-04
2,2',4,4',5',6-Hexachlorobiphenyl	154	0	0	0.03	0	0	360.85			6.76	3.80E-04
2,2',4,4',6,6'-Hexachlorobiphenyl	155	0	0	0	0	0	360.85		2.28E-03	6.41	8.32E-04
2,3,3',4,4',5-Hexachlorobiphenyl	156	0	0.01	0.975	0.52	0	360.85	724		7.18	8.91E+14
2,3,3',4,4',5'-Hexachlorobiphenyl	157	0	0	0.245	0.02	0	360.85			7.18	8.51E+14
2,2',4,4',5,5'-Hexachlorobiphenyl	153	0	0.06	3.53	9.39	0	360.85	654	8.84E-04	6.92	1.66E-04
2,2',4,4',5',6-Hexachlorobiphenyl	154	0	0	0.03	0	0	360.85			6.76	3.80E-04
2,2',4,4',6,6'-Hexachlorobiphenyl	155	0	0	0	0	0	360.85		2.28E-03	6.41	8.32E-04
2,3,3',4,4',5-Hexachlorobiphenyl	156	0	0.01	0.975	0.52	0	360.85	724		7.18	8.91E+14
2,3,3',4,4',5'-Hexachlorobiphenyl	157	0	0	0.245	0.02	0	360.85			7.18	8.51E+14
2,3,3',4,4',6-Hexachlorobiphenyl	158	0	0.01	0.855	0.58	0	360.85	914		7.02	1.66E-04
2,3,3',4,5,5'-Hexachlorobiphenyl	159	0	0	0	0	0	360.85			7.24	1.55E-04
2,3,3',4,5,6-Hexachlorobiphenyl	160	0	0	0	0	0	360.85		1.58E-03	6.93	2.14E-04
2,3,3',4,5',6-Hexachlorobiphenyl	161	0	0	0	0	0	360.85			7.08	2.82E-04
2,3,3',4',5,5'-Hexachlorobiphenyl	162	0	0	0	0	0	360.85			7.24	1.32E-04
2,3,3',4',5,6-Hexachlorobiphenyl	163	0	0.01	0.865	2.43	0	360.85			6.99	1.66E-04
2,3,3',4',5',6-Hexachlorobiphenyl	164	0	0	0.355	0.69	0	360.85			7.02	1.78E-04
2,3,3',5,5',6-Hexachlorobiphenyl	165	0	0	0	0	0	360.85			7.05	2.75E-04
2,3,4,4',5,6-Hexachlorobiphenyl	166	0	0	0.05	0	0	360.85		2.44E-04	6.93	1.82E-04
2,3,4,4',5,5'-Hexachlorobiphenyl	167	0	0	0.31	0.19	0	360.85	186		7.27	1.10E-04
2,3',4,4',5',6-Hexachlorobiphenyl	168	0	0	0	0	0	360.85		9.71E-04	7.11	2.75E-04
3,3',4,4',5,5'-Hexachlorobiphenyl	169	0	0	0	0	0	360.85		4.24E+14	7.42	6.46E+14
2,2',3,3',4,4',5-Heptachlorobiphenyl	170	0	0	0.435	4.11	0	395.29	367	1.19E-04	7.27	8.71E+13
2,2',3,3',4,4',6-Heptachlorobiphenyl	171	0	0	0.11	1.11	2.78	395.29	463		7.11	1.74E-04

PCB Congener	Congener No.	Congener Weight Percents					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
		Frame December 1996 and Anderson, 1991					Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
2,2',3,3',4,5,5'-Heptachlorobiphenyl	172	0	0	0.05	0.7	0	395.29	548		7.33	1.20E-04
2,2',3,3',4,5,6-Heptachlorobiphenyl	173	0	0	0	0.10	0	395.29			7.02	1.82E-04
2,2',3,3',4,5,6'-Heptachlorobiphenyl	174	0	0	0.24	4.96	0	395.29	119	3.19E-04	7.11	1.70E-04
2,2',3,3',4,5',6-Heptachlorobiphenyl	175	0	0	0	0.18	0	395.29			7.17	2.24E-04
2,2',3,3',4,6,6'-Heptachlorobiphenyl	176	0	0	0.02	0.59	0	395.29			6.76	2.95E-04
2,2',3,3',4',5,6-Heptachlorobiphenyl	177	0	0	0.14	2.57	0	395.29	434		7.08	1.62E-04
2,2',3,3',5,5',6-Heptachlorobiphenyl	178	0	0	0.015	0.83	0	395.29	648		7.14	2.14E-04
2,2',3,3',5,6,6'-Heptachlorobiphenyl	179	0	0	0.06	2.03	0	395.29	14		6.73	2.75E-04
2,2',3,4,4',5,5'-Heptachlorobiphenyl	180	0	0	0.545	11.38	1.14	395.29	499	2.25E-04	7.36	1.07E-04
