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PCB Chemical Action Plan

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PCB Chemical Action Plan

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Summary of Findings

PBT Rule and Chemical Action Plans

A Chemical Action Plan (CAP) identifies, characterizes, and evaluates uses and releases of specific persistent, bioaccumulative and toxic chemicals (PBT) or a group of chemicals and recommends actions to protect human health and the environment (173-333 WAC). PBTs are considered the “worst of the worst” chemical contaminants because they remain in the environment for a long time, and build up within organisms and/or the food chain.

This Polychlorinated Biphenyls (PCBs) CAP estimates releases of PCBs from various sources to air, land, and water. It also describes the physical and chemical properties of PCBs and why they are considered toxic to humans and other organisms. The recommendations are a set of actions to reduce and phase out uses, releases, and exposures in Washington in consideration of current management approaches. An economic analysis on the cost of recommendations and the most promising options is also included.

PCBs

From 1929 to 1979 about 600,000 metric tons of PCBs were commercially manufactured in the US. The 1976 *Toxics Substances Control Act* (TSCA) prohibited manufacture, processing, and distribution of PCBs. While TSCA is often referred to as a “ban” on PCBs, the law allowed some historical uses to continue, and set allowable levels of inadvertent production of PCBs in other products. PCBs are also regulated under additional state and federal laws, and they are not always consistent. For example, the level of PCBs that is allowed in products under TSCA is millions of times higher than what is allowed in water under the Clean Water Act. This leads to water permit holders being held responsible at the end of their pipe for PCBs that came from other products. Back in the late 70’s the total amount seemed small and the amount allowed in each product seemed low, but now we know that it’s high compared to levels that impact human health..

PCBs are synthetic compounds that consist of 209 possible arrangements (called congeners) of chlorines around a biphenyl molecule. PCBs were sold commercially as various mixtures of these different arrangements. They are also found in the environment as various mixtures, bioaccumulate as complex mixtures, and have been assessed for toxicity largely as mixtures. They are largely regulated as total PCBs. As a result, Ecology chose to evaluate available information on all PCB compounds.

Major sources

For the purposes of this CAP, sources are considered to be the original material, such as PCBs in transformers. PCBs move through pathways such as stormwater and expose people and wildlife.

Current PCB levels in Washington State represent both historical uses and ongoing manufacturing processes that create PCBs. A large reservoir of past uses of PCBs includes electrical equipment such as transformers and capacitors, and building materials such as caulk and paint. About 75 percent of PCBs produced before 1979 were used in transformers and capacitors, including small capacitors in lamp ballasts and appliances. The second largest pre-1979 use, about 10 percent, was as plasticizers, including in caulk.

PCBs are still unintentionally generated by combustion and by different manufacturing processes, such as for some pigments and dyes. While there is a lot of recent research on the generation of PCBs during production of pigments and dyes, little work has been done to shed light on other processes that are likely to generate and release new PCBs. Non-point releases, such as from consumer products, are becoming increasingly important to control and reduce overall PCB delivery to humans and the environment.

Pathways

Lower chlorinated congeners are more readily emitted to the air from sources such as old caulk and intact lamp ballasts. When lamp ballasts fail or caulk is disturbed, a greater amount of all of the congeners are released. Lower chlorinated congeners travel further in air compared to the higher chlorinated congeners, and eventually all the congeners are deposited onto surfaces. PCBs do not readily dissolve in water and they bind to particles. Particle-bound PCBs can be transported through stormwater and end up in sediment. The relative abundance of PCBs in sediment is seen in Puget Sound where 97 percent of the PCBs are bound to sediment (1440 kg), less than three percent are in organisms (40kg), and less than one percent (10 kg) are dissolved in water. Under certain conditions, such as in the Spokane River, PCBs are found in the water column rather than in sediments.

Stormwater is the largest delivery pathway to surface waters for PCBs statewide. Loadings from water treatment plants and atmospheric deposition are each less than 10 percent of the total, although atmospheric deposition is less well studied. There are smaller pathways, such as from salmon that accumulate PCBs while in the Pacific Ocean and then return to Washington to spawn. While the long-term goal is to prevent PCBs from entering stormwater, it is important to continue work on stormwater management, including piloting new technologies.

Exposure

Levels of PCBs in the environment are mostly declining, but PCBs are still widespread. Wildlife are exposed to PCBs in their diet, along with PCBs in water, soil, and sediments. PCBs accumulate in fatty tissues, including in animals eaten for food. PCBs in food are the most significant source of exposure for most people, and we are particularly concerned with levels of PCBs in fish we eat. People are also exposed to PCBs in air, water, soil, and house dust. Levels of PCBs in people have declined since the 1980s, but everyone in the US has detectable levels of PCBs in their bodies. PCBs remain in people and animals for different numbers of years, varying by type of organism and type of PCB congener. Because PCBs are more readily absorbed than excreted, they accumulate in the body over time.

Toxic effects

PCBs are persistent in the environment, build up in the food chain, and can cause adverse health effects in humans and wildlife including cancer and harm to immune, nervous, and reproductive systems. PCBs disrupt thyroid hormone levels in animals and humans, hindering growth and development.

Priorities for new actions

As shown in Table 1 below, there are a variety of PCB sources with different concerns (each estimate is presented in the order it is discussed in the section on Sources, Uses and Releases and how each is derived is explained in that section). The table divides sources into those that are a legacy of the historic uses before 1979 and those that are currently ongoing.

We are especially concerned about exposure to children in school buildings with old lamp ballasts and other PCB-containing building materials. It is uncertain how many pre-1979 lamp ballasts are still in use, but they should be removed both for their potential to expose people to PCBs when they fail and because newer lights are more energy efficient. A large reservoir of PCBs in old caulk and other building materials is slowly being released into the environment. Releases from building materials can be greatly accelerated during remodeling and demolition. There is an opportunity, through use of best management practices, to prevent releases of PCBs during remodeling and demolition.

Inadvertent generation of PCBs is a potentially large and important source of uncontained PCBs, but little is known about the processes that inadvertently generate PCBs and what products contain them. We do know PCBs are created as a byproduct of pigments and dyes, and this creates a regulatory burden for paper recycling, municipal treatment works, and other dischargers in Washington. Finding alternative pigments and dyes will reduce PCB releases to the environment and alleviate water treatment burdens on business and municipalities.

While about 75 percent of the PCBs produced prior to 1979 were used in electrical equipment, most of the transformers and large capacitors that contain PCBs have been identified and replaced. The remaining equipment is largely monitored for spills that are cleaned up, further reducing the impact to people and the environment.

Table 1. Summary of sources, reservoirs, releases, exposures and priorities.

Source	Legacy reservoir of PCBs	Annual releases of PCBs (kg/yr)	Potential exposure pathways and concerns	Is the release contained?	Priorities
Historic uses					
transformers	100-200 kg	< 2	Accidental spills, which are identified and cleaned up.	Yes	
large capacitors	20 metric tons	10 to 80	Accidental spills, which are identified and cleaned up.	Yes	
lamp ballasts	100-350 metric tons	400 to 1,500	Continual release of lower concentrations, with high concentrations released when the ballast fails.	Yes	In school buildings as part of energy efficiency improvements.
small capacitors	1-35 metric tons	3 to 150	Disposal in landfills from a variety of old appliances.	Yes	
other closed uses		unknown		Yes	
caulk	87 metric tons	160	Continual release of lower concentrations into the air, with high concentrations released when materials are disturbed.	No	Remodeling and demolition, especially in schools.
other open uses		unknown		No	
Current generation					
pigments and dyes	N/A	0.02 to 31 ^a	Continual release of lower concentrations, with higher concentrations released during recycling.	No	Identify and promote safer alternatives.
other inadvertent generation	N/A	900	Concerns about both continual releases and potential large releases.	No	Identify processes and products first and then identify and promote safer alternatives.
residential waste burning	N/A	199	Released to air and already addressed by current regulations.	No	
commercial marine vehicles	N/A	0.4	Released to air and already addressed by current regulations.	No	

a. This estimate is for PCB-11, although additional congeners are present.

Recommendations for New Actions

The goal of a CAP is to recommend actions to protect human health and the environment. Averting toxic exposures and avoiding future costs is the smartest, cheapest, and healthiest approach. The priority recommendations address the largest sources, largest reservoirs, uncontrolled sources, protect the most people, or protect especially vulnerable children, in the context of existing programs, costs, and available technology. Ongoing permitting, cleanup, and other actions are crucial to any efforts on PCBs. The following recommendations are for new actions in addition to our existing efforts to reduce PCBs.

The recommendations are based on an evaluation of the following factors associated with implementing the action: 1) environmental and human health benefits, 2) economic and social impacts, 3) feasibility, 4) availability and effectiveness of safer substitutes, and 5) consistency with existing federal and state regulatory requirements.

Historic PCB-Containing Building Materials

1. Identify PCB-containing lamp ballasts in schools and other public buildings. Encourage replacement with more energy efficient PCB-free fixtures.

Goal: Remove remaining PCBs lamp ballasts from schools and other publically owned buildings.

Before 1979 PCBs were widely used in fluorescent lamp ballasts. PCB-containing lamp ballasts still in use should be identified and replaced with more energy efficient lighting. These ballasts have outlived their useful lives and are at high risk for failing (dripping, smoking, and catching fire). Ballast failures can expose children to concentrated PCB oils and elevated PCBs in air. Low concentrations of lower chlorinated PCB congeners are continually released from lamp ballasts. When ballasts fail, high concentrations of a broader spectrum of congeners are released, so it is important to find and remove the lamp ballasts before they fail.

There is no easily accessible source of information on how many of our approximately 9,000 school buildings are of the age and construction type likely to have PCB-containing lamp ballasts. The first step is to conduct a survey on schools (and other public buildings as time and resources allow) to identify buildings most likely to contain PCBs based on age, type of construction and scope of any past remodeling. This data will be used to identify those buildings where PCB-containing light ballasts are likely still in use. Lamp ballasts with PCBs can then be identified through visual inspection.

Public money should be used to remove PCB-containing lamp ballasts from schools and other public buildings. Since 2009, the legislature has provided money to the Office of the Superintendent of Public Instruction (OSPI) and the Department of Commerce to support energy

efficiency measures in schools and other public buildings. It makes sense to combine PCB removal with increasing energy efficiency rather than create a new program just for removal of PCB-containing ballasts. If the grant programs are not funded, the legislature should establish a fund to help offset the costs of replacing PCB-containing lamp ballasts. Schools with PCB-containing lamp ballasts will be provided with information about the importance of removing these ballasts and referred to OSPI (or Washington State Department of Health and other available resources) to replace these fixtures with more energy-efficient lighting. Environmental justice will also be considered in setting priorities for removing PCB-containing lamp ballasts.

2. Develop and promote Best Management Practices (BMPs) to contain of PCBs in building materials currently in use and those slated for remodel or demolition.

Goal: Reduce exposure to people from PCBs in historic building materials and prevent PCBs in building materials from getting into stormwater.

Ecology should work to prevent PCBs currently in building materials from being released into the environment. Historically, PCBs were used at high levels in some caulks and paints. Studies in other areas have shown the widespread occurrence of PCB-containing caulk in buildings from about 1950-1980, especially masonry buildings, and smaller sampling efforts in Washington support this conclusion. There is some information about PCB-containing building materials in the Duwamish basin and other information from source tracing, such as PCBs in sidewalk and building caulk in Tacoma.

Based on available data in Washington, other government programs, and the scientific literature, Ecology would develop BMPs for containing PCBs to prevent exposure during the life of the building and during remodeling or demolition. Lower concentrations of lower chlorinated congeners are continually released from caulk and paint, with higher concentrations of a broader spectrum of congeners released when the materials are disturbed. Ecology should also provide education and outreach on BMPs to local governments and those in the building trades.

While Ecology is working on BMPs, it should also support assembling existing information into a PCB Source Control Guidance Manual that can aid Local Source Control work to identify and control sources of PCBs. PCB source identification work has been performed by a number of urban waters programs around the Northwest. To date, the lessons learned from each of these programs has not been synthesized and summarized for the benefit of future pollution prevention efforts at the state and local level

3. Assess schools and other public buildings for the presence of PCB-containing building materials.

Goal: Reduce children's exposure to PCB-containing building materials in schools.

Goal: Prevent PCBs in building materials from getting into stormwater.

Many historical building materials, such as caulk and paint, have been found to contain high levels of PCBs. These materials are more common in industrial buildings, including schools, compared to residential buildings. It makes sense to focus on schools for testing and remediating these materials, as children are more sensitive to PCBs and the buildings are usually publically owned. Washington has not tested schools for PCBs, but other states have found high levels of PCB contamination in schools.

The first step in Recommendation #1 is to get information on how many of our approximately 9,000 school buildings are of the age and construction type likely to have PCB-containing materials. The information would be used to prioritize schools for testing, pending the availability of funding to either contain or remediate PCBs that pose a risk for children and teachers. A similar approach should be used to assess other public buildings once the assessment and remediation of schools is complete.

Ecology would initially focus on determining how many schools are likely to contain PCBs in historic building materials, narrow that list with visual inspections and then physical testing to determine the scope of the problem in Washington. This will determine how much time and money will be required for remediation and allow for long term planning, including funding. As Ecology learns more about PCB-containing building materials in Washington schools and other buildings, that information will be used to improve efforts to locate and remediate buildings. Environmental justice will also be considered in setting priorities for removing PCB-containing building materials.

Current Manufacturing Processes

4. Learn more about what products contain PCBs and promote the use of processes that don't inadvertently generate PCBs.

Goal: Reduce newly generated PCBs in manufacturing processes.

In 1982, the Environmental Protection Agency (EPA) identified 70 manufacturing processes likely to inadvertently generate PCBs. Little is known about most of this potentially large source of uncontained PCBs, including which congeners are produced. More information is known about PCBs in pigments and dyes, which are known to be released into the environment in stormwater, effluents from municipal treatment works, and effluents from pulp mills re-pulping post-consumer paper. Unpermitted non-point releases, such as from consumer products, are becoming increasingly important to control to reduce overall PCB delivery. Ecology should

work with EPA, manufacturers, the Northwest Green Chemistry Center, and other partners to identify products likely to contain PCBs, including a workshop focused on bringing together the supply chain to look for solutions to the current PCBs in products issue.

Ecology should test identified products and give that information to the Department of Enterprise Services (DES) to assist them in implementing new purchasing policies (RCW 39.26.280) that provide a preference for products that do not contain PCBs. Government purchasing of non-PCB-containing products is an effective way to both identify products that don't contain PCBs and encourage suppliers to remove PCBs from their products. Once products are identified that contain fewer PCBs, the information will be available shared with other purchasers, such as by schools, cities and residents. Ecology should support other government and business entities that adopt similar purchasing policies to drive the market-demand for PCB-free products.

Ecology, the Washington State Department of Health (DOH), and DES should work together to educate purchasers and vendors in the state supply chain by developing a focus sheet that concisely outlines the problem and its potential impacts on compliance with water quality standards, as well as impacts on people and the ecosystem.

Ecology should begin with directing an alternatives assessment for pigments and dyes, based on the Interstate Chemicals Clearinghouse (IC2) Alternatives Assessment Guide. Businesses and other concerned stakeholders would be asked to participate in the alternatives assessment process. If there are currently no alternatives that do not generate PCBs, Northwest Green Chemistry should work to develop alternative processes.

In addition to investigating which products contain inadvertently generated PCBs and finding safer alternatives, Ecology and DOH should petition the federal government to reform current regulations under the *Toxics Substances Control Act* (TSCA). TSCA generally allow a maximum of 50 ppm of inadvertently generated PCBs in most products, while Washington standards under the *Clean Water Act* (CWA) to protect human health that allow only 0.00000017 ppm (170 ppq or parts per quadrillion) PCBs in water bodies. The TSCA allowance is over 294 million times greater than the CWA criteria for human health and it is suspected that the TSCA allowance is likely a pathway for new PCBs to enter the environment, resulting in a paradox between these regulatory structures that must be resolved. The lower CWA standards are based on protecting human health and what we know about the health effects of PCBs. The higher allowable level of PCBs in products leads to higher levels of PCBs in water, and the responsibility of PCB levels in water are borne by downstream permittees that are not generating PCBs. Allowable levels of newly generated PCBs in products must be lowered by the federal government in order to meet water quality standards to protect human health and the environment.

Historic Electrical Equipment

5. Survey owners of historic electrical equipment, including transformers and large capacitors.

Goal: Confirm estimates of EPA-regulated electrical equipment with more than 500 parts per million (ppm) PCBs, learn what is known about electrical equipment with PCBs greater than 2ppm, and find out when such electrical equipment is estimated to be replaced.

Before 1979, the majority of PCBs were produced for use in electrical equipment. Major industries and electrical utilities indicate that they have either already removed these potential sources or have plans to do so. Ecology should survey the state's 61 utilities and other owners of electrical equipment to confirm that this is the case and provide technical assistance for proper replacement and disposal.

Federal regulations focused on transformers with more than 500 ppm PCBs. According to industry, many of these transformers and other electrical equipment have already been disposed of, but we do not have updated inventories of this equipment to reflect this progress and target technical assistance to remaining equipment. To avoid spills or other unexpected releases, the users should know which pieces of equipment have PCBs and have a plan to remove all such pre-1979 equipment from service or an estimate on when they will be replaced during regular maintenance. This inventory would not include small capacitors. This survey would not require additional testing or disposal of equipment by a certain date. Owners would be asked what they know about detectable levels of PCBs in their equipment, using the industry standard detection level (currently 2 ppm) and when they expect all the equipment to be replaced based on their current maintenance practices. A statewide inventory will allow the state to confirm current inventories and target efforts to prevent releases of PCBs from this equipment. Ecology should also work with EPA to update EPA's 1998 inventory and more accurately reflect the PCB transformers that are no longer in use.

PCB concentrations in many pieces of electrical equipment are high compared to other sources, so relatively rare leaks and spills can release a significant amount of PCBs into the environment. While PCB spills from electrical equipment are cleaned up, there are some spills where PCBs enter the waterways before being cleaned up, such as from transformers that are located close to storm drains or water bodies.

Ecology should also investigate the possibility of providing state financial assistance to businesses, state agencies, cities, municipalities, and schools to accelerate this process of collecting and properly disposing of equipment with concentrated PCBs.

Multi-Source

6. Expand environmental monitoring to identify any new areas requiring cleanup and investigate air deposition.

Goal: Find areas with highly concentrated PCBs and clean them up to prevent the wider release of PCBs.

Goal: Find out more about distribution of PCBs in the state to prioritize future actions.

Ecology should expand environmental monitoring of water, fish tissue, and sediment to identify PCB hot spots. For example levels of PCBs in fish were high enough to prompt Oregon and Washington to issue a joint consumption advisory for select species from Bonneville Dam upstream to McNary Dam. This led to the discovery of an historical landfill of electrical equipment on Bradford Island near Bonneville Dam on the Columbia River. This site is currently a federal Superfund site. A number of fish sampling efforts in the Columbia basin (CRITFC, Hanford Corridor Study and Ecology's Freshwater Fish Contaminant Monitoring Program) found other areas (mid-Columbia and Snake River) with elevated levels of PCBs and a number of hydroelectric facilities. To our knowledge, no work has been done to identify sources of contaminants in these areas. The proposed monitoring would conduct sampling to determine if contaminant sources exist in areas with a focus on hydroelectric facilities. Mapping and prioritization of historical information on the location of potential sites, such as landfills, industrial sites, railroad switching yards, etc., should also be used to find potential sites. Newly identified sites would be prioritized for cleanup using existing procedures.

In addition to identifying new hot spots, Ecology should continue its trend monitoring to show changes in PCBs in the environment and organisms over time.

Air deposition is a potentially significant pathway for PCBs to move into the environment. Ecology should investigate monitoring air deposition to assess the relative importance of this pathway.

7. Conduct a public educational campaign.

Goal: Provide information to residents about ways they can minimize exposure.

Goal: Raise awareness of the problems associated with current and past production of PCBs.

Goal: Educate residents to identify and address possible household sources of PCBs.

Ecology and DOH should work together with local entities to help residents, people who fish, schools, local governments, and businesses understand the risks associated with PCB exposure and ways to reduce risks, including the availability of safer alternatives.

The public educational campaign will include perspectives on public health risks and information on where exposures to PCB are most likely. It will also include advice on how individuals can

minimize their own exposures to PCBs. The campaign will include where to look for potential sources of PCBs in households, such as in old appliances, electrical equipment, and building materials. It will also teach the public how to safely remove and dispose of these materials to prevent PCB releases.

8. Conduct a study on which PCB congeners are present in Washington residents.

Goal: Learn more about PCB congeners to which Washington residents are exposed.

Goal: Find out more about the distribution of PCBs in Washington to prioritize future actions.

Within available resources, DOH should conduct biomonitoring of Washington residents for PCBs including PCB-11 and other inadvertently produced PCBs associated with dyes, pigments, and printing inks. This would be in tandem with learning more about what other processes produce certain PCB congeners. Use the data to better understand 1) the extent of total human exposure from multiple potential pathways and 2) the relative contribution of these congeners to human body burden of PCBs. In addition, use the data to estimate the statewide distribution of PCBs in Washington residents. This will provide a better baseline than national data, given the elevated levels of PCBs in local fish populations and relatively high fish consumption in a number of Washington communities and regions.

Summary of Recommendations

1. Identify PCB-containing lamp ballasts in schools and other public buildings. Encourage replacement with more energy efficient PCB-free fixtures.
2. Develop and promote Best Management Practices (BMPs) to contain PCBs in building materials currently in use and those slated for remodel or demolition.
3. Assess schools and other public buildings for the presence of PCB-containing building materials.
4. Learn more about what products contain PCBs and promote the use of processes that don't inadvertently generate PCBs.
5. Survey owners of historic electrical equipment, including transformers and large capacitors.
6. Expand environmental monitoring to identify any new areas requiring cleanup and investigate air deposition.
7. Conduct a public educational campaign.
8. Conduct a study on which PCB congeners are present in Washington residents.

Implementation Steps

The recommendations outline a set of first steps in a long-term plan to reduce PCB releases and exposures. Due to the magnitude and diversity PCB sources, many of the approaches will take significant commitments of time and money to implement effectively. In addition, Ecology and DOH can support other agencies, but it is up to the other agencies to carry out some of the recommendations.

Ecology focuses on prevention, which is the smartest, cheapest, and healthiest approach to reducing PBTs. Our priority is actions that result in the biggest reduction in exposure to the most sensitive receptors. However, sometimes other opportunities to reduce PCBs may arise and it makes sense to reduce all sources of PCBs where possible.

Ecology will continue our existing programs on PCBs to the environment, such as cleanup, stormwater management, and permits. DOH will also continue their existing programs, including fish advisories and working with residents to reduce their exposures. Expanding or increasing programs will require additional funds. Ecology and DOH will work on acquiring additional funds, but cannot predict when we will be able to obtain them.

Ecology and DOH will seek resources to implement the following recommendations in:

FY16-17

Recommendation 1. Survey and assess PCB-containing lamp ballasts in schools and other public buildings. Encourage replacement with more energy efficient PCB-free fixtures.

Recommendation 2. Develop and promote Best Management Practices (BMPs) for containment of PCB-containing materials in buildings currently in use and those slated for demolition.

Recommendation 4. Learn more about what products contain PCBs and promote the use of processes that don't inadvertently generate PCBs. This will begin with an alternatives assessment on PCBs in pigments. Use this information to continue to request reforms of PCB regulations under TSCA.

Recommendation 5. Survey owners of historic electrical equipment.

Recommendation 6. Expand environmental monitoring to identify any new areas requiring cleanup.

Recommendation 7. Collaborate with DOH to conduct an educational campaign.

FY18 -21

Recommendation 3. Assess schools and other public buildings for the presence of PCB-containing building materials. This work will start once school buildings have been surveyed (Recommendation 1) and the BMPs have been developed (Recommendation 2).

Recommendation 4. Learn more about what products contain PCBs and promote the use of processes that don't inadvertently generate PCBs. Ongoing work will focus on determining other processes that inadvertently generate PCBs and alternatives that do not generate PCBs. Ongoing work to support reforms of PCB regulations under TSCA.

Recommendation 6. Expand environmental monitoring to identify any new areas requiring cleanup. This project is expected to be finished in FY18.

Recommendation 7. Conduct an educational campaign. This education and outreach will be ongoing past FY17.

Recommendation 8: DOH will seek resources to design and conduct biomonitoring.

General Chemical Information

Summary

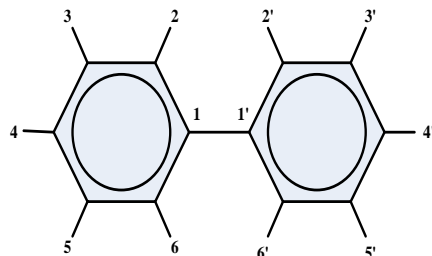


Figure 1. PCB Structure

Polychlorinated biphenyls (PCB) are a family of man-made chemicals consisting of two benzene rings joined together and containing one to 10 chlorine atoms attached to the benzene rings. There are 209 possible combinations of chlorine positions, called congeners. Depending upon the amount of chlorine present, PCBs appear as oily liquids to white crystalline solids and hard non-crystalline resins (HSDB, 2013). PCBs are hydrophobic and bind to particles. Due to their non-flammability, chemical stability, high boiling point and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and many other industrial applications (EPA 2013a).

From 1929 to 1979, 700,000 tons (or 1.4 billion lbs or 600,000 metric tons) of PCBs were commercially manufactured in the US (EPA 1997a). Most of the PCBs in the US were manufactured by Monsanto, which continued manufacture in the US until 1979 when US production stopped. PCBs were not typically manufactured as individual congeners but as mixtures called Aroclors. Individual Aroclor mixtures were manufactured using specific chemical processes imparting varying chemical characteristics such as vapor pressure, solubility, viscosity, amount of chlorination, etc. that produced a unique distribution of congeners in the different Aroclor mixtures. (HSDB, 2013) Much of the research and discussion on PCBs is centered upon the specific Aroclor mixtures. The 1976 Toxic Substances Control Act (TSCA) prohibited manufacture, processing, and distribution of PCBs. Some legacy uses of PCBs were allowed to continue.

PCBs are identified as persistent, bioaccumulative and toxic (PBT). Because of their persistence, PCBs continue to be found in the environment and contamination from legacy sources remains a problem. In addition, PCBs are not prohibited in some products at concentrations below 50 ppm. PCB concentrations of less than 50 ppm are considered to be “PCB-free.” Recent evidence has also indicated that PCBs may be found as contaminants in a wide range of consumer products because of the presence in several pigments and dyes (Hu *et al.* 2010, Rodenburg *et al.* 2010)

Physical and Chemical Properties of PCBs

A summary of typical characteristics for PCBs can be found in Table 2 (ATSDR 2000).

In general, PCB compounds range from heavy oily liquids to sticky resins, or melting crystalline solids depending upon the amount of chlorine present. These man-made compounds are odorless, colorless to light yellow or amber, and very stable and have relatively low volatility at ambient temperatures. PCBs were attractive in many applications because they resist breakdown at high temperatures or from aging, or oxidation. They persist in the environment since they do not easily biodegrade. PCBs are hydrophobic and thus do not dissolve well in water. As hydrophobic and very stable compounds, PCBs may volatilize from water despite their low vapor pressure. PCBs also easily adsorb onto organic particles in soils, sediments, biological systems, or water. (Panero *et al.* 2005) These organic particles can be transported long distances and has been shown as one of the reasons PCBs are distributed throughout the planet including remote areas.

Washington State's PBT Rule (WAC 173-333) defines persistence, bioaccumulation, and toxicity:

- The criterion for persistence is the half-life (the time it takes for half of the chemical to breakdown) of the chemical in water, soil, or sediment is greater than or equal to 60 days.
- The criterion for bioaccumulation is either:
 - The bioconcentration factor (BCF) or bioaccumulation factor (BAF) in aquatic species for the chemical is greater than 1,000.
 - In the absence of such data, the log-octanol water partition coefficient ($\log K_{ow}$) is greater than five.
- In order for a chemical to be considered toxic, it must meet at least one of the following criteria:
 - Be a carcinogen, a developmental or reproductive toxicant, or a neurotoxicant.
 - Have a reference dose or equivalent toxicity measure less than 0.003 mg/kg/day.
 - Have a chronic no-observed-effect concentration (NOEC) or equivalent toxicity measure less than 0.1 mg/L or an acute NOEC or equivalent toxicity measure less than 1.0 mg/L.

Many but not all PCB congeners are persistent and bioaccumulative as defined in Washington's PBT Rule. Table 2 demonstrates persistence and bioaccumulation for a series of PCBs, one from each of the ten homolog groups as predicted by EPA's PBT Profiler (EPA 2012b). PCBs are often grouped by the total number of chlorine atoms and a group with the same number of chlorines is called a homolog. Washington's PBT characteristics are included in the bottom of the table (WAC 173-333). Table 4 (IPCS 1995) provides ranges of characteristics for congener groups and also includes Washington's PBT characteristics on the bottom of the table.

Although the information in Table 2 is modeled data, which should not be confused with analytical results, the PBT Profiler results do demonstrate some trends. In general, persistence as indicated by the half-lives increases as the number of chlorine atoms increase. The tendency to bioaccumulate increases until the molecular structure of the PCB becomes large enough that the amount of bioaccumulation plateaus and begins to decrease. This plateauing is a direct result of the size of the PCB molecule, which can restrict transport through cell walls. Although all PCBs shown meet Ecology's persistence criterion, some of the mono-substituted may have sufficiently low bioaccumulation factors (BCF) that they may not meet Ecology's PBT criteria.

Table 2. Summary of Typical PCB (Aroclor) Physical Characteristics (from ATSDR 2000)

Property	Aroclor 1254	Aroclor 1260	Aroclor 1262	Aroclor 1268
Molecular weight	328	357.7	389	453
Color	Light yellow	Light yellow	No data	Clear
Physical state	Viscous liquid	Sticky resin	No data	Viscous liquid
Melting point, °C	No data	No data	No data	No data
Boiling point, °C	365 - 390	385 - 420	390 - 425	435 - 450
Density, g/cm ³ , 25 °C	1.54	1.62	1.64	1.81
Odor	Mild hydrocarbon	No data	No data	No data
Solubility:				
Water, mg/L	0.012, 0.57 (24°C)	0.0027, 0.08 (24°C)	0.052 (24°C)	0.300 (24°C)
Organic solvent(s)	Very soluble	Very soluble	No data	Soluble
Partition coefficients:				
Log K _{ow}	6.5	6.8	No data	No data
Vapor pressure, mm Hg at 25 °C	7.71x10 ⁻⁵	4.05x10 ⁻⁵	No data	No data
Henry's law constant, atm-m ³ /mol at 25 °C	2.0x10 ⁻³	4.6x10 ⁻³	No data	No data
Flashpoint, °C (Cleveland open cup)	No data	No data	195 °C	195 °C
Flammability limits, °C	None to boiling pt	None to boiling pt	None to boiling pt	None to boiling pt
Conversion factors				
Air (25 °C)	1 mg/m ³ = 0.075 ppm	1 mg/m ³ = 0.065 ppm	1 mg/m ³ = 0.061 ppm	1 mg/m ³ = 0.052 ppm

Table 3. EPA PBT Profiler Estimates of Persistence and Bioaccumulation for Select PCB congeners

PCB	Congener number	CAS	Half-Life (days)				BCF ¹
			Water	Soil	Sed.	Air	
4-Chlorobiphenyl	PCB-3	2051-62-9	38	75	340	4.2	510
3,3'-Dichlorobiphenyl	PCB-11	2050-67-1	38	75	340	3.9	5,400
2,3,4'-Trichlorobiphenyl	PCB-22	38444-85-8	60	120	540	15	6,700
2,3',5,5'-Tetrachlorobiphenyl	PCB-72	41464-42-0	180	360	1,600	13	27,000
2,2',4,4'5-Pentachlorobiphenyl	PCB-99	38380-01-7	180	360	1,600	13	40,000
2,3,3',4,4',5-Hexachlorobiphenyl	PCB-156	38380-08-4	180	360	1,600	75	26,000
2,3,3',4,4',5,6'-Heptachlorobiphenyl	PCB-190	41411-64-7	180	360	1,600	130	12,000
2,2',3,3',4',5,5',6'-Octachlorobiphenyl	PCB-199	52663-75-9	180	360	1,600	290	5,900
2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl	PCB-207	52663-79-3	180	360	1600	370	2,900
Decachlorobiphenyl	PCB-209	2051-24-3	180	360	1,600	880	12,000
WA PBT Characteristics			> 60	> 60	> 60		>1,000

BCF = Bioconcentration Factor; half-life = the amount of time it takes for the concentration of a chemical to diminish to half its original value; N/A = Not Applicable

Table 4. PCB Homolog Chemical properties (IPCS, 1995)

Congener Group	CASRN	Molecular weight (g/molecular)	Vapour Pressure (Pa)	Water Solubility (g/m ³)	log K _{ow}
Monochlorobiphenyl	27323-18-8	188.7	0.9-2.5	1.21-5.5	4.3-4.6
Dichlorobiphenyl	25512-42-9	223.1	0.008-0.60	0.06-2.0	4.9-5.3
Trichlorobiphenyl	25323-68-6	257.5	0.003-0.22	0.015-0.4	5.5-5.9
Tetrachlorobiphenyl	26914-33-0	292.0	0.002	0.0043-0.010	5.6-6.5
Pentachlorobiphenyl	25429-29-2	326.4	0.0023-0.051	0.004-0.02	6.2-6.5
Hexachlorobiphenyl	26601-64-9	360.9	0.0007-0.012	0.0004-0.0007	6.7-7.3
Heptachlorobiphenyl	28655-71-2	395.3	0.00025	0.000045-0.000	6.7-7
Octachlorobiphenyl	55722-26-4	429.8	0.0006	0.0002-0.0003	7.1
Nonachlorobiphenyl	53742-07-7	464.2	-	0.00018-0.0012	7.2-8.16
Decachlorobiphenyl	2051-24-3	498.7	0.00003	0.000001-0.000	8.26
WA PBT Criterion					>5

log K_{ow} = natural log of the octanol/water coefficient

¹ EPA's PBT Profiler defines the [bioconcentration factor \(BCF\)](#) as '... a measure of the ability for a water-borne chemical substance to concentrate in fatty tissue of fish and aquatic organisms relative to its surroundings. EPA defines bioconcentration as the net accumulation of a substance by an aquatic organism as a result of uptake directly from the ambient water through gill membranes or other external body surfaces (60 FR 15366).'

Stability of Ring Structure and Carbon to Halogen Bond

The chemistry and related stability of ring compounds was discussed extensively in the Polycyclic Aromatic Hydrocarbon (PAH) Chemical Action Plan (CAP) (Ecology, 2012a). Benzene (cyclohexa-1,3,5-triene)² is cyclohexane with three double bonds equally spaced throughout the molecule. Unlike compounds where the electrons forming the double bonds are localized around specific carbon atoms, the electrons in benzene's double bonds are equally shared among all six-carbon atoms. This is a defining characteristic of aromatic compounds. Benzene is typically represented by chemists as a six-carbon ring with a circle inside to represent the sharing of all electrons equally among the carbon atoms (Figure 2):

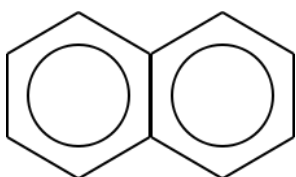


Figure 2. Chemical abbreviation for benzene

The most common theory currently accepted by chemists is that this sharing of electrons accounts for the thermodynamic stability of benzene and other aromatic compounds. Other theories have been promulgated (Cooper *et al.*, 1986) but are not currently widely accepted. Regardless, the increased stability of benzene and benzene-based compounds like PCBs can be attributed to the unique ringed structure and sharing of electrons throughout the molecule.

PCBs have another feature that contributes greatly to their stability. Carbon and chlorine form a very strong bond and the amount of energy needed to break apart the bond is higher than most other covalent bonds. The strength of this bond greatly increases the ability of PCBs to persist in the environment. Persistence is also related to the number of chlorine atoms with increasing degree of persistence with increasing chlorine mass. Comparatively, the mono- and di-chlorobiphenyls are less persistent than the larger congeners; however, all PCBs meet the definition of persistence (see Table 3 for examples).

Naming of PCB congeners

PCBs have a variable structure with two benzene rings joined together. Each benzene ring can have one to five chlorine atoms attached. The number and location of the chlorine atoms attached to the biphenyl ring determine the physical properties and characteristics of the PCB congener.

² The formal name for benzene describes a cyclical compound (cyclo) with six carbons (hexa) and three (tri) double bonds (ene). The '1,3,5' indicates which carbon atoms contain the double bond. Given the structure, the double bonds are represented as between the carbons 1 & 2, 3 & 4 and 5 & 6, although in reality the electrons are equally shared with all of the carbons on the ring.

The position of the chlorine atoms are differentiated by using 2 through 6 for one benzene atom and 2' (two prime) through 6' (six prime) for chlorine atoms on the second benzene ring. The naming convention assumes that the two benzene molecules are joined together at the 1 and 1' position. See Figure 3 for the carbon numbering.

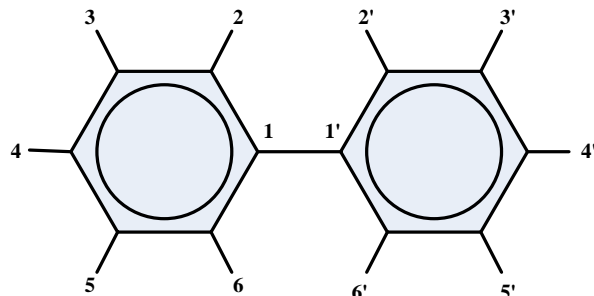


Figure 3. PCB Structure

This naming convention allows chemists to identify the structure of specific PCB congeners. For example, PCB-11 (3,3'-dichloro-1,1'-biphenyl or 3,3'-dichlorobiphenyl) contains two chlorine atoms in the 3 and 3' position. Unless indicated otherwise, a hydrogen atom is located on the benzene ring in all the unmarked locations.

Because it is possible for the PCB-11 molecule to rotate around the 1-1' carbon bond, there is no chemical difference between the above structure and 3,5'-dichlorobiphenyl (Figure 4).

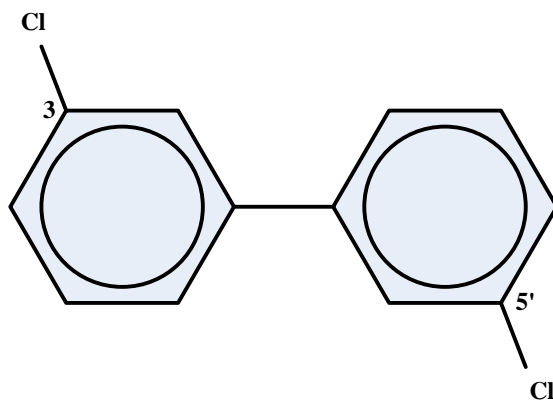


Figure 4. Alternate PCB-11 Structure

Several additional names potentially exist for PCB-11 including 5,3'-dichlorobiphenyl and 5,5'-dichlorobiphenyl. To prevent confusion, the naming convention uses the lowest numbers for these equivalent structures leading to PCB-11 being identified as 3,3'-dichlorobiphenyl. The naming convention can lead to confusion if an incorrect name is used.

Planar and non-planar PCBs

The issue of rotation can also have an impact on the relative toxicity of the PCB congeners. PCB congeners can either exist as planar where the two benzene rings are in the same plane or non-planar where the benzene rings are at 90 degree angle from each other. (ATSDR 2000). Planar and non-planar PCBs can have very different toxicity and this issue will be an important consideration in the relative toxicity of the PCB congeners discussed in subsequent sections.

A further naming convention using the terms ortho, meta and para are also used to identify the position of the chlorine atoms in a PCB molecule. If a chlorine atom is attached to the carbons adjacent to the 1 to 1' bond between the two benzene molecules (positions 2, 2', 6 or 6'), the chlorine atoms are said to be in the meta position. If the chlorine atom is attached to positions 3, 3', 5 or 5', they are in the ortho position. If they are attached to the 4 or 4' position, they are in the para position. Table 5 and Figure 5 indicate the position of the chlorine atoms in a PCB congener using the three naming conventions:

Table 5. Table of location of chlorine atoms

Name	Carbon atom location
Meta	3,3',5,5'
Ortho	2,2,6,6'
Para	4,4'

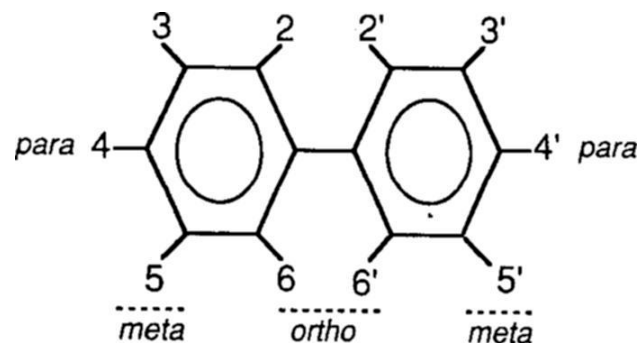


Figure 5. Location of meta, ortho, and para positions

The location of chlorine atoms plays an important role in the decomposition and toxicity of specific PCB congeners. Degradation reactions, for example, may selectively remove chlorine atoms from specific locations while PCB molecules with specific arrangements of chlorine atoms may have greater toxicity than related congeners.

Using the base structure (Figure 3), 209 different and unique PCBs (also known as congeners) can exist depending upon the number and position of chlorines involved. A list of these 209 congeners (EPA 2003) can be found in Appendix A. In addition to specific congeners, PCBs are also often grouped by the total number of chlorine atoms also called homologs (Table 4).

Historic Manufacturing

Historically, PCBs were not manufactured as specific congeners or homologs but as mixtures. Globally there was a wide range of product names for PCB mixtures (Appendix B). There were nine major mixtures in the US called Aroclors (Table 6). Prior to 1971, the Monsanto Chemical Company produced Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268. (ATSDR 2000). Figure 6 shows the amounts and uses of PCBs produced in the US between 1957 and 1971. (EPA 1987). Most Aroclor mixtures are named utilizing a code. Most begin with a 12 and the last two digits indicate the percentage amount of chlorine in the mixture. Therefore Aroclor 1254 contained 54% chlorine by weight, Aroclor 1216 contained 16% chlorine, etc. The only major Aroclor mixture that deviates from this system is 1016.

In 1971, Monsanto voluntarily restricted the uses of PCBs and subsequently produced only Aroclor 1016, 1242, 1254, and small quantities of Aroclor 1221. In 1974, the Monsanto Chemical Company produced slightly more than 40 million pounds (18 million kg) of Aroclor mixtures. Of the total volume of Aroclors sold in the United States for that year, the percentages of the market for each of the Aroclors were: Aroclor 1016, 64%; Aroclor 1242, 17.9%; Aroclor 1254, 17.9%; and Aroclor 1221, 0.1%. The estimated, cumulative production and consumption volumes (in millions of pounds) of PCBs in the United States from 1930 to 1975 were: total production, 1,400 (635 million kg); imports, 3 (1.4 million kg); domestic sales, 1,253 (568 million kg); and exports, 150 (68 million kg) (ATSDR 2000).

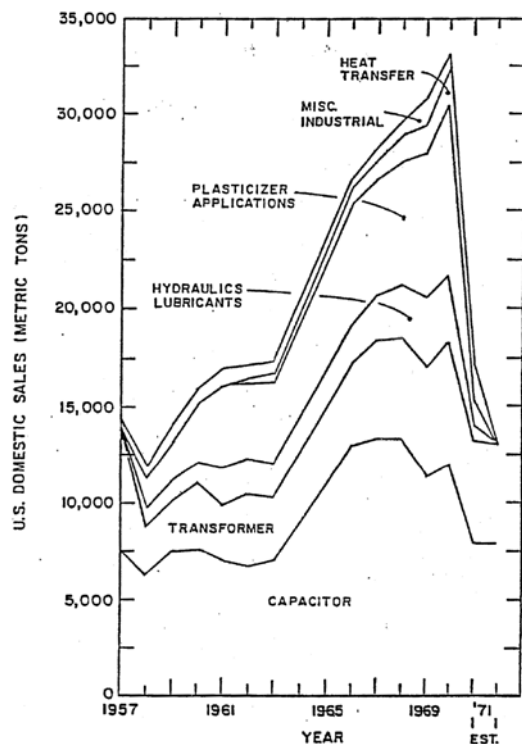


Figure 6. Monsanto Domestic sales of PCBs in the US by use (EPA 1987)

Table 6. Table of Aroclors (EPA 2013a)

CASRN	IUPAC Name
12674-11-2	Aroclor 1016
147601-87-4	Aroclor 1210
151820-27-8	Aroclor 1216
11104-28-2	Aroclor 1221
37234-40-5	Aroclor 1231
11141-16-5	Aroclor 1232
71328-89-7	Aroclor 1240
53469-21-9	Aroclor 1242
12672-29-6	Aroclor 1248
165245-51-2	Aroclor 1250
89577-78-6	Aroclor 1252
11097-69-1	Aroclor 1254
11096-82-5	Aroclor 1260
37324-23-5	Aroclor 1262
11100-14-4	Aroclor 1268
12767-79-2	Aroclor (unspecified)

These Aroclor mixtures can be fingerprinted depending upon the distribution of specific PCB congeners as indicated below (Figure 7) for the Aroclor 1260 mixture.

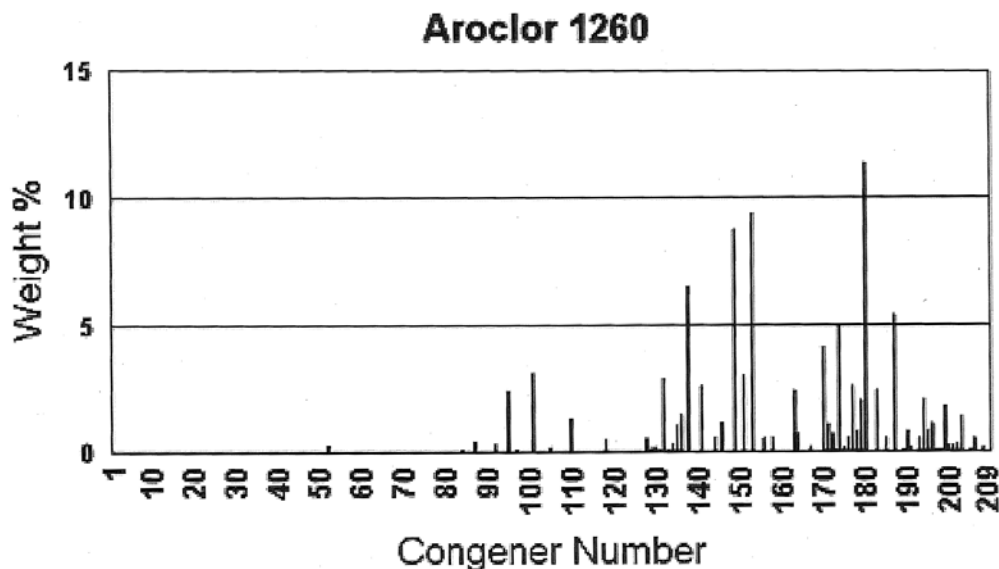


Figure 7. PCB Distribution in Aroclor1260 (EPA 2013e)

Additional fingerprints of common Aroclor mixtures can be found in Appendix C. Fingerprinting is an analytical technique that shows a distinct distribution of chemicals. Each Aroclor mixture has an identifiable distribution of PCB congeners. Aroclor fingerprinting is important as it can point toward potential PCB sources when contamination has been found in the environment. However, due to differential uptake by organisms, differential volatilization, and differential degradation, the congeners present in weathered mixtures in the environment will be different than the original congeners present in the Aroclors.

Analytical Methods

Because of their impact upon human health and the environment, considerable data exists on the presence of PCBs in a wide range of media. Historically, analytical methods were developed based upon the Aroclor fingerprints or values for total PCB concentrations. Recently, more sensitive and detailed congener-specific analyses have been developed to enable more detailed study of PCBs in the environment. PCBs are regulated under the Toxics Substances Control Act (TSCA), other Federal regulations (EPA 2013f) and state regulations such as Washington State's Dangerous Waste Regulations (WAC 173-303). Special analytical methods have been developed to meet these regulatory requirements. Methods range from traditional gas chromatography (GC), more recent high resolution GC mass spectroscopy, to new immunoassay techniques.

Numerous methods (Table 7 from National Environmental Methods Index) have been developed to analyze PCBs in a wide range of media using techniques with variable costs and detection levels. Although the list is not complete, it is indicative of the variety and type of methods currently available to test samples for PCBs. In Table 7 "Source" refers to the organization that developed the method, although it may now be required by different regulations.

For the purposes of this CAP, the three most commonly used analytical methods will be discussed in more detail:

- Aroclor methods
- Congener specific methods
- Screening methods

Table 7. Methods developed to test for PCBs in a wide range of media (NEMI, 2013)

Method Number	Source	Method Descriptive Name	Detection Level	Instrumentation	Relative Cost
530021	Abraxis	PCBs by Immunoassay, Lower Chlorinated, Magnetic Particle	5 ppb	IA	\$
530011	Abraxis	Coplanar PCBs by Immunoassay, Microtiter Plate	14 ng/L	IA	\$
530001	Abraxis	PCBs by Immunoassay, Higher Chlorinated, Magnetic Particle	0.1 ppb	IA	\$
505	EPA-NERL	Pesticides and PCBs in Water GC-ECD	N/A	GC-ECD	\$\$\$
525.3	EPA-NERL	Organics in Water Using GCMS	N/A	GC-MS	\$\$\$
508A	EPA-NERL	PCBs by GC-ECD	N/A	GC-ECD	\$\$\$
508.1	EPA-OGWDW/TSC	Chlorinated Pesticides, Herbicides, and Organohalides in Water by GC-ECD	N/A	GC-ECD	\$\$\$
8082A	EPA-RCRA	Polychlorinated Biphenyls (PCBs) by GC	N/A	GC-ECD/ELCD	\$\$
508	EPA-TSC/NERL	Chlorinated Pesticides in Water Using GC-ECD	N/A	GC-ECD	\$\$\$
ET013	Envirologix	PCB (polychlorinated biphenyl) immunoassay	.3 µg/g	IA	\$
A00134	MWI	PCB (polychlorinated biphenyl) in water by immunoassay	.2 µg/L	IA	\$
A00134/A00137	MWI	PCB (polychlorinated biphenyl) in soils/sediment by immunoassay	.5 µg/g	IA	\$
130.10	NOAA NST	Organic contaminants in marine sediments by GC-ECD	.05 ng/g	GC-ECD	\$\$\$
130.11	NOAA NST	Organic contaminants in marine animal tissues by GC-ECD	.05 ng/g	GC-ECD	\$\$\$
SPMDs	USGS	Passive sampling of organic compounds in water, air, and soils/sediments by SPMDs	N/A	SPMD	\$\$\$\$
O-1104	USGS-NWQL	Organochlorine and organophosphorous compounds, dissolved	.01 µg/L	GC-ECD	\$\$\$
O-3104	USGS-NWQL	Organochlorine and organophosphorous compounds, total recoverable	.01 µg/L	GC-ECD	\$\$\$
O-5129-95	USGS-NWQL	Organochlorine Pesticides and Gross PCBs in Bottom Sediment by GC	50 µg/kg	GC-ECD	\$\$\$\$
525.2	EPA-NERL	Organics in Water Using GCMS	.11 µg/L	GC-MS	\$\$\$
1668a (Tissue)	EPA-OGWDW/TSC	Chlorinated Biphenyls in Tissue by HRGC/HRMS	.011 ng/g	GC-MS	\$\$\$\$
1668a (Water)	EPA-OGWDW/TSC	Chlorinated Biphenyls in Aqueous Samples by HRGC/HRMS	112 pg/L	GC-MS	\$\$\$\$
1668a (Soil/Sediment)	EPA-OGWDW/TSC	Chlorinated Biphenyls in Soil, Sediment, and Mixed Samples by HRGC/HRMS	.011 ng/g	GC-MS	\$\$\$\$
ECD = Electron capture detector		MS = Mass Spectroscopy	OGWDW = Office of Ground Water and Drinking Water		
		MWI = Modern Water Inc.			
ELCD = Electrolytic conductivity detector		NERL = New England Regional Laboratory	RCRA = Resource Conservation and Recovery Act		
GC = Gas Chromatography		NOAA = National Oceanographic and Atmospheric Association	SPMD = Semi-permeable membrane device		
HRGC = High Resolution Gas Chromatography		NST = National Standards and Trends	TSC = Technical Support Center		
HRMC = High Resolution Mass Spectroscopy		NWQL = National Water Quality Laboratory	USGS = United States Geological Survey		

Aroclor detection

EPA developed specific methods to comply with TSCA and other applicable legislation. In order to meet the requirements of the Resource Conservation and Recovery Act or RCRA, EPA developed Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, more commonly known as SW-846 (EPA 2012a). Included in SW-846 are two specific methods for analyzing PCBs in a wide range of media:

- Method 8082A: Polychlorinated Biphenyls (PCBs) by Gas Chromatography
- Method 8275A: Semi-volatile Organic Compounds (PAHs and PCBs) in Soils/Sludges and Solid Wastes Using Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS)

Method 8082A is the more traditionally used as one of the earliest methods developed to meet regulatory requirements and is responsible for much of the legacy data reported as Aroclor mixtures or specific PCB congeners identified in the method. Method 8082A is ‘... *used to determine the concentrations of polychlorinated biphenyls (PCBs) as Aroclors or as individual PCB congeners in extracts from solid, tissue, and aqueous matrices, using open-tubular, capillary columns with electron capture detectors (ECD) or electrolytic conductivity detectors (ELCD).*’ (EPA 2012a) The specific chemicals reported by this method (Table 8) are detected in the parts per billion (ppb) to parts per million (ppm) levels depending upon complexity of sample and matrix involved.