2,2',3,4,4',5,6-Heptachlorobiphenyl	181	0	0	0	0	0	395.29			7.11	2.29E-04
2,2',3,4,4',5,6'-Heptachlorobiphenyl	182	0	0	0	0	0	395.29		1.37E-04	7.2	2.57E-04
2,2',3,4,4',5',6-Heptachlorobiphenyl	183	0	0	0.135	2.41	0	395.29	63		7.2	2.00E-04
2,2',3,4,4',6,6'-Heptachlorobiphenyl	184	0	0	0	0	0	395.29			6.85	4.57E-04
2,2',3,4,5,5',6-Heptachlorobiphenyl	185	0	0	0	0.55	0	395.29	718	1.93E-04	7.11	2.14E-04
2,2',3,4,5,6,6'-Heptachlorobiphenyl	186	0	0	0	0	0	395.29			6.69	3.72E-04
2,2',3,4,5,5',6-Heptachlorobiphenyl	187	0	0	0.17	5.4	3.79	395.29	59		7.17	2.04E-04
2,2',3,4',5,6,6'-Heptachlorobiphenyl	188	0	0	0	0	0	395.29			6.82	4.47E-04
2,3,3',4,4',5,5'-Heptachlorobiphenyl	189	0	0	0.005	0.10	0	395.29		4.44E+14	7.71	6.61E+14
2,3,3',4,4',5,6-Heptachlorobiphenyl	190	0	0	0.06	0.82	0	395.29	193	2.20E-04	7.46	1.12E-04
2,3,3',4,4',5',6-Heptachlorobiphenyl	191	0	0	0	0.17	0	395.29			7.55	1.32E-04
2,3,3',4,5,5',6-Heptachlorobiphenyl	192	0	0	0	0	0	395.29			7.52	1.91E-04
2,3,3',4',5,5',6-Heptachlorobiphenyl	193	0	0	0.015	0.53	0	395.29			7.52	1.35E-04
2,2',3,3',4,4',5,5'-Octachlorobiphenyl	194	0	0	0.005	2.07	3.19	429.73	381	2.10E+14	7.8	6.76E+14
2,2',3,3',4,4',5,6-Octachlorobiphenyl	195	0	0	0	0.84	6.12	429.73	979		7.56	1.17E-04

PCB Congener	Congener No.	Congener Weight Percents					Erickson, 1997	Burkhard, 1985	Conversion using Dunnivant, 1992	Hawker & Connell, 1988	
		Frame December 1996 and Anderson, 1991					Molecular Wt	Vapor Pressure	Congener Solubility	Congener Octanol/ Water Partitioning Coefficient	Henry's Law Constant
		A1016	A1242	A1254	A1260	A1268	MW	Pv	S	log Kow	H
		Wt%	Wt%	Wt%	Wt%	Wt%	(g/mol)	atm	mg/L	cm3/g	atm-m3/mol
2,2',3,3',4,4',5,6'-Octachlorobiphenyl	196	0	0	0	1.09	5.67	429.73			7.65	1.17E-04
2,2',3,3',4,4',6,6'-Octachlorobiphenyl	197	0	0	0	0.07	0	429.73		1.03E-04	7.3	2.51E-04
2,2',3,3',4,5,5',6-Octachlorobiphenyl	198	0	0	0	0.1	0	429.73			7.62	1.55E-04
2,2',3,3',4,5,5',6'-Octachlorobiphenyl	199	0	0	0.005	1.78	0	429.73	316		7.2	2.29E-04
2,2',3,3',4,5,6,6'-Octachlorobiphenyl	200	0	0	0	0.25	1.46	429.73			7.27	2.40E-04
2,2',3,3',4,5',6,6'-Octachlorobiphenyl	201	0	0	0	0.24	14.92	429.73			7.62	1.32E-04
2,2',3,3',5,5',6,6'-Octachlorobiphenyl	202	0	0	0	0.33	2.78	429.73		4.60E+14	7.24	2.24E-04
2,2',3,4,4',5,5',6-Octachlorobiphenyl	203	0	0	0.01	1.07	5.67	429.73	133		7.65	1.41E-04
2,2',3,4,4',5,6,6'-Octachlorobiphenyl	204	0	0	0	0	0	429.73			7.3	3.47E-04
2,3,3',4,4',5,5',6-Octachlorobiphenyl	205	0	0	0	0.1	0	429.73			8	8.71E+13
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	206	0	0	0.03	0.53	28.7	464.17	102	2.67E-06	8.09	8.71E+13
2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl	207	0	0	0	0.05	2.47	464.17			7.74	1.70E-04
2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl	208	0	0	0.01	0.13	6.12	464.17			7.71	1.66E-04
Decachlorobiphenyl	209	0	0	0	0	8.12	498.61		1.28E-07	8.18	1.12E-04