Congener detection

As technology improved and the need for congener specific analysis was identified, Method 1668C (USGS 2010) was developed. Method 1668 was created to analyze PCBs in water, soil, sediment, biosolids and tissue. It provides analytical results for ‘... *the 12 polychlorinated biphenyls (PCBs) designated as toxic by the World Health Organization (WHO): congeners 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189 [and] the remaining 197 CBs [chlorinated biphenyls], approximately 125 of which are resolved adequately on an SPB-octyl gas chromatographic column to be determined as individual congeners. The remaining approximately 70 congeners are determined as mixtures of isomers (co-elutions).*’ (EPA 2010) Method 1668 requires the use of a high-resolution mass spectrometer for detection and, therefore, is considerably more expensive than Method 8082. Method 1668, however, is becoming more common as concerns have been raised about PCBs from non-legacy sources and potential degradation products from legacy Aroclor mixtures. Detection limits for Method 1668 can be in the low part per quadrillion (PPQ) levels in clean water to ppb levels or higher depending upon complexity of sample and matrix involved.

It is important to note that PCB detection methods have improved over time. Current methods provide detailed data on specific congeners while earlier methods provided data on specific PCB mixtures and homologs. This improvement of analytical methods can prove challenging as it is

often difficult to compare data over time as the methods do not provide comparable information at similar detection levels.

Table 8. PCBs reported by Method 8082A (EPA 2012a)

Compound	CAS No.	IUPAC #
Aroclor 1016	12674-11-2	-
Aroclor 1221	11104-28-2	-
Aroclor 1232	11141-16-5	-
Aroclor 1242	53469-21-9	-
Aroclor 1248	12672-29-6	-
Aroclor 1254	11097-69-1	-
Aroclor 1260	11096-82-5	
2-Chlorobiphenyl	2051-60-7	1
2,3-Dichlorobiphenyl	16605-91-7	5
2,2',5-Trichlorobiphenyl	37680-65-2	18
2,4',5-Trichlorobiphenyl	16606-02-3	31
2,2',3,5'-Tetrachlorobiphenyl	41464-39-5	44
2,2',5,5'-Tetrachlorobiphenyl	35693-99-3	52
2,3',4,4'-Tetrachlorobiphenyl	32598-10-0	66
2,2',3,4,5'-Pentachlorobiphenyl	38380-02-8	87
2,2',4,5,5'-Pentachlorobiphenyl	37680-73-2	101
2,3,3',4',6-Pentachlorobiphenyl	38380-03-9	110
2,2',3,4,4',5'-Hexachlorobiphenyl	35065-28-2	138
2,2',3,4,5,5'-Hexachlorobiphenyl	52712-04-6	141
2,2',3,5,5',6-Hexachlorobiphenyl	52663-63-5	151
2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1	153
2,2',3,3',4,4',5-Heptachlorobiphenyl	35065-30-6	170
2,2',3,4,4',5,5'-Heptachlorobiphenyl	35065-29-3	180
2,2',3,4,4',5',6-Heptachlorobiphenyl	52663-69-1	183
2,2',3,4',5,5',6-Heptachlorobiphenyl	52663-68-0	187
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	40186-72-9	206

Screening methods

In response to a need by industry to test wastes quickly and cheaply, manufacturers developed screening methods to test specific waste types. These methods were reviewed and adopted by EPA into SW-846. Specifically, PCB applicable screening methods listed in SW-846 include:

- Method 9077: Test Methods for Total Chlorine in New and Used Petroleum Products (Field Test Kit Methods)
- Method 9078: Screening Test Method for Polychlorinated Biphenyls in Soil
- Method 9079: Screening Test Method for Polychlorinated Biphenyls in Transformer Oil
- Method 4020: Screening for Polychlorinated Biphenyls by Immunoassay

Method 9077 is '*... used to determine if a new or used petroleum product meets or exceeds requirements for total halogen measured as chloride. An analysis of the chlorine content of petroleum products is often required prior to their use as a fuel. The method is specifically designed for used oils, permitting onsite testing at remote locations by nontechnical personnel to avoid the delays for laboratory testing*' (EPA 2012a). It provides results ranging from 300 to 4,000 parts per million (ppm).

Method 9077, however, tests for total chlorine and cannot differentiate PCBs from other chlorinated species such as chlorinated solvents commonly used in industry. Methods 9078 and 9079 test specifically for PCBs. Method 9078 is '*...used to determine the amount of PCB (polychlorinated biphenyl) contamination in soils such as sand, gravel, loam, sediment, and clay, assuming that PCBs are the sole source of organic halogens in the sample.*' Detection levels range from 2 to 2,000 ppm PCBs. The method provides inaccurate results if other chlorinated species are present and should be used with caution. However, in those instances where PCB contamination is known, it provides a quick and easy method to determine the extent of contamination and is often used as a screening tool to limit the number of samples sent to a laboratory for more detailed analyses.

Method 9079 is '*... used to screen hydrocarbon based electrical insulating fluids for polychlorinated biphenyls (PCBs) at preset levels of 20, 50, 100, or 500 µg/g [ppm].*' The method is calibrated using Aroclor 1242 as a standard and results for other Aroclor mixtures may vary slightly. Method 4020 is '*... a procedure for screening soils and non-aqueous waste liquids to determine when total polychlorinated biphenyls (PCBs) are present at concentrations above 5, 10 or 50 mg/kg.*' Method 4020 only works on soils containing more than 0.625 ppm PCBs.

Used correctly, Methods 9078, 9079 and 4020 are specifically designed to help meet regulatory requirements. Simple PCB kits meeting the requirements of these methods include but are not limited to:

- Dexsil® Clor-N-Oil Field Test Kit³
- Dexsil® Clor-N-Soil Field Test Kit⁴
- Dexsil® Clor-d-TECT Field Test Kit⁵
- EnSys Field Test⁶
- RaPID Assay Field Test⁷

In addition to these wet chemical methods, several simple instrumentation and detection kits are also available to test for PCBs including, but are not limited to:

- Dexsil® L2000DX PCB/Chloride Analyzer System (LP-2000)⁸
- Hach® PCB in Soil Pocket Colorimeter II Test Kit⁹
- Hach® DR 2700™ Portable Spectrophotometer¹⁰

These field test kits are useful as they allow detection for PCBs in the field by individuals with limited technical knowledge and expertise.

³ More information available at: http://www.dexsil.com/products/detail.php?product_id=2, accessed 7/2013.

⁴ More information available at: http://www.dexsil.com/products/detail.php?product_id=4, accessed 7/2013.

⁵ More information available at: http://www.dexsil.com/products/detail.php?product_id=29, accessed 7/2013.

⁶ More information available at: <http://www.ttenviro.com/store/ensys>, accessed 7/2013.

⁷ More information available at: <http://www.ttenviro.com/store/rapid-assay>, accessed 7/2013.

⁸ More information available at: http://www.dexsil.com/products/detail.php?product_id=13, accessed 7/2013.

⁹ More information available at: <http://www.hach.com/pcb-in-soil-pocket-colorimeter-ii-test-kit/product-parameter-reagent?id=7640220978>, accessed 7/2013.

¹⁰ More information available at: <http://www.hach.com/dr-2700-portable-spectrophotometer/product?id=7640439006&callback=bp>, accessed 7/2013.

PCB Uses and Sources

Legacy

Historically, PCBs were used in closed systems such as electrical transformers and capacitors, partially closed uses such as heat transfer and hydraulic systems, and open systems such as surface coatings, adhesives, plasticizers, inks, insulating materials, and pesticides (UNEP 1999). PCBs were valued for their stability, inability to conduct electricity and anti-microbial effects. 60% of worldwide and 77% of US production was used in the production of transformers and capacitors and total worldwide production from 1929 to 1989 is estimated at 1.2 million tons (Tanabe 1988).

PCBs were intentionally added to some products in open applications where the PCBs are in direct contact with the environment and may be transferred from the product into the environment. Plasticizers were the most common use of PCBs in products such as PVC (polyvinyl chloride), neoprene and other chlorinated rubbers. PCBs have also been used in paints and surface coatings as flame retardants and adhesives as plasticizers (UNEP 1999). PCBs were often added to caulk and paint in the field at varying amounts.

Current levels in the environment are due to cycling of PCBs from these historical uses with additional releases of PCBs from legacy uses and new inadvertently produced by-products of chemical manufacture. Specific Aroclor mixtures were often used in specific applications (Table 9). Companies have found alternatives for most PCB uses.

Table 9. Historical Aroclor Uses (from ATSDR 2000)

End Use	Aroclor								
	1016	1221	1232	1242	1248	1254	1260	1262	1268
Capacitors	•	•				•			
Transformers				•		•	•		
Heat transfer				•					
Hydraulics/lubricants									
Hydraulic fluids			•	•	•	•	•		
Vacuum pumps					•	•			
Gas-transmission turbines		•		•					
Plasticizers									
Rubbers		•	•	•	•	•			•
Synthetic resins					•	•	•	•	•
Carbonless paper				•					
Miscellaneous									

End Use	Aroclor								
	1016	1221	1232	1242	1248	1254	1260	1262	1268
Adhesives		•	•	•	•	•			
Wax extenders				•		•			•
De-dusting agents						•	•		
Inks						•			
Cutting oils						•			
Pesticide extenders						•			
Sealants/caulks						•			

Inadvertent Generation in New Products

PCBs may be found as contaminants in a wide range of chemical processes involving chlorine and can be found in recycled materials contaminated with PCBs. As part of 1984 TSCA rulemaking on PCBs the EPA identified about 200 chemical processes that may inadvertently create PCBs and narrowed the list to 70 chemical processes that are likely to contain PCBs as contaminants from manufacturing processes (Panero *et al.* 2005, see Appendix D for list). Most of these chemical processes have not been evaluated to determine if PCBs are actually a reaction byproduct and present in the final product. In addition there are other processes that may inadvertently generate PCBs that are not on this list. Nor have these processes been analyzed to determine how inadvertently generated PCBs enters the consumer supply chain.

Recent studies on PCBs from pigment manufacturing have shown that PCBs can still be found in products. Many of these products contain PCBs as an impurity created during the production process. Inadvertent sources include contaminants or byproducts from manufacturing processes using chlorinated compounds either as a reaction component or solvent. As shown in Table 10, PCBs have been found in various pigments at substantial levels (EPA 1982b).

Table 10. PCBs congeners found in specific pigments (EPA 1982)

PCB Congeners	Pigment	Levels found (µg/g or ppm)
PCB-11	Diarylide yellow	70
PCB-209	Phthalocyanine green	40
Mix of penta- and hexa-	Phthalocyanine blue	90*

*Total of PCB congeners

According to one of the rules created by EPA to implement TSCA (49 FR 28172) products may contain low levels of PCBs if the certain conditions are met (see section on Regulations).

Over the last few years, researchers have begun to test consumer products for the potential presence of PCBs. Numerous organic pigments and dyes exist that may contain PCBs as an unintentional byproduct including diarylides (yellow and orange), naphtharylamides (oranges and reds), phthalocyanines (blue), and basic dye complex pigments (reds, violets, blues and greens) (Christie 2013). In general pigments are insoluble in their application medium and dyes are soluble, with inks mostly being used for textile coloration and pigments having broader uses (Christie 2013, Guo *et al.* 2014). Many of these pigments fall into the broad category of azo compounds. An azo compound contains one or more double-bonded nitrogen atoms (R-N=N-R') where R and R' are organic additions with varying degrees of complexity. Azo compounds are very efficient at absorbing light and emitting the radiation in specific wavelengths, thereby providing specific colors. Chlorinated compounds are often used in azo pigments as they can greatly increase the lifetime of the resultant product.

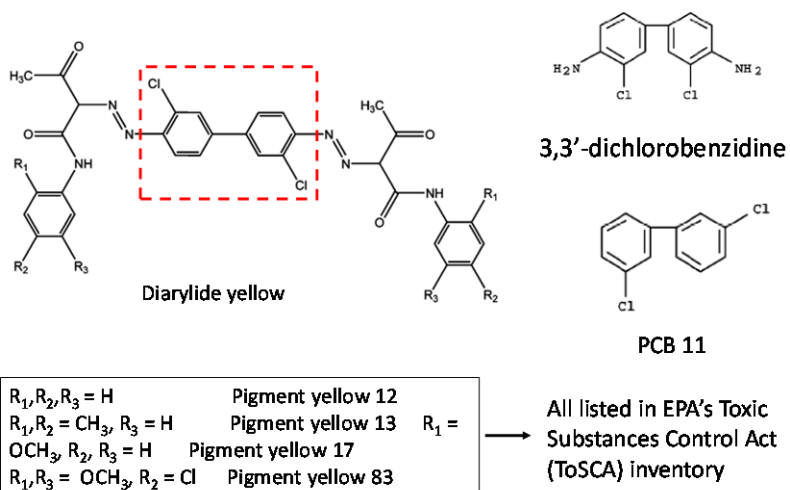
Hu and Hornbuckle (2010) conducted sampling of consumer paints containing specific azo (yellow) and phthalocyanine (blue and green) organic pigments and found PCB levels ranging from 2 to 200 ppb in 15 of 33 consumer paints tested. PCB-11 is also found in printed materials (Table 11) from various locations around the world (Guo *et al.* 2014).

Table 11. PCB-11 worldwide concentrations from printed materials

Printed Material (Country)	PCB 11 concentration (ng/g or ppb)
Black and white printed newspaper (Georgia)	1.6
Black and white printed newspaper (Moldova)	9.7
Black and white printed newspaper (China)	15
Color newspaper (Georgia)	6.5
Color newspaper (Moldova)	16
Food packaging box (Czech Republic)	6.8
Food packaging box (Ukraine)	5.0

As an example of dyes contaminated with PCBs, diarylide yellow comprises approximately 25% of the 250 million tons of organic pigments produced yearly worldwide (Rodenberg 2012) and testing has shown PCBs and especially PCB-11 are produced during pigment manufacture. PCB-11 is part of the structure of diarylide yellow (Figure 8) as indicated in the red box. PCB-11 can be produced either as a byproduct during the manufacturing process or from degradation of the pigment.

PCB 11 from Diarylide Yellow



(Basu et al. 2009)

Figure 8. Diarylide yellow and PCB-11 (Rodenburg, 2012)

In addition to PCB-11, purification of the inorganic pigment titanium dioxide (TiO_2) produces larger molecular weight PCBs as a byproduct (Rodenburg 2012). Chlorine is reacted at high temperatures with titanium dioxide (TiO_2) ores containing other metal oxides such as rutile (TiO_2) or ilmenite ($FeTiO_3$) to form titanium tetrachloride ($TiCl_4$) which as a liquid is easily collected. $TiCl_4$ is then reacted with oxygen to make pure TiO_2 (UNEP 2007). During this product process, the larger molecular weight PCBs are created as a reaction byproduct.

Titanium dioxide can also be produced by a sulphate process that does not generate PCB contamination. The sulfate process uses 2.4-3.5 tons of concentrated sulfuric acid (H_2SO_4) per ton of titanium dioxide and the process creates large amounts of acid waste that must be further treated. The chloride process does not generate spent acids and, therefore, creates less waste to be dealt with. (UNEP 2007)

Research is continuing on alternatives to the organic azo pigments. The main challenges faced with replacements (Christie 2013) are:

- Required color performance
- Required degree of transparency or opacity
- Level of fastness or permanence to light, solvents, heat, chemicals, etc. demanded by specific applications
- Cost effectiveness
- Acceptable toxicological and environmental profile.

Research is continuing and alternatives have been identified which appear to address many of these concerns (Christie 2013).

Combustion

Lastly, PCBs are formed through incomplete combustion of products containing carbon and a chlorine source (ATSDR 2000). Given the widespread use of chlorinated compounds such as polyvinylchloride for packaging, tubing, and other applications, incomplete combustion forms a wide range of halogenated compounds such as chlorinated dioxins and furans and PCBs. Most municipal incinerators are not effective in destroying PCBs and it is recommended that PCB-contaminated waste be burned at temperatures above 1,100 degrees Celsius and that care is taken with the temperature, residence time and turbulence of the waste in order to guarantee complete combustion (UNEP 1999). There is only one municipal solid waste incinerator in Washington.

Methods of Manufacturing

PCBs were first mentioned in a publication in Germany in the 1880s. The Swann Chemical Company in Anniston, Alabama was the first US company to manufacture PCBs commercially by bubbling benzene through molten lead to create biphenyl with subsequent chlorination of the biphenyl. Monsanto purchased the Swann Chemical Company in 1935 (Erickson and Kaley 2011).

Much has been written about the methods in which PCBs were manufactured (Panero *et al.* 2005, ATSDR 2000, Pomerantz 1978). Similar methods were used to manufacture PCBs with the main variable being the starting materials of biphenyl and naphthalene. The manufacturing process for Aroclors involved the ‘... *chlorination of biphenyl with anhydrous chlorine in the presence of a catalyst, such as iron filings or ferric chloride. The degree of chlorination, which determines the nature of the Aroclor, was controlled by the chlorine-contact time (range, 12–36 hours) in the reactor.*’ (ATSDR 2000)

Once the manufacturing process was complete, ‘*The crude product [was] blown with air, and a small amount of lime ... added to remove hydrogen chloride and ferric chloride. The resulting chlorinated mixtures [were] batch-distilled to remove color and traces of hydrogen chloride and ferric chloride*’ (HSDB 2013).

PCBs were also created using naphthalene which was ‘... *reacted to varying degrees with chlorine to produce a number of compounds designated by various trade names such as Aroclor*’ (HSDB 2013).

Environmental Transformation and Degradation

Although very stable in the environment, the major pathways for degradation (ATSDR 2000) are:

- Vapor phase degradation with hydroxyl radicals
- Photolysis in water
- Aerobic biodegradation (preferentially less chlorinated congeners)
- Anaerobic microbial degradation (more highly chlorinated congeners favored)

PCBs in the atmosphere undergo complicated reactions (Figure 9) primarily with hydroxyl radicals created when water absorbs sunlight and separates into hydroxyl ($\cdot\text{OH}$) and hydrogen ($\cdot\text{H}$) radicals. Reactions with hydroxyl radicals are most prevalent. A radical is an atom or chemical that has a net charge of zero (neither negative nor positive) but has less than the preferred number of electrons in its outer shell. This instability causes a radical to be very reactive (ATSDR 2000).

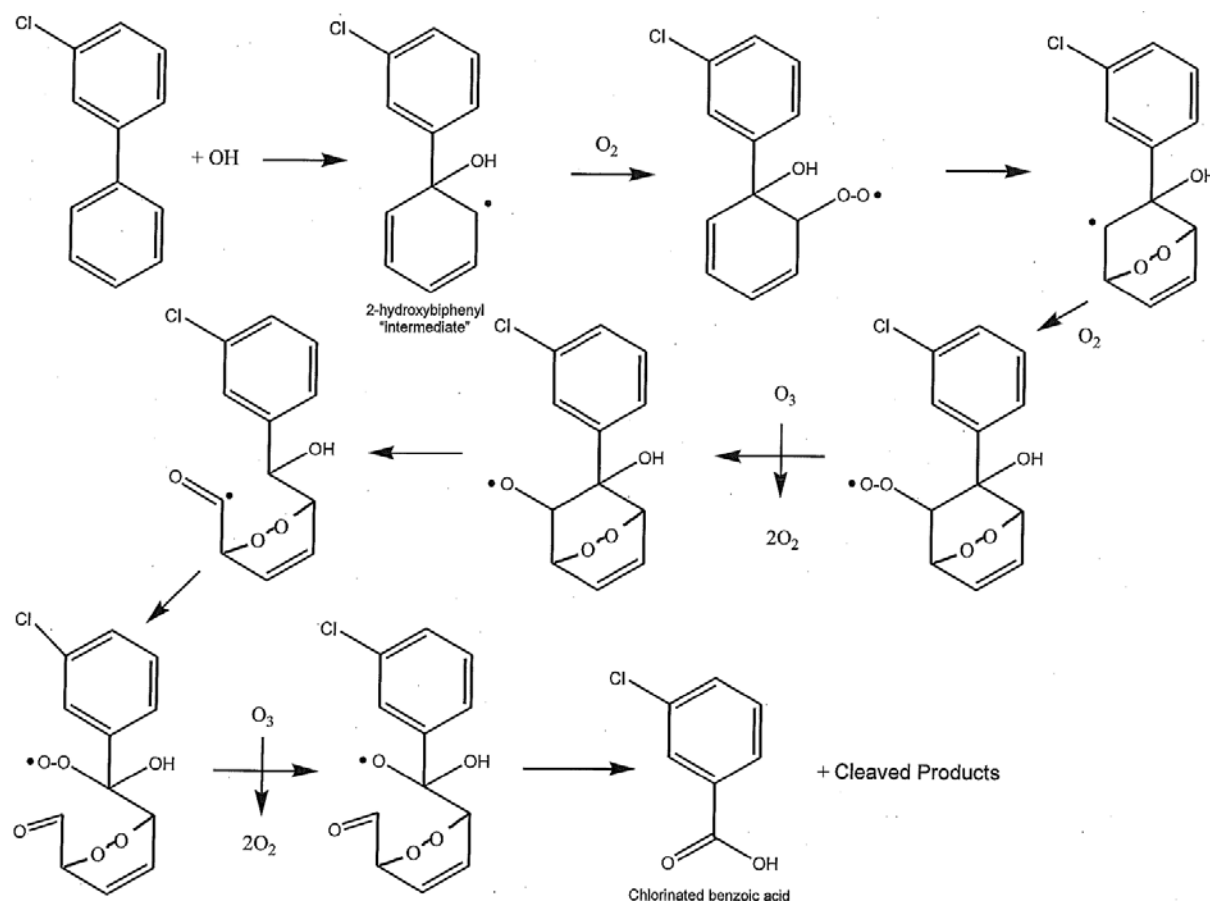
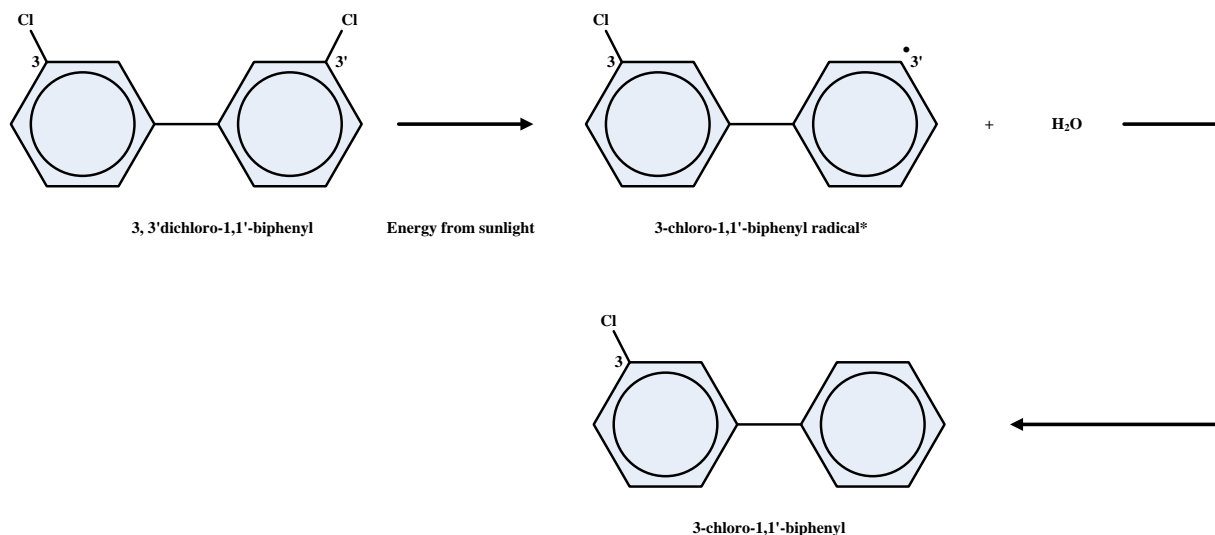


Figure 9. Hydroxyl photo-degradation pathways for PCBs in air (ATSDR 2000)

In water, photolysis is the primary pathway for degradation as other more common reaction mechanisms such as hydrolysis and oxidation do not appear to contribute substantially. In these reactions, a carbon to chlorine bond absorbs energy from sunlight and separates into PCB and chlorine radicals. The PCB radical reacts with water forming a stable PCB compound but with one less chlorine (Figure 10). This reaction is particularly important for the larger PCBs as the more chlorines present, the easier it is to cleave a carbon to chlorine bond. In large PCB molecules, cleavage occurs preferentially on the ring with the most carbons. (ATSDR 2000)



*Note: Although the radical is shown on the 3' position, the electron is actually dispersed throughout the benzene ring.

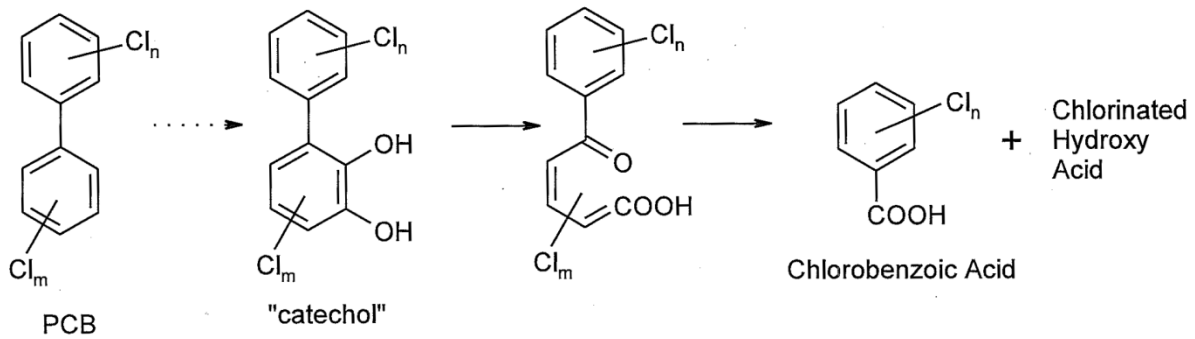
Figure 10. Photolysis of PCB-11

In sediment and soil, no abiotic process is known that significantly degrades PCBs. PCBs, however, have been found to degrade readily in both aerobic and anaerobic conditions. Both bacterial and fungal species have been shown to biodegrade PCBs using aerobic processes. Because of size restrictions, PCBs with 1 to 4 chlorine atoms are most likely to be degraded under aerobic conditions via a two step process (Figure 11). First, one of the two benzene rings is oxygenated and separated from the other ring. The remaining benzene ring is left as a chlorobenzoic acid. This combined process is called cometabolism.

After cometabolism has occurred, the remaining chlorobenzoic acid is further broken down into water and carbon dioxide (mineralization) in a series of reactions that continually add oxygen to the compound. Aerobic biodegradation of PCBs also occurs primarily in soil and surface sediments. Interestingly, PCBs with fewer chlorine atoms (1-3) degrade faster than those with more chlorine atoms. This causes a fractionating effect where less chlorinated species biodegrade first while those with higher levels of chlorine atoms are left behind for long-term build up in the environment. (ATSDR 2000)

Anaerobic degradation of PCBs is a much slower process compared with aerobic degradation and occurs primarily by reductive dechlorination where chlorine atoms are removed one after the other from a PCB molecule. At least eight distinct and complicated anaerobic pathways have been identified which may occur alone or in combination. Different pathways may favor chlorine in specific positions on the PCB molecule. (ATSDR 2000)

Cometabolism



Example of mineralization

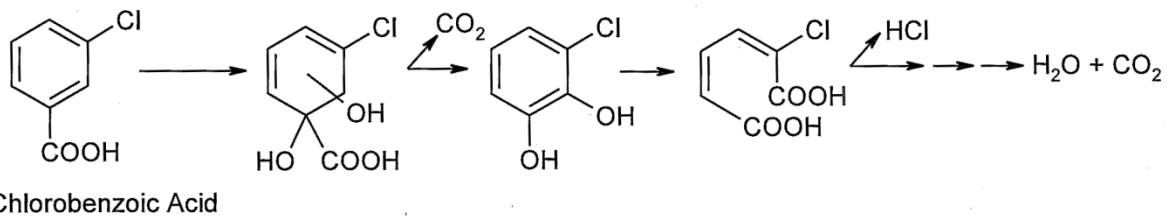


Figure 11. Pathways for Aerobic Degradation of PCBs (ATSDR 2000)

Production, Uses, and Releases

According to the PBT Rule (WAC 173-333) chemical action plans (CAPs) must include a section on “production, uses and releases” that contains information on the production of the chemical and estimates on the amount of the PBT used and released from all sources or activities in Washington.

From 1929 to 1979 the production of PCBs in the US was approximately 1.4 billion lbs (600,000 metric tons), with the largest use for electrical equipment (EPA 1997a). Monsanto, the primary manufacturer of PCBs in North America, voluntarily limited production to certain Aroclors in 1971 (ATSDR 2000) and commercial production was stopped by 1979 under TSCA.

Washington’s portion was estimated based on population size to give an estimate of the expected uses in Washington State.

Table 12. Industrial Uses of PCBs (1929-1975) from EPA 1997

PCB Use	Pounds (millions)	Percentage of Total	Washington’s portion (millions of pounds)	Washington’s portion (metric tons)
Capacitors	630	50.3%	13	5,700
Transformers	335	26.7%	7	3,040
Plasticizer uses	115	9.2%	2	1,040
Hydraulics and lubricants	80	6.4%	2	730
Carbonless copy paper	45	3.6%	1	410
Heat transfer fluids	20	1.6%	0.4	180
Petroleum additives	1	0.1%	.02	9
Miscellaneous industrial uses	27	2.2%	.5	250
TOTALS	1,253	100.0%	25	11,400

EPA defines transformers and capacitors as closed uses. There are partially closed uses, such as hydraulic fluids, heat exchange fluids, and gas pipelines. There is a much larger variety of open uses as detailed in Table 13. In closed sources PCBs are contained, barring accidental spill or leakage. In partially contained sources PCBs are partially contained and there is some exposure to the environment. In open sources PCBs are exposed to environment with no containment.

Table 13. Examples of legacy uses of PCBs

Class	US consumption	Examples
Closed	75%	Industrial scale transformers, capacitors, voltage regulators
		Fluorescent light ballasts
		Consumer electrical items (fridges, televisions, washing machines)
		Manufacturing machinery (capacitors, transformers, associated switchgear)
Partially closed	10%	Hydraulic fluids
		Heat exchange fluids
		Gas pipelines
Open	15%	Plasticizer in paints, resins, synthetic rubber, surface coatings, wax
		Sealants, waterproofing compound, glues and adhesives
		Caulking compounds
		Pesticide extenders
		Pigments and dyes
		Carbonless copy paper
		Microscope immersion oil
		Sound proofing materials
Window glazing		

We do not have enough information to estimate the historic use of PCBs in all of these applications or how much is still in use in Washington.

We cannot estimate the amount of PCBs currently in Washington State from partially closed applications, i.e. hydraulic fluids, heat exchange fluids, and gas pipelines. Hydraulic fluids containing PCBs were used in industrial applications that required heat and/or fire resistance. From 1929 to 1975 about 6% of PCBs produced were used for hydraulic fluids and lubricants (EPA 1997a). About 2% of PCBs produced were used heat transfer fluids (EPA 1997a) during the same time period. PCB-based oils were also used in gas transmission compressors. The compressors were used to move natural gas through thousands of miles of pipelines across the U.S. PCBs were also used as a fine mist into underground metal gas pipes to slow corrosion and lubricate the pipelines. PCBs remain in the pipelines until remediated, contributing to environmental releases through leaks and spills.

Closed Legacy Uses

Transformers and Large Capacitors

PCBs have not been manufactured in the US for use in transformers and capacitors since 1979. Although many PCB-containing transformers have been retired, some remain in use. The estimated lifetime of transformers may be as long as 85 years and 20 years for capacitors (Ecology 2011b). While transformers and capacitors are considered “totally enclosed” under TSCA, there are leaks and spills from such equipment until it is retired and replaced.

Federal regulations classify transformers into three groups:

1. *PCB transformers* with > 500 ppm PCBs.
2. *Contaminated transformers* with 50-500 ppm PCBs.
3. *Non-PCB transformers* have less than 50 ppm PCBs.

Transformers are used to transform electricity from one voltage to another through electromagnetic induction. For example, they are used to convert a power generator’s low-voltage electricity to higher voltage levels for transmission or to convert high voltages to lower voltages at the end user. Examples include pole-mounted, pad-mounted, and underground distribution transformers and larger transformers at substations. Utilities operated about 80% of mineral oil transformers (Panero *et al.* 2005). Transformers are also found in institutional, commercial, or other private facilities, including schools, mines, and railways.

Capacitors are passive electronic components used to store energy. They have many uses and come in many different sizes. This section includes large capacitors and small capacitors are discussed in the following section.

The size of transformers and capacitors vary and the amount of PCBs per unit also varies (see side bar for regulatory classification and the regulations section for more information). Mixtures of PCBs were marketed under different names in different areas. Askarel was the trade name used in the US for the blend of PCB and trichlorobenzene used for transformers. Askarel transformer fluid was typically 60-70% PCB by weight. Other transformers used mineral oil as the dielectric fluid. Transformers that were manufactured after 1979 are certified to be PCB-free by the manufacturer. Prior to that date some mineral oil transformers were contaminated with PCBs, often during manufacture when the same equipment was used for both Askarel and mineral oil fluids.

Capacitors were typically filled with nearly pure PCB oil and the largest capacitors contained as much as 35 kg PCB (Ecology 2011b). The typical large capacitor contained 31 lbs (14 kg) of PCBs (Federal Register Vol 47, No. 78).

A 1987 EPA report on sources of PCBs includes accidental release estimates from a 1982 study by the Edison Electric Institute and the Utility Solid Wastes Activity Group (USWAG/EEI) in response to an order issued by the US Court of Appeals for the District of Columbia Circuit. The

EEI/USWAG study gathered survey data from 98 of the 100 largest utilities on leaks and spills. It also estimated the number of pieces of equipment and concentrations of PCBs in the equipment based on data from utilities (USWAG/EEI 1982). This is the only study on leaks that was identified.

Estimate in Washington

An earlier report by Ecology overestimated PCBs in transformers and large capacitors in the Puget Sound basin (Ecology 2011b) in several ways. The earlier estimate relied on an EPA database of registered PCB transformers that was not up to date, estimates of unregistered PCB transformers, an assumption that the PCB transformers in Washington are Askarel transformers with 60% PCBs, and the leakage rates did not take into account the lower concentrations of PCBs in transformers currently in use. Conversations with public and private utilities in Washington, non-utility users of PCB transformers, and other experts led to much lower estimates here.

It is not appropriate to use national estimates or estimates from other regions for Washington State. Compared to other regions of the country, public utilities in Washington State have been the most progressive in testing equipment for PCBs and disposing of equipment with PCBs (Mark Pennell, personal communication).

Transformers

There are 252 registered transformers in the EPA PCB Transformer Registration Database with 121,053 kg of PCB oil in Washington (Appendix F). These are PCB transformers (>500 ppm) that were required to be registered with the EPA in 1998. The regulations do not require EPA to update the database when PCB transformers are taken out of use. We were able to contact most of the parties who registered transformers and found that most of the transformers had been disposed of (Table 14).

Table 14. PCB transformers in use in Washington

Still in use	14
Disposed of	228
Unknown	10
Total	252

The PCB transformer registry does not reflect the actual number of PCB transformers still in service and no current inventory of PCB equipment exists in the US (EPA/EC 2009). The EPA states that the database is “not particularly useful for determining the amount of PCB equipment that is remaining in service” (EPA/EC 2009). Various attempts have been made to estimate the number of units remaining in use. The Great Lakes Binational Toxics Strategy 2009 Biennial Report (EPA/EC 2009) estimates that 64,312 PCB transformers remained in use throughout the US while there are about 14,150 registered transformers in the EPA database. Scaled down from

the national to the state based on 2010 population, an estimated 1,401 transformers remained in use in Washington in 2007. This estimate assumes that about 80% of the PCB transformers still in use were not registered with EPA. Based on conversations with public and private utilities in Washington, there is not that much unknown equipment in use. A more reasonable estimate would be about 20% of transformers are unknown and never registered. Some utilities know the PCB concentration of all their transformers.

Using the 14 known PCB transformers still in use from the EPA database, adding an additional 20% results in an additional three PCB transformers still in use in Washington. If the other 10 registered PCB transformers whose status is unknown are all still in use, the total number of PCB transformers (> 500 ppm PCB) in Washington could be as high as 27, including the additional 20% of unknown and never registered PCB transformers. Based on the sizes and PCB concentrations of some of the known PCB transformers still in use, we have estimated they each contain about 665 gallons of fluid that is 1500 ppm PCB. Askarel transformers were less than 0.2% of utility transformers nationwide (USWAG/EEI 1982) and were used even less frequently in Washington State. Askarel transformers contain 60-70% PCBs and the more common mineral oil transformers have a much lower concentration of PCBs. When national data was compiled for the USWAG/EEI study (1982) 90% of the mineral oil transformers had <50 ppm PCBs. As utilities have identified and removed PCB contaminated transformers, the average concentration of PCBs has become even lower.

There do not seem to be known Askarel transformers in Washington, but each leak/spill from an Askarel transformer has the potential to release a significant amount of PCBs. The USWAG/EEI study estimated that each leak/spill would release 0.56 - 64.5 lbs (0.25 – 29 kg) of PCBs.

There are still some transformers with lower levels of PCBs, mostly < 50 ppm, that are considered PCB contaminated (50-500 ppm) or non-PCB (1-50 ppm) in the regulations. These have never been required to be tracked or reported. Utilities in Washington have been testing transformers and many have been disposing of transformers with any detectable level of PCBs (>1-2 ppm). Based on the number of these transformers that are known to be still in use by utilities, the amount of older equipment that is untested and has unknown levels of PCBs, there are about 40,000 PCB contaminated (50-500 ppm) and non-PCB (1-50 ppm) transformers in the state that have a concentration of about 25 ppm PCBs. The transformers used in distribution lines on top of poles have about 20 gallons of fluid.

Large Capacitors

Less is known about the number of large PCB capacitors in Washington compared to the number of PCB transformers. Capacitors were never required to be tested or registered. The Puget Sound study (Ecology 2011b) used the national estimate of 1,293,000 large capacitors still in use from The Great Lakes Binational Toxics Strategy 2009 Biennial Report (EPA/EC 2009). Scaled down from the national to the state level based on 2010 population size, an estimated 28,162 large PCB

capacitors could remain in use in Washington. However, based on conversations with some of the 61 public and private utilities, there are very few large PCB capacitors remaining in Washington State. PCB capacitors were never required to be inventoried and not all equipment is known, but utilities we asked were confident that all the large PCB capacitors had been removed from 10 to more than 20 years ago. About 15% of large PCB capacitors were owned by non-utilities (EPA 1987) and we have not tried to identify where those were used or if they are still in use. If we estimate 95% of the PCB capacitors have been disposed of, then there would be about 1,400 remaining still in use. We do not have any evidence for which non-utilities in Washington had PCB capacitors or how many of those capacitors are still in use. The estimate that 5% remain in use is based on the hypothesis that non-utilities have also removed capacitors over time, but have not removed all of them.

Other equipment not estimated

Utilities have other equipment that historically contained PCBs, such as reclosers, switches, circuit breakers, bushings, etc. This equipment contained much less PCBs compared with the transformers and capacitors (USWAG/EEI 1982). We have not attempted to estimate how much of the old PCB-containing equipment still remains in use. Some utilities have been testing and removing this equipment.

Leakage and Spillage Rates

In the Puget Sound study (Ecology 2011b) the leakage rates were based on PCBs/unit for Askarel transformers, which does not take into account the lower concentrations of PCBs in transformers currently in Washington.

The USWAG/EEI study (1982) found about 2% of all transformers and 0.77% large capacitors had moderate leaks or spills each year. The study includes lower rates for equipment that had > 50 ppm PCBs. They did not include equipment with < 50 ppm PCBs that is considered non-PCB in federal regulations, but we are including that equipment here. The average amount of PCBs leaked/spilled per event was 0.00004 – 0.005 lbs (18 mg – 2.27 g) for mineral oil transformers and 2 – 17.1 lbs (0.9 – 7.76 kg) for PCB capacitors. As mentioned earlier, the average amount of PCBs per leak/spill for Askarel transformers was 0.56 - 64.5 lbs (0.25 – 29 kg) of PCBs.

Leaks from transformers and large capacitors were estimated in San Francisco Bay (McKee *et al.* 2006) and NY Harbor (Panero *et al.* 2005). Both of these studies relied on the EPA transformer database that is not accurate for Washington.

This results in a total annual release estimate of < 2 kg for transformers and 10-80 kg for capacitors in Washington State (Table 15).

Table 15. Release estimate for transformers and capacitors

Equipment Type	PCB concentration	Number of units	Reservoir	PCB spill/leak rate (annual)	PCBs released per spill/leak (kg)	Annual PCB release
Transformers	>500 ppm	14 - 27	100-200 kg	2%	0.000018-0.00227	5 mg – 1.2 g
	1-500 ppm	40,000		2%		14 g- 2 kg
Large Capacitors	100 %	1,400	20 metric tons	0.77%	0.9- 7.76	10-80 kg

There is uncertainty in the number of electrical units still in use and the older data on leakage rates may not reflect current operating conditions. The estimates do not account for spill response, thus actual amounts of PCBs released to the environment may vary. Indoor spills in particular are likely to be contained and cleaned up. Additional emissions from direct volatilization from equipment are likely, but not estimated due to lack of information.

Opportunities for Reduction

- Status quo
 - 1998 EPA registry for known transformers > 500 ppm
 - Voluntary removal
- Develop a state inventory of equipment that includes the number of units and the amount of PCBs.
- Require utilities and other owners of transformers, capacitors, and other electrical equipment to develop and implement a plan for removal.
- Require complete change out to remove old units (with proper disposal) by a certain date.

Based on conversations with public and private utilities in Washington, they have been actively testing and removing equipment with PCBs beyond what is required by federal law. Several utilities in Washington (personal communication) and other states (Panero *et al.* 2005) use serial numbers of transformers to identify additional transformers that are likely to have PCBs, once one transformer in a batch has been identified as having PCBs. Many utilities are disposing of equipment with any detectable level of PCBs (> 1 ppm).

Small Capacitors

Capacitors containing less than three pounds of PCB oil are considered small capacitors. Small capacitors containing PCBs have been used in a number of items including motors, appliances, and light ballasts. Small capacitors generally contain 45-270g of PCBs in oil and lamp ballast capacitors contain 45-70 g PCBs (EPA 1982 proposed rule in the Federal Register).

Wisconsin found submersible well pumps that contain PCB filled capacitors and in 1992 estimated that 10,000 -15,000 of their 800,000 wells contained capacitors with PCBs (Wisconsin DNR 2001). This only applies to equipment that was manufactured before 1979. Wisconsin has

recommendations for owners to identify such pumps and prevent exposure. It is unknown how common this is in Washington. There is a report of one contaminated well from a pump in Whatcom County in 1990 (Seattle Times January 8, 1990).

Estimate in Washington

Several studies estimate the number of small PCB containing capacitors remaining in use that are not light ballasts. In 1992 the University of Illinois estimated that 10-25% of US household appliances contained capacitors with PCBs (Panero *et al.* 2005). EPA (1982b) estimated that historically there were 870 million small capacitors in use throughout the US in 1977 in industrial machines and small appliances. EPA (1987) also estimated a 10% annual disposal rate in 1982. Scaling the national estimate to Washington based on population and applying annual disposal rates of 20% and 10% yields an estimate of 12,000 to 586,000 small capacitors still in use in 2010.

Globally, one third of all PCB production may have gone into lighting ballasts (Ecology 2011b). National estimates of lamp ballasts currently in use include 300 million (US Army 2001) and 500 million (Missoula County 2010). In 1998 EPA, citing an unnamed industry source, estimated that 1 billion small lamp PCB ballasts remained in use in the US (EPA 1998). Scaling this estimate to Washington based on population and applying annual disposal rates of 20% and 10% yields an estimate of 1.7 million to 6.2 million such ballasts still in use in 2010 in Washington.

While we have some information on the number of PCB containing capacitors collected in Washington as hazardous waste or moderate risk waste, the information is not complete enough to use for estimating the number of units still in use.

A range of 12,000 to 6.2 million non-lamp ballast small capacitors and lamp ballasts remains in use in Washington State. While small capacitors may contain 45-270 g PCB per unit, most of the remaining units are likely to be lamp ballasts, which typically contain 45-70 g PCB per unit. For the estimate we used 57.5g PCB/unit as an average. The assumed leakage rate is 4.2 kg/metric tons of PCBs, from the 1982 study on large capacitors (EPA 1982b). This results in an estimate of 400- 1,500 kg for lamp ballasts and 3-150 kg annually for other small capacitors (Table 16).

Table 16. Lamp ballasts and other small capacitors

Equipment Type	Basis for estimate	Number of units	PCBs (kg)	PCB spill/leak rate (annual)	Annual PCB release kg/yr
Other small capacitors	Scaled from national estimate	12,000-586,000	690-33,695	4.2%	3-150
Lamp ballasts	Scaled from national estimate	1.7-6.2 million	97,750-356,500		400-1,500

There is uncertainty around both the estimate of how many small PCB capacitors remain in use and how much leaks each year. Additional emissions from direct volatilization from equipment are likely, but not estimated.

Opportunities for Reduction

- Status quo
 - Continued use of old capacitors, with expected 10-20% annual disposal/replacement rates
- Educate consumers on which lamps and small appliances are likely to contain PCBs, including appropriate disposal options
- Statewide program to remove small capacitors.
- Remove PCB-containing lamp ballasts in schools.
- Investigate the status of PCB containing materials in schools.

Removal of old light ballasts could be linked to changes for energy efficiency. EPA has national guidance for schools to replace PCB ballasts. NY settled a lawsuit in 2013 after widespread PCB contamination was found in schools and some fires (<http://www.epa.gov/region2/pcbs/>).

Open Uses

Caulk

PCBs were used in caulk and joint sealants to improve the flexibility, increase the resistance to erosion, and improve adherence to other building materials from the 1950s to the 1970s (Robson *et al.* 2010). Monsanto voluntarily stopped producing PCBs for open uses, such as caulk, in 1971 (ATSDR 2000). While the use of PCBs in open products above 50 ppm was banned in the US effective in 1979 under TSCA, materials that contain PCBs were not required to be removed. The use of PCB-containing caulk was a common practice in the 1970s and caulk formulations changed during the late 1970s (Herrick *et al.* 2004). The studies on PCBs in caulk have focused on buildings built from about 1950 to 1980 to include using up the existing stocks of PCB-containing caulk.

Sealants with high levels of PCBs have been found at varying levels in buildings in several studies. All of the studies found congener profiles consistent with Aroclors 1248, 1254, and 1260. In general, PCBs were used at 5-30% in caulk (Priha *et al.* 2005). PCBs can be lost from caulk through volatilization, as well as wash-off and erosion. PCBs in caulk are associated with higher levels of PCBs in indoor air and dust, and the external soil (Priha *et al.* 2005, Herrick *et al.* 2007, SAIC 2011). Larger amounts of PCBs may be lost during renovations or destruction. Certain removal practices can reduce the amount of PCBs released both to workers and the environment (Sundahl *et al.* 1999).

Herrick *et al.* (2004) found PCBs in schools and other buildings in the Boston area. In 13 of the 24 buildings sampled, PCBs were found at concentrations of 2 to 36,000 ppm. PCB levels in the air ranged from 111 to 393 ng/m³ and in dust samples up to 81 ppm.

There was a nationwide comprehensive survey in Switzerland (Kohler *et al.* 2005). In this study, 1348 caulk samples from concrete buildings built between 1950 and 1980 were analyzed for

PCBs. Forty-eight percent of the caulk samples contained PCBs, from < 50 ppm up to 550,000 ppm (55%).

The amount of PCBs in caulk was estimated in Toronto, Canada (Robson *et al.* 2010, Diamond *et al.* 2010). This study was based on a smaller sample size and found PCB-containing caulk in 14% of 95 buildings at concentrations of 0.57 ppm to 82 ppm. In Toronto, institutional and commercial buildings and infrastructure (e.g., bridges and parking lots) made of concrete were most likely to have PCB-containing caulk. They detected PCB in caulk in one single family detached home. As expected, they did not detect PCBs in caulk in buildings built before 1945 or after 1980. Based on the number of concrete institutional and commercial buildings built between 1945 and 1980, the size of the buildings, the amount of caulk in a typical building, the percentage estimated to have caulk, and the average concentration of PCBs in caulk, the authors estimated 13 metric tons of PCBs are in caulk in Toronto. The authors further estimated that up to 9% of the PCBs in caulk had been lost via volatilization. The observed congener pattern is consistent with volatilization of lower chlorinated congeners and comparative enrichment of higher chlorinated congeners (Robson *et al.* 2010).

There was also a study of PCB in caulk in the San Francisco Bay area as part of implementing the TMDL (Klosterhaus *et al.* 2011, 2014). This report estimates PCBs in buildings and how much is released to runoff during renovation and demolition. PCBs were detected in 88% of the 25 samples from 10 buildings. The concentrations ranged up to 220,000 ppm (22%) with 40% of the samples exceeding 50 ppm. The median and range were similar to the studies in Boston and Switzerland. The mid-range estimate was 10,500 kg of PCBs in caulk in existing buildings, using a similar method as was used in the Puget Sound Study (Ecology 2011b, Klosterhaus *et al.* 2011, 2014). Information on the number of renovations and demolitions in the San Francisco Bay area each year was used to estimate that 0.04 kg PCB is released each year to stormwater from renovation and demolition. Washington does not have information on the number of commercial buildings of that age and construction type that are renovated or demolished each year.

As part of the Lower Duwamish Waterway (LDW) cleanup in Seattle, Science Applications International Corporation (SAIC) investigated PCBs in old caulk and paint in the LDW (SAIC 2011). This was part of an effort to find additional sources of PCBs in the cleanup area, especially since high levels of PCBs in paint, caulk, and other building materials had been found at the former Rainier Brewery and North Boeing Field. They detected Aroclors in 8 of 17 composite caulk samples from representative buildings with detected concentrations from 3 to 920 mg/kg. The focus was on industrial buildings from 1950-1977. As expected, they did not find PCBs in a sample from buildings built in the 1940s. Surprisingly, they reported another building in the Seattle area that was built in 1989 and contained PCBs in caulk up to 1000 mg/kg. The use of PCBs in caulk in North America has not been reported this late. The number of samples with detectable PCBs (47%) is in agreement with the larger comprehensive study in Switzerland (Kohler *et al.* 2005).

Estimate in Washington

The report on sources of toxic chemicals released in the Puget Sound Basin (Ecology 2011b) estimated 59 metric tons of PCBs are in building sealants in that area with about 110 kg released annually. This estimate was based on the number of existing masonry commercial buildings that were built between 1945 and 1980, the average size of those buildings and the distribution of PCB concentrations in caulk found in the more comprehensive survey by Kohler *et al.* (2005). This is likely to underestimate the amount of PCBs in sealants because it does not consider all uses in buildings, such as around windows, uses in residential buildings, or in other structures, such as bridges and sidewalks. The annual release estimate was based on a release rate coefficient of 0.0018/yr from long term loss rates in Robson *et al.* 2010.

The estimate for the Puget Sound Basin was based on detailed information about buildings in Pierce and Snohomish Counties and then scaled up to the rest of the study area by population. The estimated volume of masonry buildings built from 1945 to 1980 in Pierce and Snohomish Counties was 21,941,562 m³. To estimate PCBs in caulk for the state we scaled up the volume of masonry commercial buildings that were built between 1945 and 1980 by population, leading to an estimate of 97,702,645 m³ with 5,373,645 kg of caulk for the state.

The large study in Switzerland (Kohler *et al.* 2005) found 48% of the targeted buildings had PCB- containing sealants. Applying this to the state estimate on sealants leads to 2,573,976 kg of PCB-containing sealants. The PCB concentration ranges from Kohler *et al.* (2005) were applied to the estimated mass of PCB-containing sealants in Washington, yielding an estimate of 87 metric tons of PCBs in sealants in Washington with 157 kg released annually (Table 17).

Table 17. Estimates from caulk

sealant quantity (kg)	sealants with PCBs (kg)	PCB conc bin (mg/kg)	bin mid point	% for each bin	PCB quantity (kg)	Annual releases (kg)
5,373,645	2,573,976	20-50	35	0.121	11	
		50-100	75	0.0772	15	
		100-1,000	550	0.1899	269	
		1,000-10,000	5,500	0.1815	2,569	
		10,000-100,000	55,000	0.2316	32,787	
		>100,000	100,000	0.2003	51,557	
Total				1.0	87,208	157

In addition, PCBs are released into the environment during renovation and demolition of buildings that contain PCBs in caulk and other building materials. In order to estimate this we need to know how many buildings of that age and construction type are demolished or renovated in the state, which we do not know.

Opportunities for Reduction

- Status quo
 - PCBs may be found and remediated during source identification efforts.
- Require removal or remediation of all PCB containing caulks, statewide.
- Develop best practices for demolition and renovation.
- Investigate the status of PCB containing materials in schools.
- Remove or remediate PCB-containing caulk in schools.
- Partner with EPA and federal facilities to identify and remove caulk and other PCB-containing materials.

Many schools in Washington were built when PCBs were used in caulk, lighting ballasts, paint, and other building materials. EPA has information on PCBs in caulk and other building materials that includes how to test for PCBs and how to safely remove PCB-containing materials (<http://epa.gov/pcbsincaulk/index.htm>). Their outreach has been focused on schools, due to the sensitivity of developing children. There are reports of methods for removing PCBs where more than 99% of the PCBs in caulk were captured following the use of BMPs specifically aimed at preventing PCB releases (e.g., Sundahl *et al.* 1999).

Caulk, other building materials, and other historic uses of PCBs are found on Navy vessels and other military equipment (EPA 2006). This is an opportunity for Ecology to partner with EPA and federal facilities to expand PCB source identification and removal activities.

Inadvertent generation in new products

PCBs are no longer intentionally manufactured in the U.S. and the manufacture, processing, and distribution in commerce of PCBs at concentrations of 50 ppm or greater is not allowed. EPA promulgated a rule under TSCA in 1984 for inadvertent generation of PCBs that are not in closed or controlled manufacturing processes (49 FR 28172). The concentration of inadvertently generated PCBs in products must have an annual average of < 25 ppm, with a maximum of 50 ppm. In addition, EPA required manufacturers with processes inadvertently generating PCBs and importers of products containing inadvertently generated PCBs to report to EPA any process or import for which the PCB concentration is greater than 2 mg/kg for any resolvable PCB gas chromatographic peak. More details on TSCA are in the section on Regulations.

As part of this rulemaking on inadvertently generated PCBs, EPA generated a list of 200 chemical processes with a potential for generating PCBs (Appendix D) and narrowed it to 70 with a high potential to inadvertently generate PCBs. The list does not include every process that inadvertently generates PCBs and not everything on the list inadvertently generates PCBs. In general, PCBs can be produced when chlorine and carbon are present with elevated temperatures or catalysts.

The final rule also includes an estimated annual production of inadvertently generated PCBs of 100,000 lbs (45,400 kg). Scaled to population, Washington's share of that would be about 900 kg a year. Only 11% of the PCBs were estimated to enter products, or 100 kg annually in Washington. As the economy has grown over the last 30 years, the amount of inadvertently generated PCBs may also have grown. The 100,000 lbs was an estimate from a consensus proposal from the Environmental Defense Fund, Natural Resources Defense Council, and Chemical Manufacturers Association (now known as the American Chemistry Council) that included all inadvertent generation of PCBs, without being broken down into how much came from each process. Products that are mentioned include paints, printing inks, agricultural chemicals, plastic materials, and detergent bars. The 1982 economic analysis for this rule mentions 135 manufacturing processes that generate PCBs at less than 50 ppm from a Chemical Manufacturers Association survey. The economic analysis also includes a list from EPA of about 20 "end-products of manufacturing processes in which PCBs are incidentally generated."

In their rule on inadvertent production, EPA specifically mentions surfactants as the component of detergent bars that is likely to contain PCBs. EPA also mentioned PCBs are likely to be in surfactants in skin lotions and creams that are regulated by the FDA. We have no estimate for how many PCBs are inadvertently produced in surfactant.

Reports to EPA on inadvertent generation

As mentioned above, the 1984 rule under TSCA (49 FR 28172) requires manufacturers to report inadvertent generation of PCBs. There are 77 reports for inadvertently generated PCBs from 1994 to present (Table 18). Some information on each report is in Appendix E. There are additional reports included in the docket for related topics, such as requests to produce small amounts of PCBs for research purposes. A lot of the information in the reports has been redacted to remove confidential business information (CBI). In general the reports repeated the federal requirements while stating the company is in compliance and without giving specific information about the concentration of PCBs in the products or the total amount of the products. None of the reports were for facilities in Washington State.

Many reports include a statement that the materials may contain PCBs > 2 ppm, but likely do not and the reporter was being very conservative in reporting anything that might contain PCBs > 2 ppm. The reports assert that no products contained more than 50 ppm or more than 25 ppm for an annual average (which are the limits in rule).

Table 18. Reports to EPA on inadvertent generation 1994-present

Chemical or process	Number of reports
Pigments and dyes	53
GE silicones	8
Vinyl chloride production	3
Unique	6
Unknown	7
Total	77

Some of the reports in Table 18 in the category of pigments and dyes list individual pigments (yellow, red, green, blue violet and orange with Color Index (CI) numbers), some include a general description such as “imported dyes,” while others do not include any specific information, but come from a division of the company such as the “Pigments Division.”

Eight reports are from GE Silicones. There is no additional information on the products.

There are three reports from three different companies regarding vinyl chloride production, one of which was a unique incident involving diesel contamination. Geon stated they are reporting on 740 lbs of PCBs in 62,676,000 lbs of chemical feedstocks used in a vinyl chloride monomer manufacturing facility in Texas. The third report is for incidental PCBs generated in the chlorination step of a process stream to remove an impurity.

There are six reports from six different companies on unique compounds or processes. These reports are for trichlorobenzene manufacture, 2,4,6-Trichlorophenylhydrazine (2,4,6-TCPH), 2,6-Dichloro-4-Nitro Aniline, a pesticide intermediate, chlorothalonil production process, and one report for electrical capacitors. The one report for electrical capacitors also included the information that PCBs were at 3.9 ppm in 134 liters. The report on 2,4,6-Trichlorophenylhydrazine stated the concentration was usually 9-12 ppm.

Seven reports were for unknown compounds or processes. Four of these were completely redacted with a place holder stating there was a report. Two reports redacted the name of the company in addition to the compounds. One report was for two containers of a non-PCB product with 4 and 5 ppm PCBs.

Pigments and dyes

More details on generation of PCBs during manufacturing are provided in the earlier section on Chemistry. PCBs are known to be inadvertently generated in certain pigments and dyes, including diarylides (yellow and orange), naphtharylamides (oranges and reds), phthalocyanines (blue), and basic dye complex pigments (reds, violets, blues and greens) (Christie 2013). PCB-11 is thought to be primarily from pigment production and not from legacy uses of Aroclors (Hu and Hornbuckle 2010, Guo *et al.* 2014), and so is useful as an indication of inadvertent

generation of PCBs, especially from pigments. Specifically, the ratio of PCB 11 to a characteristic dechlorination end product, PCB-4, indicates that dechlorination is not a significant source of PCB 11 where it has been examined (Rodenburg *et al.* 2010). PCB-11 has been seen to be strongly correlated with PCBs 35 and 77 (Rodenburg 2014). PCB-77 is one of the dioxin-like congeners.

Hu and Hornbuckle (2010) found PCBs in azo and phthalocyanine pigments, including PCB-11 and higher chlorinated PCBs 206-209. Previously PCB-209 was only thought to be found in ferric oxide as a by-product of titanium dioxide production (Panero *et al.* 2005). PCB-11 and PCB-209 have been found in Washington's environment and animals (Ecology EIM database).

Higher chlorinated PCBs are inadvertently generated during the production of the inorganic pigment titanium dioxide using the chlorine process (UNEP 2007). We were unable to locate estimates on the amount of PCB inadvertently generated in this process.

PCBs have been detected in general consumer products purchased in Washington. Individual congeners were detected between 1 and 45 ppb. Four congeners known to be associated with pigments (PCB 11,206,208, and 209) were selected for the initial study and were tested for in 74 samples from 68 products (Ecology 2014). The products included packaging, paper products, paint and colorants, and caulk. Ecology is in the process of reporting on the results of all the congeners for the same samples. As in previously published work (Hu and Hornbuckle 2010), we also see a wide selection of congeners in the consumer products.

Estimate in Washington

While different researchers have detected PCBs in pigments and consumer products, we don't have a good estimate for how much is released in Washington each year. Panero *et al.* (2005) estimated PCB-11 represents 5-20% of the PCBs entering NY harbor. Guo *et al.* (2014) estimated that between 5 and 7800 kg¹¹ of PCB-11 are produced worldwide each year from diarylide yellow in 2006. The US market consumes approximately 20% of global organic pigments (Guo *et al.* 2014). Washington is approximately 2% of the US population, which leads to an estimate for Washington's share of PCB-11 from yellow pigment of 0.02 and 31 kg per year. This is the amount of PCB-11 in products, with an unknown amount entering the environment.

The Color Pigments Manufacturers Association (CPMA) estimated that the total annual amount of these pigments (phthalocyanine and diarylide) imported or manufactured in the US is about 90 million lbs (41,000 metric tons). They further estimated inadvertently generated PCBs in these pigments with an upper bound of 1.1 tons per year and a more reasonable estimate of 1000 lbs

¹¹ Jia Guo is an author on an earlier paper (Rodenburg *et al.* 2010) that estimated worldwide production of PCB 11 from diarylide yellow pigment production at 1.5 t in 2006. This estimate was revised in Guo 2013 and Guo *et al.* 2014.

per year (CPMA 2010). Using the lower annual estimate of 1000 lbs (450 kg), leads to an estimate of 9 kg per year in Washington, that is within the range of the estimate above.

There are permitted releases in Washington State that are pathways for PCBs to get from sources such as pigments in paper and other consumer goods into waterways. Looking at the PCBs in these permitted pathways illustrates that some PCBs from pigments are released in Washington, even though the permittees are not the source of the PCBs. Paper mills that recycle paper and municipal wastewater treatment plants discharge small amounts of PCBs into Washington waterways. In 2012 the average PCB concentrations in the discharge of two paper recycling mills were 2,520 and 1079 pg/L, respectively. Based on flow rate, the estimated PCB loading for these two facilities is 28 g per year, with 3.8 g being PCB-11. It is suspected that dyes from clothing and other consumer products such as soaps, lotions, and creams are also contributing PCBs to municipal wastewater treatment plants. For example, the Spokane River Source Assessment (Ecology 2011c) estimated that the Spokane waste water treatment plant was discharging 194 mg of PCBs/day.

Opportunities for Reduction

Inadvertent generation

- Status quo
 - Continue to permit products containing less than 50 ppm (with discount factor for mono- and bi-chlorinated biphenyls- see Regulations section) to be sold in Washington.
 - Implement RCW 39.26.280- Preference for PCB free products by state agencies.
- Assess alternatives for pigments and dyes to identify the availability of safer materials.
- Encourage businesses to use alternate processes/materials that do not generate PCBs.
- Conduct research using green chemistry to develop new processes that do not inadvertently generate PCBs.
- Test products to determine the extent of PCBs in products likely to contain PCBs.
- Require labeling to educate consumers on what products contain PCBs and which ones do not.
- Petition EPA to revise the federal regulatory limit on PCBs in products to align with the federal Clean Water Act.

There are many processes that might inadvertently generate PCBs, but not much is known about most of them. If the state doesn't make progress in reducing inadvertent generation of PCBs, permitted facilities might be forced to close or eliminate environmentally beneficial processes (such as recycling), which are undesired outcomes.

Commercial and industrial releases

Toxics Release Inventory (TRI)

The federal Toxics Release Inventory (TRI) includes permitted estimated releases from facilities that discharge from certain industries. The TRI database is authorized under the federal Emergency Planning and Community Right to Know Act to aid in community planning in case of an emergency and to generally inform the public about releases of toxic chemicals.

PCBs are subject to reporting and listed with the general CAS number 1336-36-3 for all PCBs. Because PCBs are PBTs, there is a lower level for reporting and the reporting threshold is 10 lbs.

There are only two reporters of PCBs in Washington on the TRI. Burlington Environmental in King County and Perma-Fix Northwest in Benton County are both hazardous waste treatment and disposal companies. From 2007-2011 they reported an average off-site waste disposal of 25,000 pounds (Table 19).

Table 19. Table of TRI reports from 2007-2011

Year	Reporter	Offsite waste reported (pounds)
2007	BURLINGTON ENVIRONMENTAL INC	485
2007	PERMA-FIX NORTHWEST RICHLAND INC.	14,163
2008	BURLINGTON ENVIRONMENTAL INC	389
2008	PERMA-FIX NORTHWEST RICHLAND INC	710
2009	BURLINGTON ENVIRONMENTAL INC	565
2009	PERMA-FIX NORTHWEST RICHLAND INC	11,869
2010	BURLINGTON ENVIRONMENTAL INC	1,081
2010	PERMA-FIX NORTHWEST RICHLAND INC	61,554
2011	BURLINGTON ENVIRONMENTAL LLC	1,000
2011	PERMA-FIX NORTHWEST RICHLAND INC	31,543

National Emissions Inventory (NEI)

The National Emissions Inventory (NEI) is a comprehensive and detailed estimate of air pollutants from all air emissions sources. The NEI is prepared every three years by the EPA based primarily upon emission estimates and emission model inputs provided by State, Local, and Tribal air agencies for sources in their jurisdictions, and supplemented by data developed by the EPA. According to the most recent NEI for 2008, there were 439 lbs (199 kg) of PCBs released to the air in Washington State from residential waste burning and 0.8 lbs (0.4 kg) released from commercial marine vessels. In addition to these sources, the Spokane Regional Clean Air Agency reported about 1 lb of PCB emitted from the Waste to Energy facility in 2011.

To obtain emission estimates for residential waste burning, EPA applies emission factors to an assumed mass of residential waste burned at the county level across the country. Some of the key assumptions are that residential waste burning only occurs in rural counties, and roughly 28% of the waste generated in these counties is burned in backyard burn barrels. This estimate is very uncertain, but can only be improved with location specific information regarding local compliance with residential waste burning rules.

Summary

Table 20 below summarizes the estimates for uses and sources in Washington State found in this section.

Table 20. Summary of Uses and Releases for Washington State

Source		Historic reservoir	Annual releases (kg/yr)
Closed	transformers	100-200 kg	< 2
	large capacitors	20 metric tons	10-80
	lamp ballasts	100-350 metric tons	400-1,500
	small capacitors	1-34 metric tons	3-150
	other closed uses		unknown
Partially closed			unknown
Open	caulk	87 metric tons	160
	other open uses		unknown
	pigments and dyes		(PCB-11) 0.02-31
	other inadvertent generation		900
	residential waste burning		199
	commercial marine vehicles		0.4

Pathways and Environmental Fate

Current PCB levels represent both historical and ongoing loadings and cycling among environmental compartments. We consider sources to be the original use of the material, such as PCBs in transformers. PCBs move through pathways such as stormwater and expose people and wildlife.

Unfortunately, we don't know where much of the PCBs that were produced prior to 1979 are currently located. For example, small capacitors used large amounts of PCBs, but since they were used in unregulated appliances, we don't know how many are still in appliances in people's homes, how many were disposed of in municipal waste landfills (and how much PCBs have since leaked out of those landfills or volatilized), and how many were disposed of outside of landfills.

Pathways

Assessments of both Puget Sound (Ecology 2011a) and freshwater systems (Ecology 2011c, King Co 2013b) have found the largest pathway for PCBs to reach the aquatic environment statewide is stormwater. Figure 12 shows the estimated loadings to Puget Sound by pathway (Ecology 2011a) and Figure 13 shows the relative stormwater loadings by type of land cover. In the Puget Sound study, we looked at the concentration of PCBs and other chemicals in surface runoff from four land-cover types: commercial/industrial, residential, agricultural, and forest, field, and other undeveloped lands. The concentration of PCBs in surface runoff was higher from commercial/industrial areas, especially during storm events, but the total loading was lower since industrial/commercial lands occupy less area than other land covers. Overall loads from forests accounted for 83% of the load (Ecology 2011g).

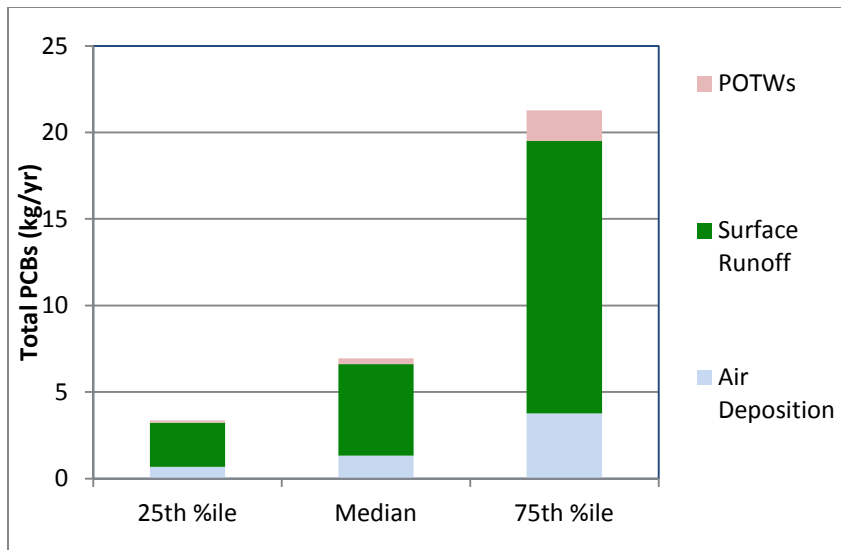


Figure 12. Total estimated PCB loading to Puget Sound by pathway (kg/yr)

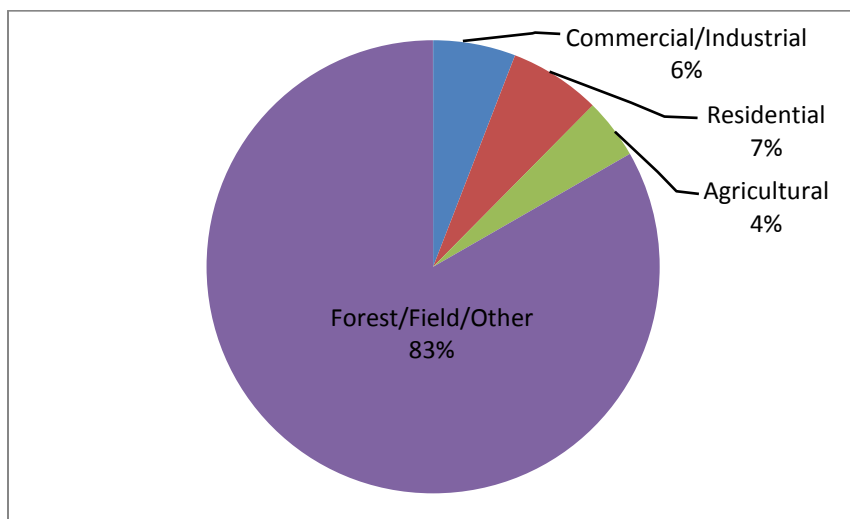


Figure 13: Relative contributions of different land use covers to PCBs in surface runoff in Puget Sound (Ecology 2011g)

Figure 14 shows the relative importance of different pathways in three freshwater systems in Washington. Publically owned treatment works (POTWs) are a smaller pathway in all the systems, with less than 10% of total loading. Direct air deposition was estimated to be the second largest pathway in the Puget Sound and Lake Washington study (Ecology 2010d, King County 2013b). There is a large and variable amount of PCB loading from unknown pathways.

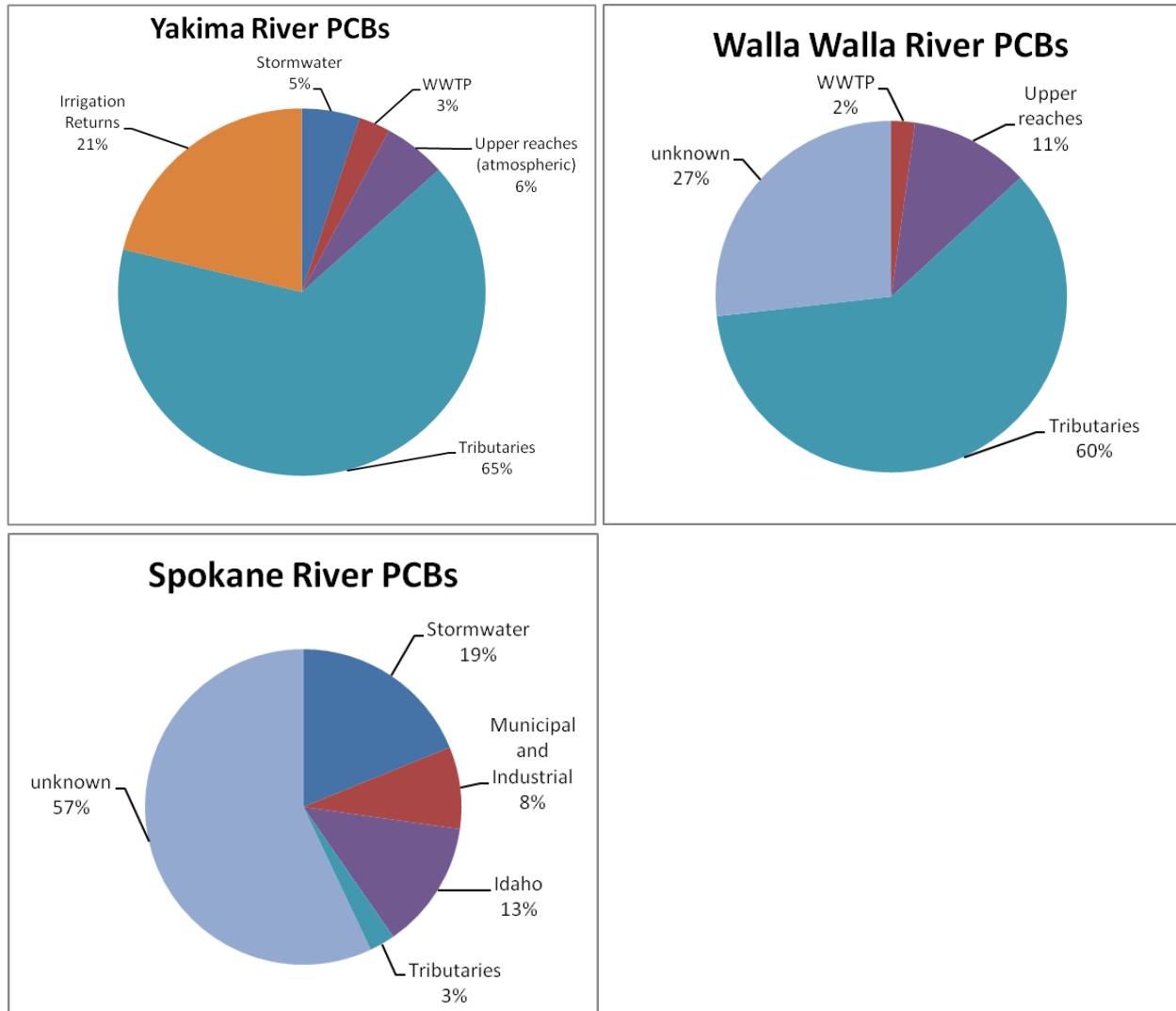


Figure 14. Relative importance of pathways assessed in freshwater systems

Salmon

Pacific salmon returning to spawn are another pathway for PCBs to enter Washington. Salmon have complex life histories and long-range migrations for feeding. The accumulation of PCBs in fish depends on many things including contaminated habitats, which food they eat and the levels of PCBs in food, lipid level, and age. Chinook salmon are 3-5 times more contaminated than coastal Chinook (West 2011). Most (99%) of the final weight of adult Chinook is achieved in salt water, both ocean and Puget Sound, and >96% of the PCBs in adult Chinook accumulated

during their marine life history phase (O'Neill and West 2009). O'Neill estimated that 0.265 kg/yr PCBs enters Washington through this pathway (Ecology 2011a). This estimate comes from whole body PCB concentrations for five species of Pacific salmon and their estimated biomass.

Motor oil

The City of Spokane reported measurements of PCBs in motor oil in their 2013 Adaptive Management Plan for Reducing PCBs in Stormwater Discharges from the Wastewater Management Department. The concentration of total PCBs in four samples of motor oil ranged from 14 to 116 ppb with an average of 54 ppb. In the PAH CAP (Ecology 2012a), Ecology estimated that 9,737,812 kg of motor oil is released annually in Washington from drips and leaks and another 1,555,179 kg of used motor oil is released to the environment through improper disposal. Using the average concentration of PCBs in motor oil from sampling in Spokane (54 ug/kg) and the statewide estimate of drips and leaks from motor vehicles and improper disposal of used motor oil in Washington (11,292,991 kg), gives an estimate of 0.6 kg of PCBs per year from motor oil.

PCBs are not created in motor oil, so motor oil is not considered a source here. The PCBs in motor oil are likely contamination from an unknown source. The homologue pattern is different from the PCBs found in sediments from stormwater catch basins in Spokane, with a much larger percentage of mono and dichlorobiphenyls and smaller percentage of higher chlorinated congeners. Of course, the congeners in sediment have been weathered and would no longer match the profile of the original source.

Environmental Partitioning

The estimates we do have for the fate of all the PCBs produced are not current. Newer publications cite estimates in earlier publications. These estimates vary, but they agree that much of the PCBs that were produced up to 1979 are still in use. This is a large reservoir of PCBs that are slowly leaking out into the environment. For transformers in particular, we know that much of the PCBs in transformers have been removed since these estimates were made. Transformers and capacitors were the largest use of PCBs and have been targeted for PCB removal.

In 1997 EPA estimated the inventory of PCBs as of 1977 as “Of the 700,000 [short] tons of PCBs produced, 150,000 tons had been landfilled; 75,000 tons had entered the air, water, and soil; 25,000 tons had been incinerated; and 375,000 tons remained in electrical equipment. The remainder, approximately 75,000 tons, had been exported.”

Converting this 1997 EPA estimate of short tons into metric tons leads to:

- 636,000 Produced (1927-1976)
- 568,000 Used (68,000 exported)

- 340,000 Remaining in use (60%)
- 228,000 Disposal/environment
- 132,000 Landfill (23%)
- 68,000 Environmental media (12%)
- 28,000 Incinerated (5%)

Table 21 shows estimates for the status of PCBs. The estimates in Keeler (1993) for the status of PCBs in the US as of 1982 are similar to those of the EPA above. The Canadian government estimated PCBs in Canada as of 1992 (CCME 1995) and Tanabe (1988) estimated similar percentages worldwide in 1985 (Table 21). All of these estimates include a large percentage of PCBs still in use and a small percentage destroyed by incineration. Unfortunately, we do not have more current estimates of PCB stocks and many of the PCBs that were in use at the time of these estimates have been taken out of use for disposal.

Table 21. Estimates for the status of PCBs (in metric tons)

Status	US 1977 (EPA 1997)	US 1982 (Keeler <i>et al</i> 1993)	Canada 1992 (CCME 1995)	Global 1985 (Tanabe 1988)
Produced	636,000	640,000		1,200,000
Used	538,000	582,000 (91%)	40,000	1,200,000
Remaining in Use	340,000 (40%)	346,000 (54%)	15,000 (38%)	780,000 (65%)
Landfill/Storage	132,000 (23%)	134,000 (21%)	6000 (15%)	
Environment	68,000 (12%)	70,000 (11%)	12,400 (31%)	370,000 (31%)
Incinerated	28,000 (5%)	19,000 (3%)	6,200 (16%)	50,000 (4%)

Tanabe (1988) also broke down the global PCBs in the environment into different media (Table 22). Not shown in Table 22 is that the largest global reservoir of PCBs is ocean water (while PCBs are not very soluble in water, the vast quantities of oceans worldwide hold more than half of the PCBs in the environment). Table 22 only includes estimates from the terrestrial and coastal waters and not ocean water.

Table 22. Global PCBs from Tanabe 1988 for PCBs on land, rivers and coastal waters

	PCB loads (metric tons)	percent
air	500	0.35
river and lakewater	3,500	2.45
seawater	2,400	1.68
soil	2,400	1.68
sediment	130,000	90.85
biota	4,300	3.00
Total	143,100	100

The estimates from Tanabe 1988 in Table 22 agree well with the model for Puget Sound (Ecology 2009b) and Lake Washington (King County 2013). For Puget Sound it was estimated approximately 97% (1440 kg) of the total mass of PCBs currently in the aquatic ecosystem of Puget Sound is contained in the active sediment layer (top 10 cm), <1% (10kg) is stored in the water column, and <3% (40 kg) is stored in the biota. O'Neill and West (2007) estimated PCBs in biota using PCB concentrations and biomass. Their total estimate is less than 40 kg of PCBs in Puget Sound biota.

Wildlife Health

Introduction

PCBs have similar effects in wildlife, people, and model organisms used to study people in laboratory experiments. Thus, this section and the section on Human Health have many similarities, although the health effects that are measured often differ between people and wildlife. Negative effects of PCBs in wildlife are of concern because of the effects on animal populations, because animal populations may be sentinels for human health, and because we are also part of the food chain and are exposed to PCBs through our diet.

PCBs can be acutely toxic to wildlife, but most of the impacts occur due to chronic exposure. Data are most prevalent on mortality, reproduction, development, and endocrine effects. In addition to toxicity endpoints, the induction of enzymes and genes are also used to assay PCB effects. Other endpoints include cancer, immunological, neurological/behavioral, and hepatic effects. Experimental studies are often performed for certain endpoints because of correlations seen in the field with PCB levels and specific endpoints.

Wildlife is exposed to varied mixtures of PCBs in the environment. Different PCB congeners behave differently in the environment; they preferentially partition into different media and they are preferentially degraded and bioaccumulated. In addition, there are multiple sources of PCBs that contain different mixtures of congeners that release PCBs into the environment. Therefore, the actual environmental conditions are different than many of the laboratory studies on specific Aroclor mixtures or specific congeners.

Sensitivity to PCBs varies among species and within species. For example, fish are most susceptible in early life stages. Inter-species variation is also due to different lipid levels, because PCBs are lipophilic and sequestered in lipid-rich tissues. PCBs are biomagnified up the food chain, so organisms on higher trophic levels have higher concentrations of PCBs. There are other differences among species that affect PCB metabolism. For example, invertebrates lack the enzyme systems that react with dioxin-like PCBs.

Although environmental levels of PCBs have declined substantially since they first came under regulation in the 1970s, the rate of decline has slowed in recent years and significant contamination continues to be widespread in Washington State..

Puget Sound is a regional hot spot for PCBs compared to the Pacific coast and British Columbia. Within Puget Sound, the most contaminated areas are in the main basin, especially Seattle's Elliott Bay and Tacoma's Commencement Bay, and, to a lesser extent, Everett Harbor and the Bainbridge Basin. Puget Sound's food web, from plankton on up to harbor seals and killer whales, has significant PCB contamination. Herring and Chinook salmon are notably affected.

Hot spots for PCBs are also present in Washington rivers and lakes. Based on PCB levels in resident fish species, major waterbodies of most concern are the Wenatchee River, Lake Washington, the Columbia River, and the Spokane River.

Health effects in wildlife

Table 23 (from ATSDR 2000) summarizes PCB effects seen in laboratory experiments and field studies with wildlife species. Most species have mortality at high doses.

Adverse effects in birds include:

- Reduced egg hatchability and live births
- Reduced avoidance response
- Altered mating, reproductive, parenting, and nesting behavior
- Suppression of immune response

Adverse effects in fish include:

- Reduced hatchability in eggs
- Altered muscle coordination
- Depressed immune system with increased susceptibility to infections
- Loss of fins and tails in flatfish

Adverse effects in mammals include:

- Loss of embryos and fetuses and reduced live births
- Alteration in the immune system in mink, sea lions, and seals
- Tumors and deformities of skeleton and skin in seals

Table 23. PCB Hazards in Wildlife with references noted in original (ATSDR 2000 Table 3-6)

Adverse effect	Wild mammals				Birds			Reptiles	Amphibians		Fish	
	Primate	Mustelid	Cetacean, pinniped	Other	Piscivore	Galliform	Other	Turtle	Frog	Toad	Freshwater	Marine
Mortality	OE1	OE1		OE3	OE3	OE1	OE3		OE1	OE1	OE1	OE3
		OE3				OE3			OE3	OE3	OE2	
		OE4									OE3	
Systemic effects												
Respiratory		OE4				OE3						OE3
Cardiovascular		OE3	OC4			OE3						
		OE4										
Gastrointestinal	OE1	OE1	OC4			OE3						
	OE3											
Hematological		OE4									OE3	
Musculo-skeletal						OE3					OE3	
Hepatic	OE3	OE1			OE3	OE1	OE1				OE3	OE3
		OE3				OE2	OE3					
		OE4				OE3						
		OE5				OE5						
Renal		OE4	OC4			OE3					OE3	
Endocrine	OE3	OE3	OE3		OE3	OE3	OE1				OE3	OE3
		OE4	OE4		OC4		OE3					
		OE5	OC4									
Dermal/ocular	OE1	OE3	OC4								OE3	
	OE3											
Body weight	OE1	OE1				OE2	OE1			OE3	OE3	
	OE3	OE3										
Metabolic		OE5					OE1		OE2		OE3	

Adverse effect	Wild mammals				Birds			Reptiles	Amphibians		Fish	
	Primate	Mustelid	Cetacean, pinniped	Other	Piscivore	Galliform	Other	Turtle	Frog	Toad	Freshwater	Marine
Enzyme induction		OE1				OE1	OE1				OE1	OC4
		OE3				OE2	OE2				OE3	
		OE4				OE3	OE3					
		OE5										
Blood chemistry	OE1	OE5				OE3	OE1				OE3	
Immunological/ lymphoreticular	OE1	OE4	OE4		OC4	OE1	OE1				OE3	OE3
	OE3		OC4			OE3	OE3					
Neurological/ behavioral	OE2	OE2		OE3		OE3	OE3				OE2	OE3
	OE3	OE4									OE3	
Reproductive	OE3	OE1	OC4	OE3	OC4	OE3	OE1	OC4			OE3	OE3
		OE3	OE4				OE3				OC4	OC4
		OE4										
		OE5										
		OC4										
Developmental	OE3	OE3		OE3	OE1	OE1		OE4	OE1	OE1	OE3	
		OE4			OC1	OE3			OE3	OE3	OC4	
					OC4							
Egg shell					OC4	OE3	OE3					
							OC4					
Genotoxic							OE3					

O= observed effect E= experimental observation C= correlational field observation
1 = dioxin-like PCB congener (AhR binder; planar; chlorine para-substituted and non- or mono-*ortho*-substituted)
2 = non-dioxin-like PCB congener (poorly binds to AhR; non-planar; chlorine di-, tri-, or quatro-*ortho*-substituted)
3 = commercial PCB mixture (e.g., Aroclor 1016)
4 = "weathered" (i.e., environmentally degraded and/or metabolized) PCB mixture, usually in combination with other chemicals (e.g., PCBs in wild-caught fish)
5 = unspecified PCB

Examples of major endpoints

Reproduction and development

PCBs affect reproduction and development in different species. Mink are particularly sensitive to the reproductive effects of PCBs (Eisler 1986). Farm-raised mink fed a diet of PCB-contaminated fish from the upper Hudson River at the same levels wild mink are exposed to PCBs in food, showed effects on reproduction and offspring growth and mortality (Bursian *et al.* 2013). Females with higher levels of PCBs had fewer live kits per litter. Kit mortality increased over time, with no kits surviving in the animals fed higher levels of PCBs. The surviving kits also had lower body masses after 6 weeks. The effects on reproductive performance were similar to those seen in earlier studies on mink fed contaminated fish from Saginaw Bay (Heaton *et al.* 1995a).

Immune System

PCBs are linked to increased disease susceptibility in several species. Captive harbor seals exhibit negative effects on their immune system after being fed PCB-contaminated herring, as assayed by immune cell function and response (Ross *et al.* 1996). This research was undertaken to understand factors contributing to virus-caused mass mortalities of marine mammals, especially when attributed to a virus that does not always cause mass mortalities. The results suggest higher levels of PCBs contribute to higher virus-caused mortality.

Cancer

PCBs have been shown to cause cancer in laboratory animals (ATSDR 2000) and are considered to be probable human carcinogens by EPA. PCBs are thought to cause cancer indirectly, rather than by direct alterations to DNA.

Cancer is less well studied in wild populations compared to laboratory species, partly due to lower incidence. However, beluga whales in the St. Lawrence estuary and Hudson Bay have been found to have a high incidence of cancers and high levels of PCBs (Mikaelian *et al.* 2003). There is also evidence linking cancer in St. Lawrence estuary belugas to PAHs from nearby point sources (Martineau *et al.* 2002), illustrating the difficulties in pointing to a specific group of chemicals in these marine mammals with many different industrial contaminants. PCB levels in California sea lions have also been found to be significantly associated with death from cancer (Ylitalo *et al.* 2005).

Mechanisms of action

Endocrine

PCBs interfere with estrogen and thyroid hormone levels. Studies on PCB endocrine disruption have been done in the laboratory with model animals and cell cultures (see section on Human Health). The endocrine system regulates all biological processes, although endocrine disruption

is often used just to refer to the disruption of thyroid hormones and the sex hormones estrogen and androgen. These hormones are important for growth and development, especially of the brain and nervous system and reproductive systems. While hormones are important throughout the life cycle, they are particularly important during fetal development. Hormones are signaling molecules that function at low levels, and compounds that either mimic or block natural hormones may have effects at low levels.

Ah-receptor dependent

Similar to dioxins, non-ortho (co-planar) and mono-ortho PCBs can bind to the aryl hydrocarbon (Ah) receptor. Subsequent to binding of the Ah receptor, there are changes in gene expression (e.g., induction of cytochrome p450 CYP1A1/1A2) leading to toxic responses. Induction varies by degree and pattern of chlorines and is the basis for the World Health Organization (WHO) toxic equivalency factors (TEFs) for dioxins and dioxin-like PCB congeners. These have been reviewed and modified several times. In 2005 WHO updated the TEFs for humans and mammals to replace the 1998 values (Van den Berg *et al.* 2006, see Table 29 in the Human Health Section). The adverse effects for these compounds are mediated through the Ah receptor and the relative potencies are compared to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Consensus TEFs for wildlife were developed in 1998 (Van den Berg *et al.* 1998). The WHO working group harmonized the TEFs across different taxa as much as they could, but there are large differences in responses among different taxa.

Table 24. WHO TEFs for fish and birds (Van den Berg *et al.* 1998)

Type	Congener	TEFs	
		Fish	Birds
Co-planar PCBs	3,3',4,4'-TCB (77)	0.0001	0.05
	3,4,4',5-TCB (81)	0.0005	0.1
	3,3',4,4'-5-PeCB (126)	0.005	0.1
	3,3',4,4',5,5'-HxCB (169)	0.00005	0.001
Mono-ortho PCBs	2,3,3',4,4'-PeCB (105)	<0.000005	0.0001
	2,3,4,4',5-PeCB (114)	<0.000005	0.0001
	2,3',4,4',5-PeCB (118)	<0.000005	0.00001
	2',3,4,4',5-PeCB (123)	<0.000005	0.00001
	2,3,3',4,4',5-HxCB (156)	<0.000005	0.001
	2,3,3',4,4',5'- HxCB (157)	<0.000005	0.0001
	2,3',4,4',5,5'- HxCB (167)	<0.000005	0.00001
	2,3, 3',4,4',5,5'- HpCB (189)	<0.000005	0.00001

PCBs in Washington's Environment

Air and Soil

Due to long-range regional and global atmospheric transport, PCBs are present in all parts of the environment. Most of the PCBs in air come from volatilization of PCB-contaminated soil and surface water. In the atmosphere, PCBs are primarily associated with the gaseous phase; approximately 10% is adsorbed to particulates, especially the higher chlorinated forms. Less chlorinated compounds travel farther than highly chlorinated compounds, which tend to stay closer to the source of contamination. Atmospheric deposition is, in turn, the dominant source of PCBs to most soil and water surfaces. The cycle of persistent compounds like PCBs depositing onto soil and then revolatilizing back into air is often referred to as the grasshopper effect.

PCB levels in the atmosphere have been decreasing slowly since the late 1970s when EPA began restricting their use (EPA Integrated Atmospheric Deposition Network <http://www.epa.gov/glnpo/glindicators/air/airb.html>, Venier and Hites 2010, ASTDR 2000). Due to residual sources in the U.S. and long-range transport from other countries, PCB levels in air may be leveling off after a period of decreasing.

Air in rural and remote locations has lower PCB levels than urban air, which is a source to nearby environments. Nationally, average total PCB concentrations at background locations (not near known sources of PCBs) are in the approximate range of one to several hundred pg/m^3 (Hornbuckle and Robertson, 2010). In contrast, concentrations near Lake Superior in the 1970s were well over 1,000 pg/m^3 due to influences from upstate New York and the East Coast (EPA Integrated Atmospheric Deposition Network)

The limited data available for PCBs in Washington's air has been from measurements of wet (rainfall) and dry (particulate) deposition rates to water and land surfaces ($\text{ng}/\text{m}^2/\text{day}$) rather than mass per unit volume. In 2008, Brandenberger *et al.* (Ecology 2010d) recorded PCB fluxes to the Puget Sound basin at seven stations from Nisqually River to Padilla Bay. The median flux across all stations and rain events was 0.51 $\text{ng}/\text{m}^2/\text{day}$. Similar results were obtained for most areas, except Tacoma's Commencement Bay had a median of 1.8 $\text{ng}/\text{m}^2/\text{day}$. Brandenberger *et al.* concluded that PCB deposition rates to the Puget Sound basin were similar to background sites in New Jersey (0.82 $\text{ng}/\text{m}^2/\text{day}$; 1999-2000), but lower than Chesapeake Bay (9.0 $\text{ng}/\text{m}^2/\text{day}$; 1990-1991) and Jersey City, NJ (11 $\text{ng}/\text{m}^2/\text{day}$; 1999). King County recently completed an air deposition study at six stations in the Lower Duwamish/Green River watershed (King County 2013a). Station locations included three in the Lower Duwamish River area, two in downtown Kent and one in Enumclaw. Median fluxes of total PCBs ranged from 1.1 $\text{ng}/\text{m}^2/\text{day}$ in Enumclaw to 16.9 $\text{ng}/\text{m}^2/\text{day}$ in the South Park neighborhood of the Lower Duwamish River. King County has also measured air deposition to Lake Washington at one station near Sand Point; a median flux of 1.39 $\text{ng}/\text{m}^2/\text{day}$ was estimated from these measurements (King County 2013b).

The Western Airborne Contaminants Assessment Project for national parks in the western U.S. included Mount Rainier, Olympic, and North Cascades parks (Landers *et al.* 2008). The results, however, are of limited use for present purposes in that only eight PCB compounds were analyzed and detection frequency was low.

Meijer *et al.* (2003) estimated that the contemporary PCB burden in background soils is about 2% of the known production volume. PCB levels in U.S. background soils generally average from several hundred to several thousand ppt dry weight (Hornbuckle and Robertson, 2010). An EPA nation-wide survey of soil at 27 remote or rural sites in 2003 put the average total PCB concentration at 3,089 ppt (EPA 2007). The single Washington site sampled during the study – Lake Ozette on the northwest coast – had 2,419 ppt.

With the exception of site-specific determinations for contaminated sites, the PCB background in Washington soils has not been well characterized. Relatively more is known about PCBs in Washington's marine and freshwater environment, as discussed below.

Marine and Fresh Waters

Historical vs. Recent Trends

PCB levels in Washington's marine and fresh waters have decreased substantially since peaking in the 1970s. This has been attributed to EPA's restrictions and bans on PCBs in the late 1970s and early 1980s, similar actions in Canada and other countries, contaminated site cleanups, improved wastewater treatment, losses through volatilization and metabolism of lighter compounds, and deep burial in aquatic sediments.

Although historical declines have been documented, there are components of Washington's marine and freshwater ecosystems where a decreasing trend is no longer evident. In most cases, the time-trend for PCBs can be characterized by an initial rapid decline after the ban, followed by a slowing and, ultimately, low to negligible rate of decrease over recent years, waterbodies benefitting from cleanups being a notable exception. Current PCB levels continue to be a concern for the health of fish, wildlife, and humans in Washington.

The effect of the 1970s and 1980s regulations can be clearly seen in age-dated sediment cores from Puget Sound and Lake Washington (Figure 15). A rapid increase in concentrations occurred in both Puget Sound and Lake Washington into the mid-1970s, reaching 35 ppb and 250 ppb, respectively, in sediments at these two locations. Concentrations in the recent past declined to around 10 to 20 ppb. (Detections shown prior to the mid-1930s when PCBs were first introduced are analytical noise.) A sediment core from Lake Spokane (lower Spokane River) in eastern Washington showed a similar steep decline in the 1960s and 1970s, followed by a gradual reduction over a 20-year period from approximately 1980 to 2000 similar to what was observed in Lake Washington (Ecology 2011c).

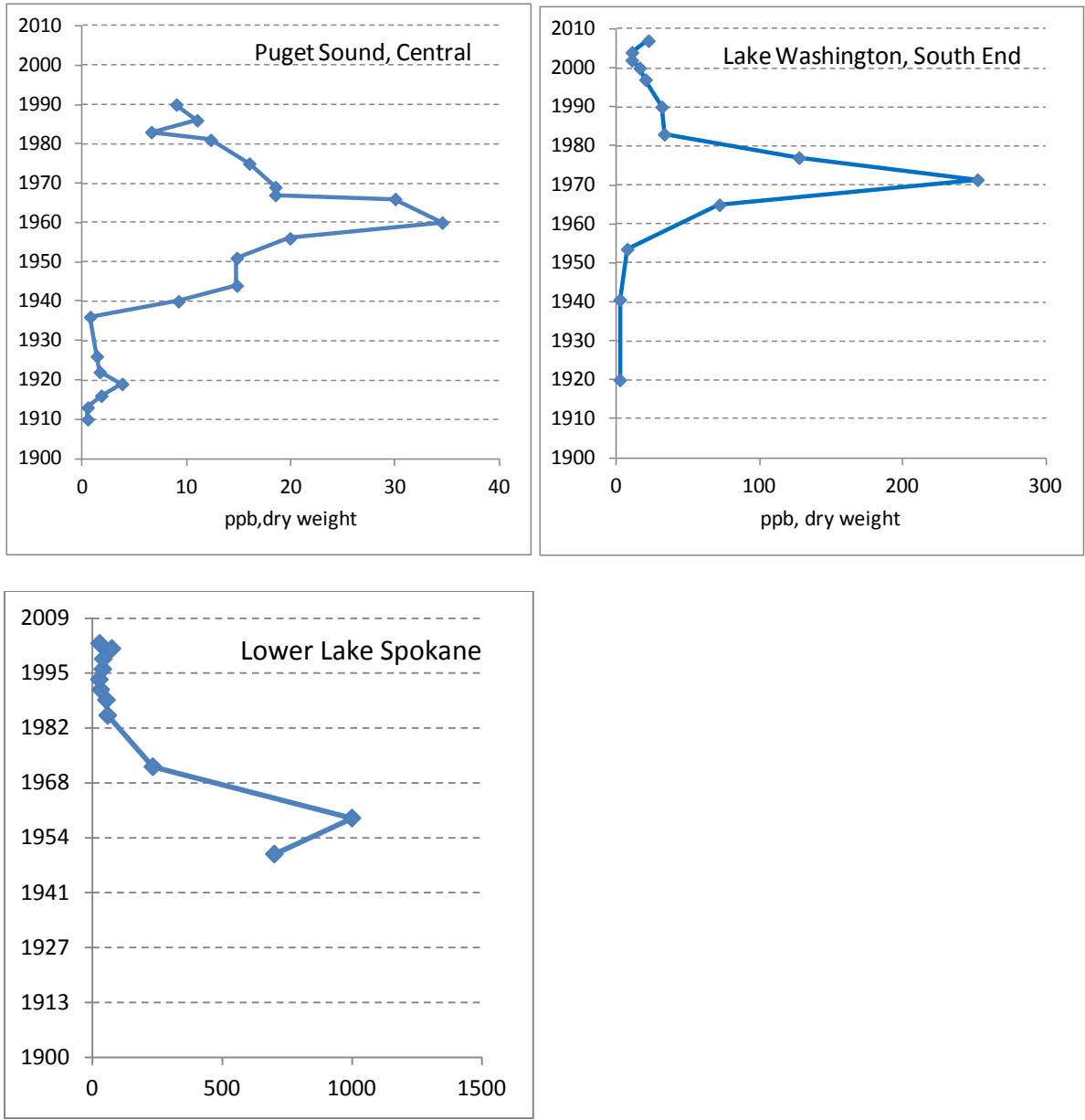


Figure 15. Total PCBs in Age-Dated Sediment Cores from Puget Sound, Lake Washington, and Lake Spokane

NOAA’s Mussel Watch has monitored PCBs in marine mussels from the mouth of the Columbia River to Puget Sound since 1986. Results show that PCBs have been declining slowly, although somewhat erratically, in Washington’s marine waters (Figure 16). After a steep decline in the mid-1980s, there have been two spikes of unknown origin, most obvious at the regional hot spot: Four-mile Rock in Elliott Bay. PCB levels in Puget Sound mussels remain well above national median concentrations (Mearns 2013, O’Connor and Lauenstein 2006).

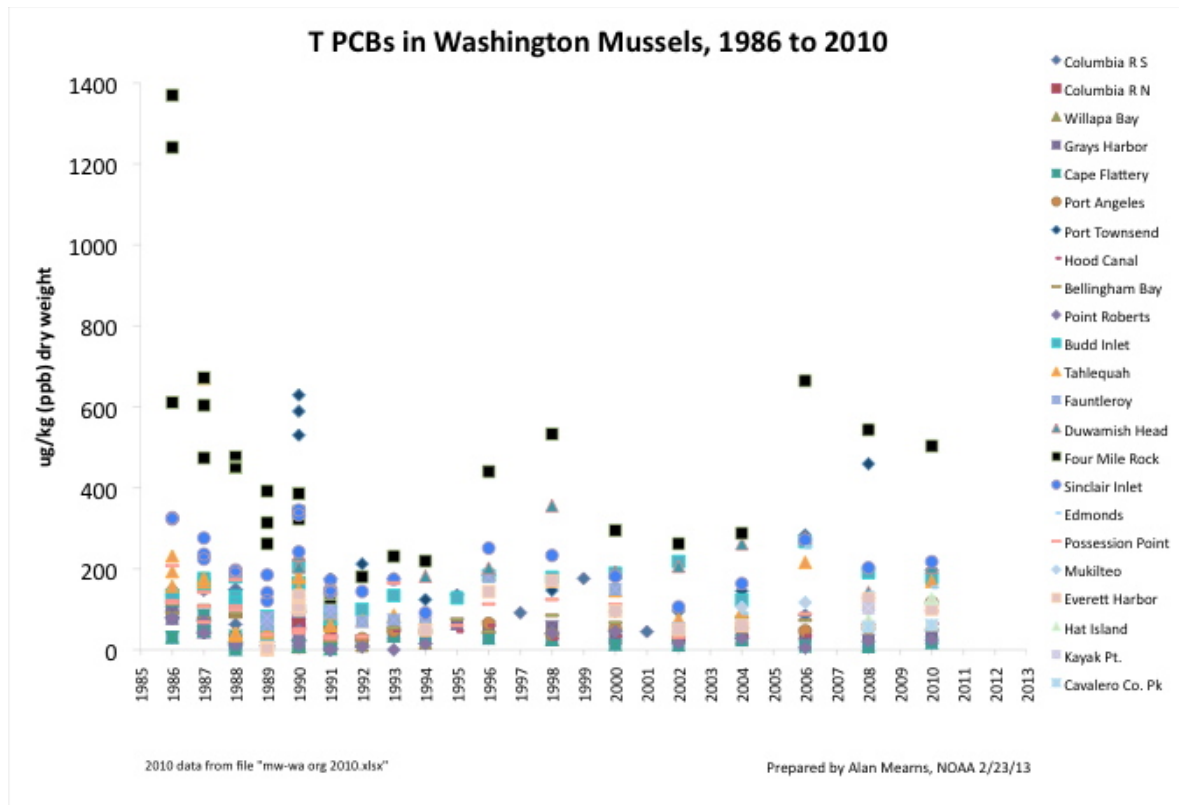


Figure 16. Total PCB Concentrations in Marine Mussels from Columbia River to Puget Sound: 1986 – 2010

(Data from NOAA National Mussel Watch Program, prepared by Alan J. Mearns, NOAA, Seattle)

Compared to historical levels, PCBs have declined in Puget Sound harbor seals (1972 to 1997) and killer whales (1993-1995 vs. 2004-2006) that inhabit or transit Puget Sound (Calamabokidis *et al.* 1999, Krahn *et al.* 2007, Hickie *et al.* 2007). Despite these declines, levels of PCB associated with health impacts are observed in seals from this region (Strait of Georgia) and most Southern Resident killer whales exceed health effects thresholds for PCB residues (Cullon *et al.* 2009, Hickie *et al.* 2007, Krahn *et al.* 2009). The PCB decline in these animals has been slowed by continued atmospheric delivery of PCBs from other parts of the world and internal cycling (Johannessen *et al.* 2008). Figure 17 shows the PCB changes observed in the blubber of South Puget Sound harbor seals up until 1997.

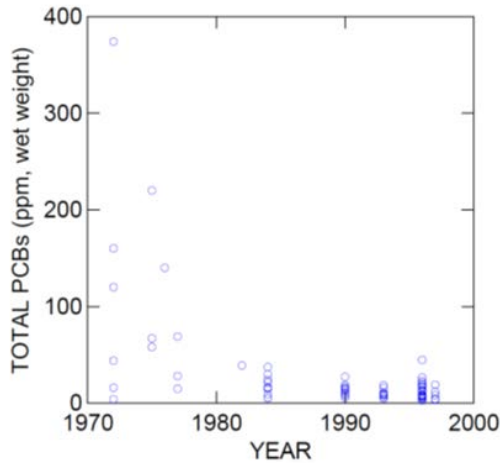


Figure 17. Historical Decline in PCB Levels among South Puget Sound Harbor Seals: Blubber Samples 1972-1991 (Calambokidis, 1999)

Monitoring by the Washington Department of Fish and Wildlife (WDFW) for the Puget Sound Estuary Monitoring Program (PSEMP) gives a mixed picture of PCB time-trends in edible tissues of marine fish (West 2011, West *et al.* 2011). Levels have declined in coho salmon from central Puget Sound, but only until the 1990s. Trend data do not exist for Chinook salmon. There is no evidence of a PCB decline in four stocks of Puget Sound herring. English sole from all urban and non-urban monitoring locations except Sinclair Inlet show no significant change in PCB concentrations over the past 20 years (Figure 18). There is some evidence of improvement in Sinclair Inlet in recent years, which has been attributed to reduced stormwater loading, and dredging and capping of contaminated sediments in 2000-2001 (O'Neill *et al.* 2011). Sole are a bottom-living species that demonstrate the link between PCBs in sediment and biota.

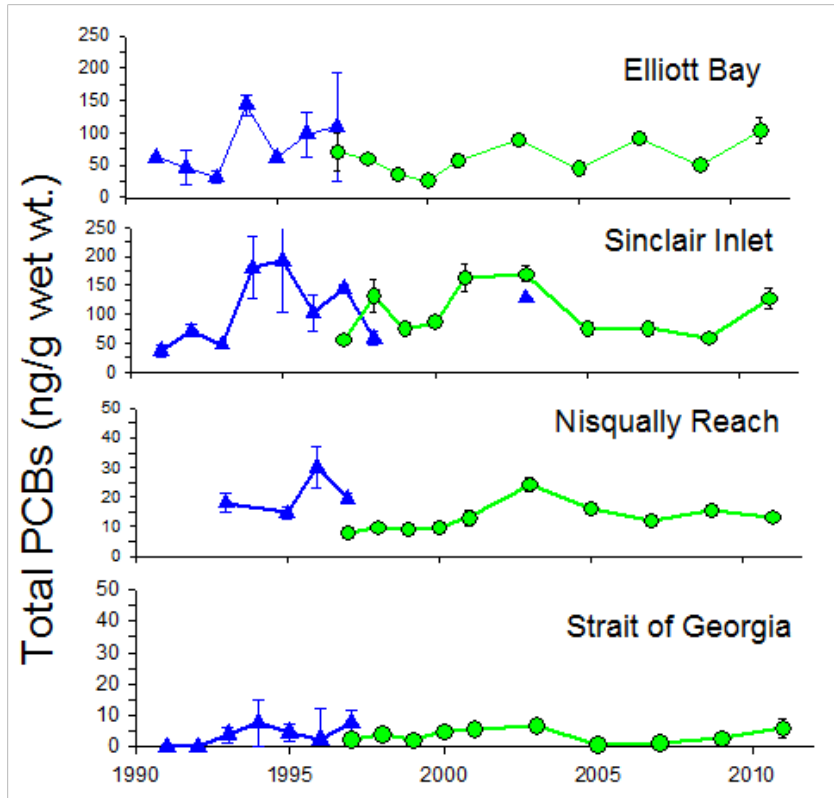


Figure 18. 20-year Time Series for PCBs in English Sole from Selected Urban and Non-urban Locations in Puget Sound (prepared by James West, WDFW; parts per billion; symbol shift indicates change in analytical method)

Long-term trend data are limited for Washington freshwater fish. PCB levels have declined in Spokane River fish since the early 1990s due to cleanup of hazardous waste sites, excavation and capping of contaminated river sediments, and reduced discharge from industrial and municipal treatment plants (Ecology 2011a, EPA 2009).

The U.S. Geological Survey (USGS) analyzed changes in PCB residues in whole fish samples collected from 16 stations in the Columbia River Basin between 1970 – 1986, and in 1997 (Hinck *et al.* 2004). Not surprisingly, a number of sites had lower levels in 1997 than in the 70s or 80s. USGS observed, however, that criteria for the health of fish or wildlife were still exceeded and concluded that PCBs remain a cause for concern. Historical declines have also been documented for PCBs in Columbia River otter, mink, eagle, and osprey (EPA 2009), all of which prey largely on fish. Here again, the comparison is primarily with samples collected in the 70s and 80s.

Current Levels and Spatial Patterns

Water

Due to the extremely low solubility of PCBs and the high cost of analysis, there have been few attempts to measure concentrations in the water column. As part of the Puget Sound Toxics Loading Analysis (PSTLA), Ecology analyzed PCBs at four sites in Puget Sound, three sites at the eastern end of the Strait of Juan de Fuca, and five major Puget Sound rivers in 2009-2010 (Ecology 2011d). Average concentrations in the Strait of Juan de Fuca (20 ppq) and Puget Sound (31 ppq) were similar to that previously reported for the Strait of Georgia (42 ppq) by Canadian researchers (Dangerfield *et al.* 2007). The mean total PCB concentration in the five Puget Sound rivers was 16 ppq. The Puyallup and Stillaguamish Rivers tended to have higher concentrations (up to approximately 40 and 60 ppq, respectively) than the Skagit, Snohomish, or Nooksack (less than 20 ppq). King County (2013b) measured PCB concentrations in Lake Washington, the Ship Canal, Sammamish and Cedar rivers, and three major tributaries to the Lake. The total PCB concentrations in Lake Washington ranged from an average of 54 ppq during mixed conditions to 62 ppq in the hypolimnion and 229 ppq in the epilimnion during stratified periods. Concentrations in the two rivers were similar and together averaged 90 ppq. Ship Canal concentrations averaged 108 to 295 ppq. Concentrations in tributaries were higher than the Ship Canal, ranging from a mean of 451 ppq during baseflow conditions to 2,985 ppq during storm events. Williston (2009) and Gries and Sloan (Ecology 2009a) report concentrations in the Green/Duwamish River, up to 2,360 and 1,600 ppq total PCBs, respectively.

A surface water study conducted for Puget Sound Toxics Loading Analysis (PSTLA) in 16 Puyallup and Snohomish county streams found higher PCB levels during storm-events than for baseflow conditions (Ecology 2011g). The median total PCB concentration was 348 ppq for storm-event samples compared to 227 ppq for baseflow samples. Washington's human health water quality criterion for PCBs is 170 ppq. Of the 70 samples analyzed, approximately 1/3 exceeded the criterion, primarily storm event samples. Except for a single sample, Washington's aquatic life criteria (ranging from 0.014 to 10.0 ppb) for PCBs were not exceeded.

PSTLA estimated the total PCB load to Puget Sound and the U.S. portions of the Straits of Georgia and Juan de Fuca was 3-20 kg per year (Ecology 2011a). Surface water was identified as the major PCB pathway, accounting for 74-76% of the total load (2.55–15.77 kg/yr). The concentration of PCBs in surface runoff was higher from commercial/industrial areas, especially during storm events, but the total loading was lower since industrial/commercial lands occupy less area than other land covers. Overall loads from forests accounted for 83% of the stormwater load (Ecology 2011g). Atmospheric deposition and publicly owned treatment works (POTWs) accounted for 18-20% (0.68-3.76 kg/yr) and 4-8% (0.126-1.75 kg/yr), respectively, of the loading (Ecology 2011a). PSTLA concluded there was insufficient data to estimate PCB loading from groundwater (Ecology 2011f).

Ecology and USGS have used passive sampling techniques (e.g., semi-permeable membrane devices (SPMDs)) to concentrate and estimate PCB concentrations in other freshwater areas (McCarthy and Gale 1999, Ecology 2012b, Ecology 2011a, Ecology 2005, Ecology 2004, Ecology 2010b, Ecology 2011m). Rivers, their tributaries, and lakes that have exceeded the human health criterion to the greatest extent are:

- Columbia River: Wenatchee River, Willamette River (Oregon), Lake River
- Spokane River: (major pathway is stormwater)
- Yakima River: Granger Drain and Sulphur Creek Wasteway (stormwater also a major pathway)
- Walla Walla River: Garrison Creek
- Lake Washington

Water Quality Assessment list

There are 158 303(d) listings for PCBs in Washington's 2012 Water Quality Assessment. The federal Clean Water Act, adopted in 1972, requires that all states restore their waters to be "fishable and swimmable." Washington's Water Quality Assessment lists the water quality status for water bodies in the state. The assessed waters are grouped into categories that describe the status of water quality. The 303(d) list comprises those waters that are in the polluted water category, for which beneficial uses— such as drinking, recreation, aquatic habitat, and industrial use – are impaired by pollution.

For the water body segments found to be impaired (category 5) Ecology conducts a total maximum daily load (TMDL) analysis and develops a cleanup plan for meeting water quality standards. Table 25 shows the PCB listings. There are 158 listings for PCBs in category 5. There are ten listings for PCBs in category 4a, which means a TMDL is completed and a plan is in place to meet water quality standards. Sinclair Inlet is in category 4b, which is similar to category 4a, but there is a pollution control plan instead of a TMDL. Fifty-six waterbody segments across the state are in category 2, meaning there is some evidence for elevated levels of PCBs, but there is not sufficient evidence to list it as impaired.

Figure 19 is a state map of the category 5 and 4 listings along with the Washington DOH fish consumption advisories. DOH guidance to develop fish consumption advisories differs from Ecology's procedures to identify impaired waters. See the section on Human Health for a more detailed explanation. While the details of how a water body segment is considered impaired differs from how a fish consumption advisory is developed, there is a lot of overlap as seen in Figure 19.

Table 25. Water Quality Assessment for PCBs

Number of Waterbody Segments	Category	Description
158	5	Polluted waters that require a TMDL
11	4a and 4b	Polluted water that have a plan in place
56	2	Waters of concern

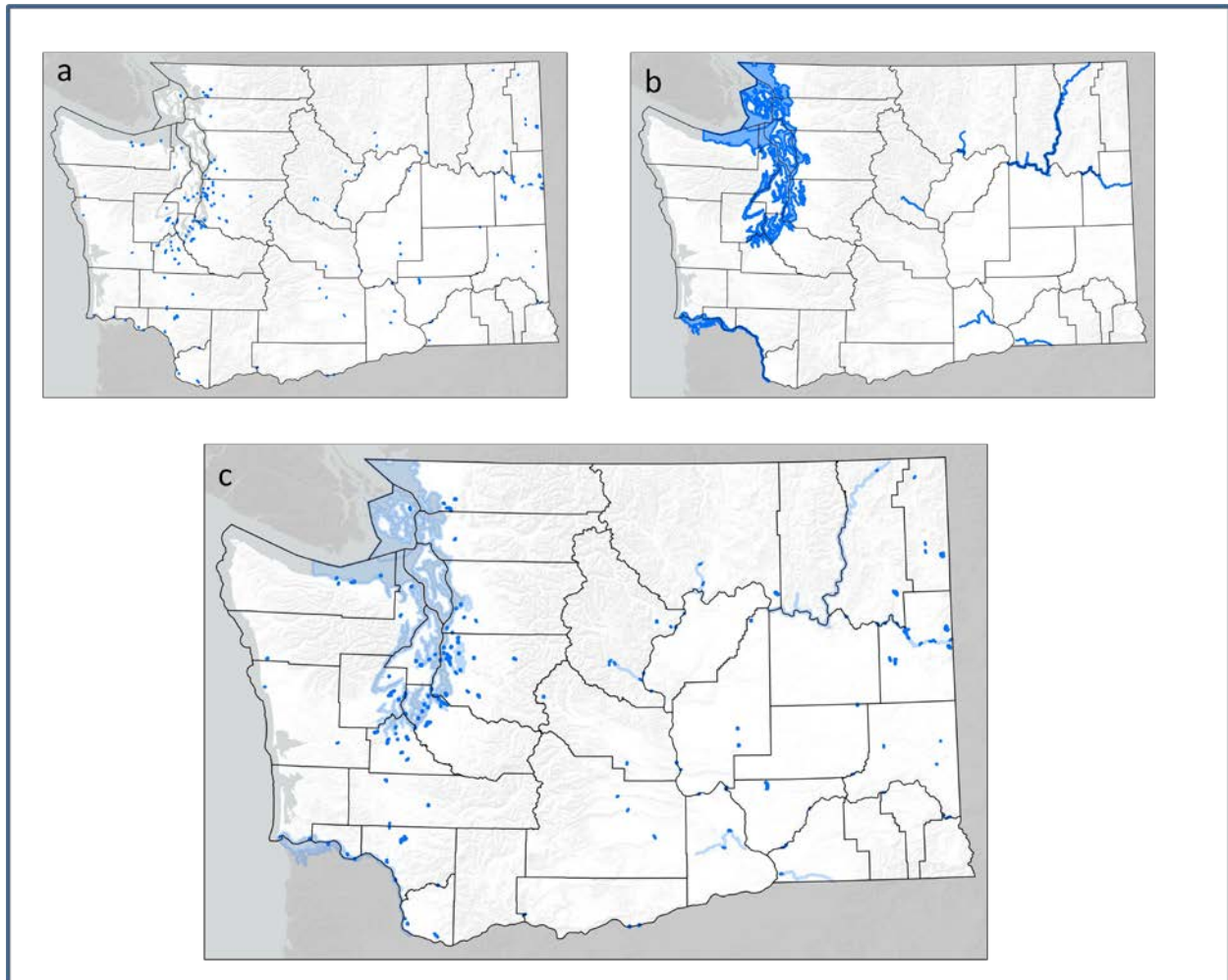


Figure 19. a. Category 4 and 5 303 (d) listings (blue dots). b. Waterbody-specific fish consumption advisories (blue lines, see section on Human Health). c. Overlap of water quality listings and fish consumption advisories.

Marine Sediments

PCBs have been extensively monitored in the marine sediments of Washington. Ecology has PCB data for 630 random sediment monitoring sites in Puget Sound and vicinity up through 2011, collected for PSEMP (e.g., Ecology 2013a). The highest levels are found in urban bays - Elliott Bay, Commencement Bay, Everett Harbor, and the Bainbridge Basin - with concentrations generally diminishing with distance from the shoreline (Figure 20). Particularly

high PCB concentrations occur in the Duwamish and Hylebos Waterways in Seattle and Tacoma. Much lower levels are typically encountered in other marine areas.

Total PCBs in Washington marine sediments range from approximately 5 to 2,000 ppb (dry weight), with an overall median of approximately 15 ppb for the greater Puget Sound area. Ninety percent of PSEMP stations have a total PCB concentration below 40 ppb. Less than one percent exceed Washington State sediment quality standards (12 ppm, organic carbon normalized). For perspective, the mean concentration reported for total PCBs in bottom sediments from the Duwamish Waterway Cleanup site is 1,100 ppb, with maximum concentrations as high as 220,000 ppb, dry weight (EPA 2013g).

Freshwater Sediments

The PCB data on freshwater sediments are limited to studies focused on specific waterbodies or cleanup sites rather than large-scale monitoring programs as in Puget Sound. Spatial patterns for PCBs in Washington rivers and lakes are best illustrated with the more comprehensive fish tissue data, discussed below.

A regional freshwater sediment study by Ecology assessed the background for PCBs in northeast Washington (Ecology 2011h). Sediment samples were collected from fifteen lakes and one river thought to be minimally impacted by local human activity. Median and 90th percentile total PCB concentrations were 2.5 and 6.3 ppb, respectively. Atmospheric deposition is assumed to be the predominant PCB source to these waterbodies. By way of comparison, PCB levels in surface sediments of urban/industrial waterbodies such as Lake Washington and Lake Spokane approach 50 - 60 ppb (Ecology 2010a, Ecology 2011c).

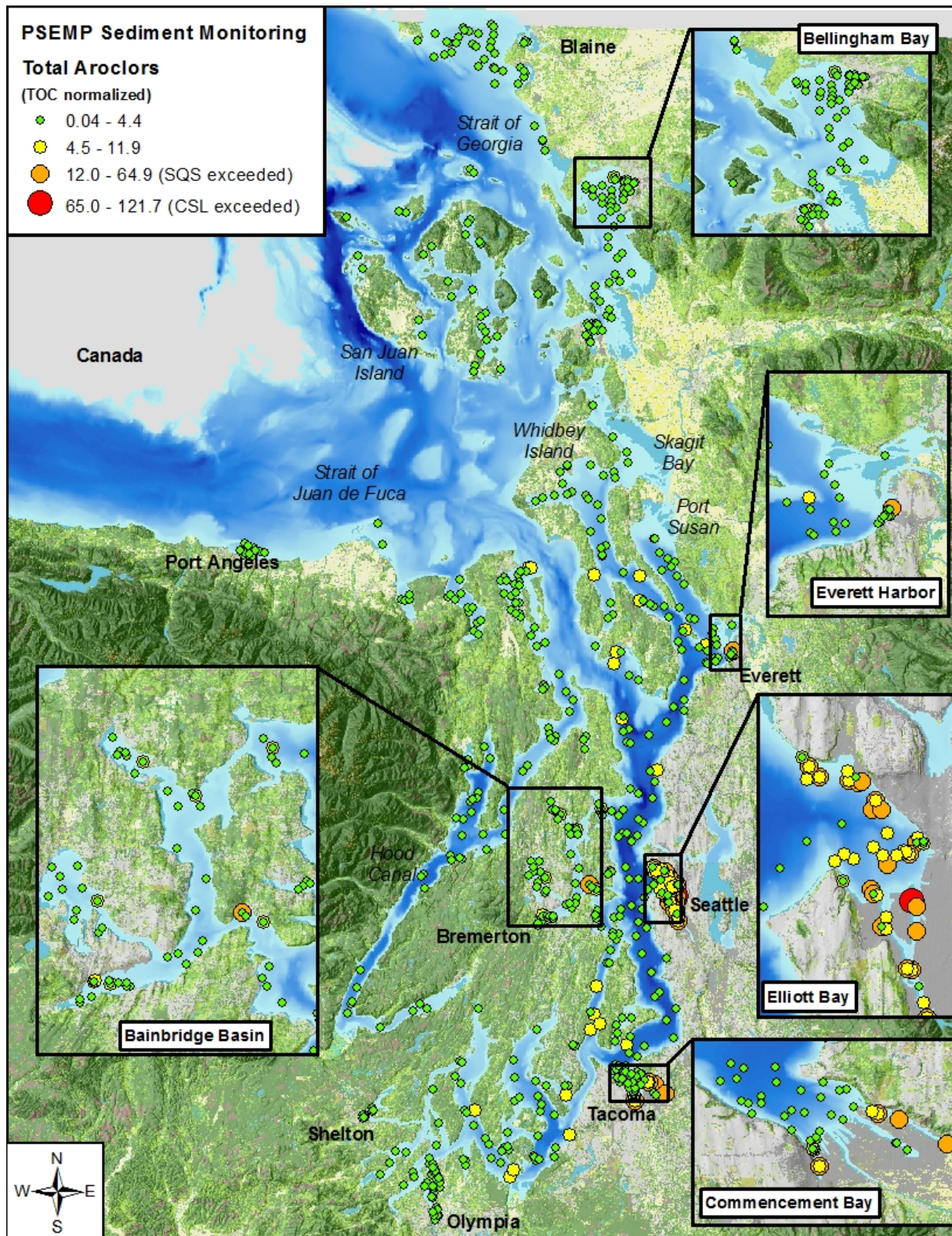


Figure 20. Distribution of PCBs in Marine Sediments from Puget Sound to Strait of Georgia (prepared by Sandra Weakland, Ecology Environmental Assessment Program; parts per billion, normalized to total organic carbon).

Fish

WDFW has monitored PCB levels in Puget Sound marine fish since 1992. Figure 21 summarizes the total PCB concentrations measured in edible tissues of four important marine and anadromous species. The highest concentrations have been observed in herring (whole fish), followed by Chinook salmon, English sole, and coho salmon, in that order. Median and 90th percentile concentrations for these species are 159/234 ppb (herring), 44/95 ppb (Chinook), 23/135 ppb (sole), and 10/26 ppb (coho). The fish tissue equivalent of Washington's human health water quality criterion for PCBs is 5.3 ppb. For more information on exposure to people from fish and fish advisories, see the section on Human Health. All samples of herring and Chinook, and most (70 – 80%) of the English sole and coho have exceeded the criterion.

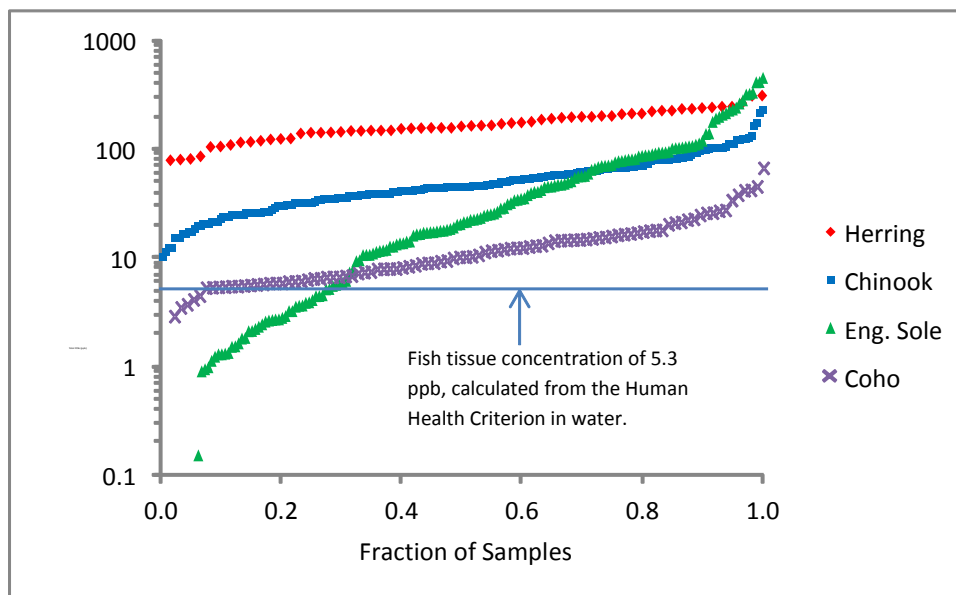


Figure 21. PCBs in Edible Tissues of Four Species of Puget Sound Fish (1992-2010 data provided by James West, WDFW; N =60 – 210)

Puget Sound herring are 3 to 9 times more contaminated with PCBs compared to Strait of Georgia herring (West *et al.* 2008). The high concentrations in this pelagic species suggest continued input of PCBs to the water column, rather than direct uptake from contaminated sediments (O'Neill *et al.* 2011). WDFW's herring studies show Puget Sound is a regional hot spot for PCBs in the food web on the Pacific coast (Figure 22). Within Puget Sound there is a gradient of decreasing PCB levels in plankton and several pelagic fish species moving away from urban areas (West *et al.* 2011).

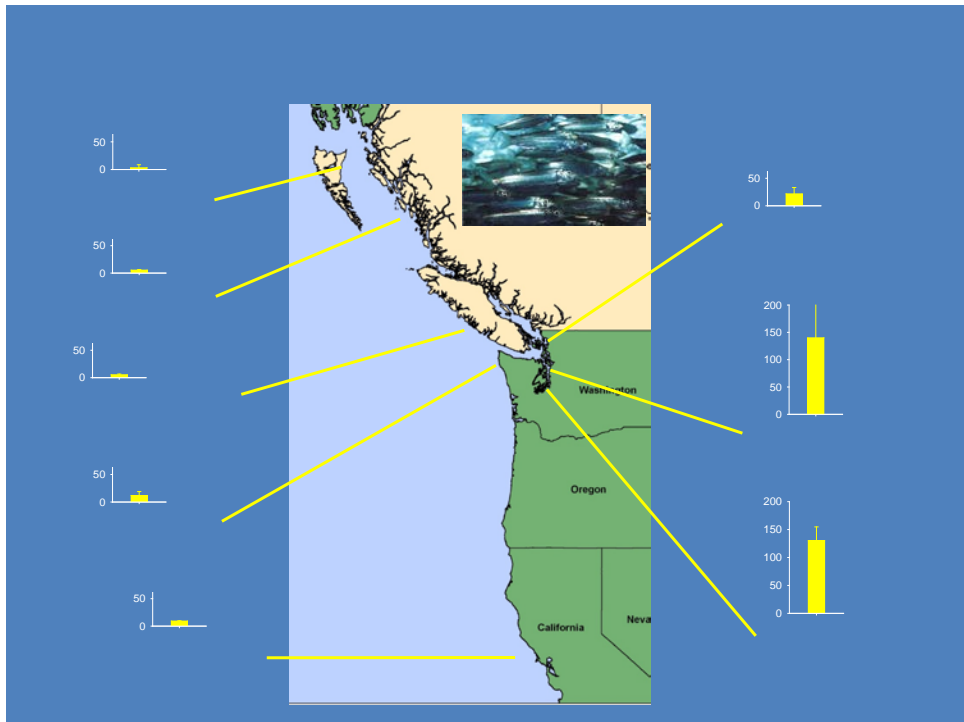


Figure 22. PCB Spatial Patterns in Herring: British Columbia, Washington, and California (prepared by James West, WDFW, and Sandie O’Neill, NOAA-NWFSC)

A high percentage of Chinook are resident in Puget Sound, with 29% of sub-yearlings and 45% of yearling out-migrants displaying resident behavior (O’Neill and West, 2009). Puget Sound Chinook are 3 to 5 times more contaminated than coastal Chinook (West 2011). According to O’Neill *et al.* (2011), 23-100% of juvenile Chinook from Puget Sound urban bays and 19% of returning adult Chinook have PCB levels above effects thresholds. The lower levels in coho are more reflective of combined oceanic and Puget Sound conditions.

English sole show a strong north-south gradient in PCB concentrations, increasing from the Strait of Georgia into Puget Sound (Figure 23). Sole from urban bays, especially the Duwamish River estuary, have much higher PCB levels than fish from non-urban locations. The degree of contamination in Puget Sound sole is positively correlated with PCB levels in the sediments (West 2011). Adverse effects on reproduction, growth, and immune response in English sole and other fish species have been attributed to the elevated levels of PCBs and other legacy contaminants in Puget Sound embayments (Collier 2009).

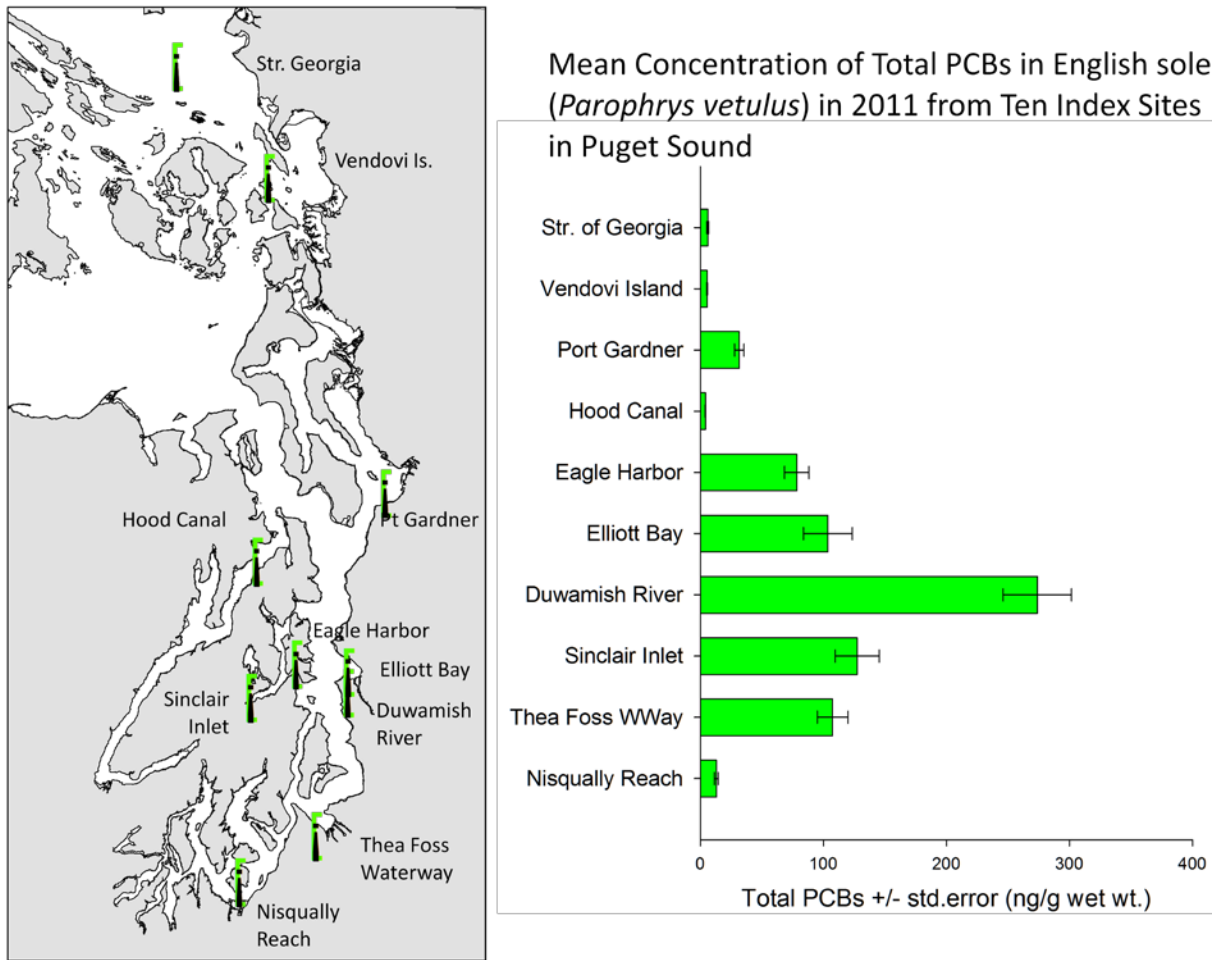


Figure 23. PCB Spatial Patterns in English Sole Muscle: Puget Sound and Vicinity (prepared by James West, WDFW; parts per billion).

A Pacific coast survey by the National Marine Fisheries Service showed outmigrating juvenile Chinook salmon typically have 2 to 5 times higher concentrations of PCBs and other contaminants compared to outmigrating coho (Ecology 2007). Of the 12 estuaries sampled, PCBs were highest in Chinook from the Duwamish River and Columbia River. The average PCB content in juvenile Chinook from these areas was near or above effects thresholds for growth and survival. For the Columbia River, the tidal freshwater portion of the estuary between Portland and Longview appears to be an important source of contamination. PCB levels were higher in fish that feed and rear in the lower river as opposed to those that migrate more rapidly through the estuary (Arkoosh *et al.* 2011, Johnson *et al.* 2013).

Figure 24 summarizes data obtained since 1997 on total PCBs in muscle tissue of resident freshwater fish collected throughout Washington, drawn from studies by EPA, Ecology, and others (CH2MHill 2007, Delistraty 2013, EPA 2002, Ecology 2004, Johnson *et al.* 2007, Ecology Washington State Toxics Monitoring Program, e.g., Seiders *et al.* 2012). The statewide natural background for PCBs in edible fish tissue has been estimated at 6.5 ppb (90th percentile;

Johnson *et al.* 2010). Large areas of the state have relatively low PCB levels (<20 ppb) not greatly above background. However, elevated to high concentrations are also commonly encountered, especially in the Columbia River, some of its major tributaries, and the Seattle urban area. In approximate decreasing order, the following ten rivers and lakes are reported to have the highest total PCB concentrations in fish muscle samples (1,100 to 60 ppb, site average):

- Wenatchee River
- Lake Washington
- Middle Columbia River
- Green Lake (Seattle)
- Spokane River
- South Fork Palouse River
- Upper Columbia River
- Walla Walla River
- Lower Columbia River
- Snake River

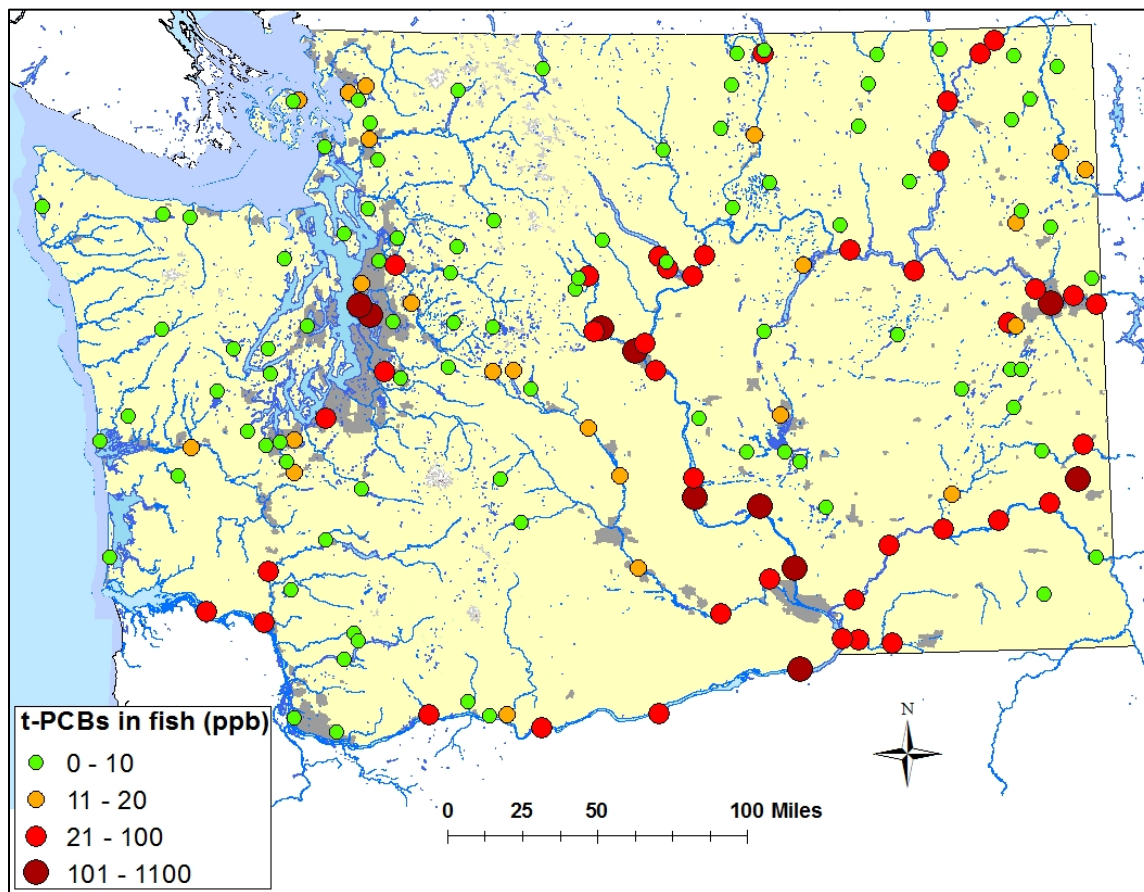


Figure 24. Average PCB Concentrations in Fish Muscle Samples from Washington Rivers and Lakes
 (prepared by Keith Seiders, Ecology Environmental Assessment Program; 1997-2010 data, N = 587).

Figure 27 in the section on Human Health shows statewide data on PCB levels in fish tissues (fillet). There is a line at 5.3 ppb, which is equivalent to the human health water quality criterion, and a line at 23 ppm, which DOH uses as a screening level for advisories. About 60% of samples exceed the 5.3 ppb level calculated from the water quality criterion. The median concentration

statewide for total PCBs in freshwater fish is approximately 10 ppb. Ninety percent of samples are less than 85 ppb.

High mountain lakes experience enhanced atmospheric deposition of PCBs due to colder temperatures and greater amounts of precipitation (Blais *et al.* 1998, Gillian and Wania 2005). USGS analyzed PCBs in fish from 14 pristine Washington lakes over 3,000 ft. elevation (Moran *et al.* 2007). Although a relatively insensitive analytical method was used, total PCB concentrations of 17 – 20 ppb were found in approximately 20% of the tissue samples.

Mammals and Birds

Southern Resident killer whales are among the world's most PCB-contaminated marine mammals, which has been implicated in a range of negative health effects (Alva *et al.* 2012). It is estimated that Southern Residents have 4 to 7 times the daily PCB intake compared to Northern Residents (Cullon *et al.* 2009). Salmon, especially Chinook, comprise most of their diet and are thus the major source of contamination (Cullon *et al.* 2009). Transient killer whales have higher levels of PCBs compared to either resident population (Ross 2006) and are in a higher trophic level, eating marine mammals (Ross *et al.* 2000). PCBs have been seen to cause reproductive impairment, immunotoxicity, skeletal abnormalities, endocrine disruption, and negative effects on population growth rate in marine mammals (Alva *et al.* 2012). While there are no established health effects thresholds for PCBs in killer whales, the levels in Puget Sound killer whales is above the health effects threshold for harbor seals that is based on immune system and endocrine endpoints and predicted to remain high for decades, mostly driven by the long half lives of PCBs (Hickey *et al.* 2007).

Total PCBs in blubber biopsy samples collected in 1993-1997 averaged 146 ppm (lipid weight) in Southern Resident males vs. 37 ppm in Northern Resident males and 251 ppm in Transient males (Ross *et al.* 2000). Southern resident males sampled in 2004/2006 averaged 62 ppm (Krahn *et al.* 2007). Females off-load PCBs during calving and lactation, resulting in lower concentrations than males, by about a factor of three in the 1993-1997 study. PCB levels rise quickly in nursing calves, then the levels fall as the PCBs are diluted with growth, with levels in males increasing with age and females increasing until the onset of reproduction (Hickey *et al.* 2007).

A north-south gradient in increasing PCB levels has also been observed in harbor seals, which are non-migratory. Ross *et al.* (2004) reported average total PCB concentrations in adult seal blubber of 1.1 ppm in Queen Charlotte Strait, 2.5 ppm in the Strait of Georgia, and 18 ppm in Puget Sound. More recently, WDFW analyzed the blubber of 24 seal pups at four locations in Puget Sound (Ecology 2011i). Total PCBs ranged from 1.0 to 9.4 ppm. Concentrations increased following the order Hood Canal < Whidbey Basin < South Sound < Main Basin (Figure 25). As with killer whales, indicators of adverse health impacts have been observed in harbor seals and

linked to PCBs or other persistent organic pollutants (Cullon *et al.* 2012, Ecology 2011i, Mos *et al.* 2010).

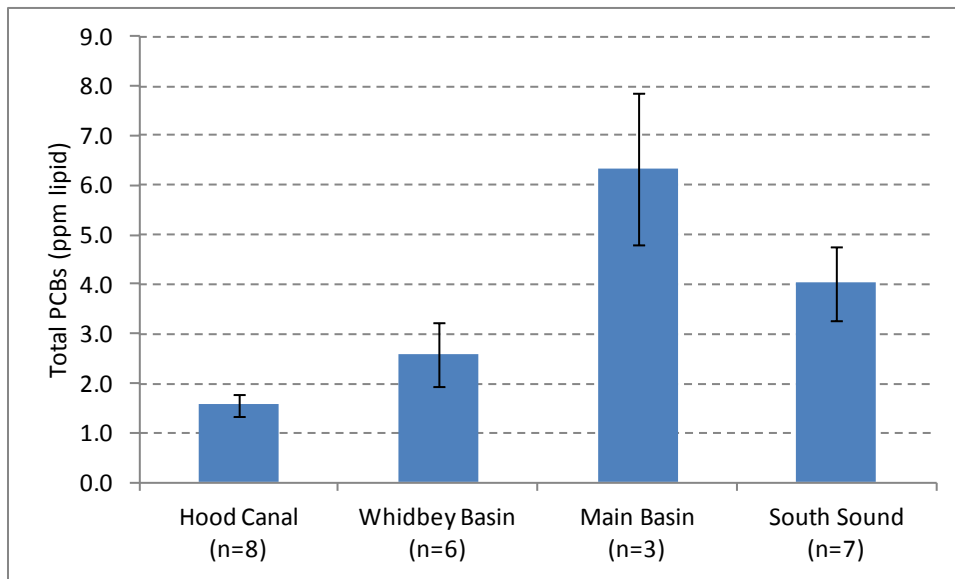


Figure 25. PCBs in Blubber of Puget Sound Seal Pups, 2009 (from Ecology 2011i; mean and standard error)

USGS and USFWS have analyzed PCBs in lower Columbia River wildlife. Their most recent data (1990-2004) show average wet weight concentrations of 0.2 ppm in mink livers, 0.5 ppm in otter livers, 0.8 ppm in osprey eggs, and 5.4 ppm in eagle eggs (Henny *et al.* 1996, Grove *et al.* 2007, Henny *et al.* 2007, Buck *et al.* 2005).

Another USGS study reported mean total PCB concentrations of 0.8 ppm in osprey eggs collected from the lower Duwamish River in 2006-07, but noted these birds had been feeding largely on hatchery raised salmon smolts (Johnson *et al.* 2009). The significance of hematological and biochemical differences observed between eggs from the Lower Duwamish and a reference site (upper Willamette River) was unclear. The same study reported 2.6 ppm, 1.9 ppm, and 0.7 ppm total PCBs, respectively, in osprey eggs collected from Lake Washington, the Lower Duwamish River, and Snohomish River estuary in 2002-2003.

Cleanup Sites

There are 336 hazardous waste sites listed in Ecology's Integrated Site Information System (ISIS) as having confirmed or suspected PCBs. Many sites had multiple media with confirmed or suspected PCB contamination. Of the sites with confirmed or suspected PCBs in sediments, all but 15 also had soil with confirmed or suspected PCB contamination.

Table 26. PCB clean up sites

Medium	# of Sites	Confirmed	Suspected	Remediated	Below CUL
Soil	295	165	99	11	20
Groundwater	173	60	109	2	2
Sediment	62	47	11	1	3
Surface Water	89	19	64	6	0
Air	18	3	14	0	1

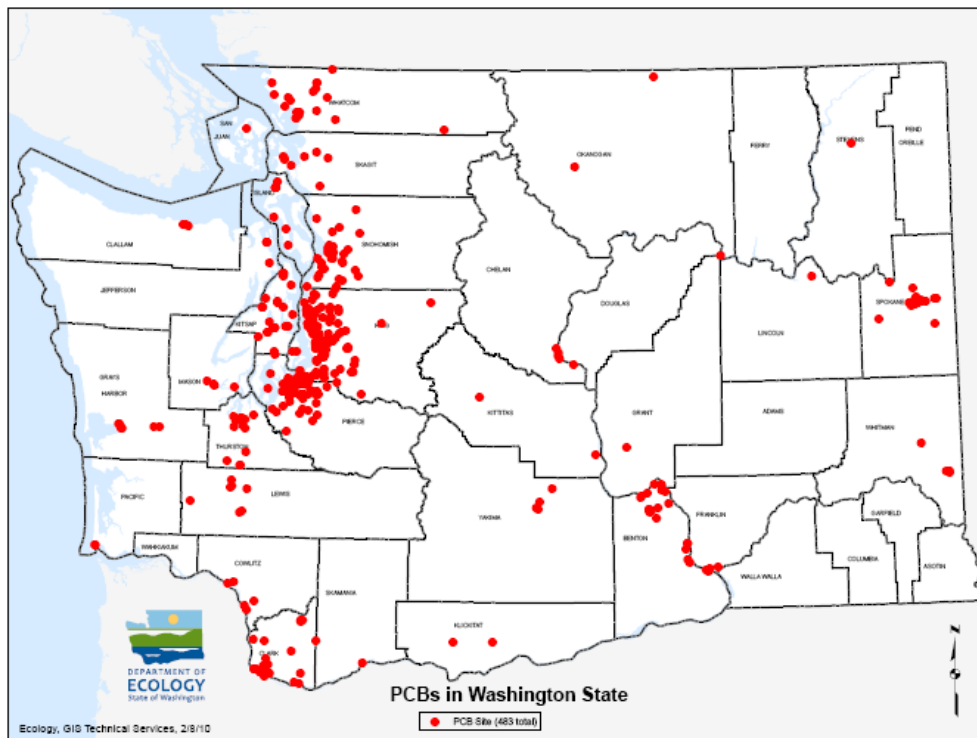


Figure 26. Figure of 483 PCB cleanup sites in Washington in 2010

Waste

Landfills

All Shred Residue

The material that remains after other parts are removed from automobiles at end of life for reuse or proper disposal is sometimes shredded and nearly all is used as landfill cover. PCBs may be present in automobiles in hydraulic fluids, plastics, voltage regulators, electric motors, switches, small capacitors, and light ballasts, leading to PCBs in the shredder waste. The all shred residue (ASR) is not just from end of life vehicles, but also includes consumer goods and commercial scrap. Feedstock sources may come from in or out of state. This material is difficult to sample, due to its heterogeneity in waste streams, metal extraction processes, and changes in manufacturing materials.

PCB concentrations in untreated shredder waste have been measured between 0.59 – 129 mg/kg and treated shredder waste contains 2.6 - 45.1 mg/kg (McKee *et al.* 2006). McKee *et al.* further estimated that there is 270,000 tons of shredder waste from automobiles and appliances in California, leading to an estimate of 30-6,970 kg of PCBs (Average = 3,500 kg) in untreated shredded waste and 140-2,440 kg of PCBs (Average = 1,300 kg) of treated shredder waste in the Bay Area.

We have some information on PCBs in shredder residue in Washington in a 2013 report prepared for EPA Region 10 (Toeroek 2013). In this study Ecology and EPA sampled four facilities for PCBs (using Method 8082) and other analytes. There were different sampling protocols to look at variation, and all included a 9.5 mm sieve. Based on observations during the sampling, end of life vehicles were only shredded during two of the four days sampling occurred and all samples included consumer goods and commercial scrap. PCB concentrations ranged from 0.4 - 59 ppm (mg/kg) for the Aroclors tested, with a mean of 19 ppm, which is similar to the other results mentioned above.

Across Washington, shredders generate over 500 tons of ASR daily (Full Circle Environmental and Ecology 2011) and landfills reported disposing of 230,157 short tons (208,983 metric tons) of ASR in 2012. Using the range of concentrations found of 0.4 - 59 and the average concentration found of 19 ppm, results in an estimated 80 to 12,000 kg (12 metric tons) with an average of 4,000 kg (4 metric tons) of PCBs in 208,983 metric tons of ASR disposed of in Washington landfills each year.

Electrical equipment

Under federal TSCA, non-leaking small capacitors are allowed to be disposed of as solid waste. However, Washington State applies its own regulations to PCB electrical equipment containing 2 ppm PCBs or more and to materials contaminated to 2 ppm PCBs or more by electrical

equipment. Unless the waste meets specific exclusions under the Washington State PCB rule (WPCB), these items must be properly disposed of and reported to Ecology as WPCB waste by the generator in annual data source reports. The waste code is for proper disposal and does not include more information on concentrations.

From 2009 – 2012, 10,577 MT of PCB-contaminated waste were reported under WPCB (Table 27).

Table 27. PCB-contaminated waste reported under WPCB

Year	WPCB (MT)
2009	2,322
2010	2,616
2011	1,310
2012	4,310

PCB-ballasts are considered moderate risk waste (MRW) when they are disposed of by households (household hazardous waste) and small businesses (small quantity generator waste). The weights reported in Table 28 include ballasts and shipping containers and we have not corrected for that due to the unknown weights of the shipping containers. Estimating that each ballast weighs 1.6 kg, and contains 44g of PCBs the estimated amount of PCBs ranges from 340 to 560 kg each year. Most of these PCB-ballasts go to a hazardous waste landfill outside of Washington State.

Table 28. PCB-ballasts collected as MRW (2010-2012)

Year	PCB-ballasts MRW (lbs)	PCBs (kg)
2010	32,871	410
2011	44,996	560
2012	26,885	340

Biosolids

Biosolids fall under the Clean Water Act (CWA) and the 503 rule (40 CFR 503). There are no requirements to monitor PCBs in biosolids, nor a regulated level of PCBs in biosolids. EPA(1995) made a “policy decision to delete all organic pollutants from land application and surface disposal sections of the final Part 503 rule because these pollutants met one of the following criteria: (1) the pollutant has been banned or restricted for use in the United States or it is no longer manufactured for use in the United States; (2) the pollutant is not present in biosolids at significant frequencies of detection based on data gathered in the NSSS [the National Sewage Sludge Survey], or (3) the limit for a pollutant from the biosolids exposure assessment is not expected to be exceeded in biosolids that are used or disposed based on data from the NSSS.”

EPA continues to investigate pollutants in sewage sludge and uses risk analysis to ascertain which pollutants require monitoring and regulatory levels.

While neither federal nor state regulations require testing of biosolids for PCBs, some jurisdictions such as King County, have tested for PCBs in biosolids (King County 2007). In 2006 Aroclor 1248, 1254, and 1260 were detected and other Aroclors were not detected at the West Point Treatment Plant. Only Aroclor 1254 was detected at the South Treatment Plant. Historically PCB Aroclors have been detected in King County biosolids at the ppb level. We do not have enough information to estimate the amount of PCBs in biosolids in Washington.

PCBs have also been measured in a few samples of Canada Goose guano in the Lower Duwamish area. In four composite samples the total Aroclor PCBs ranged from 28-103 ppb with an average concentration of 58 ppb. This is generally indicative of the ubiquitous nature of PCBs in Washington. This is not enough information to estimate the amount of PCBs in goose guano in Washington.

Environmentally Significant PCBs

As a result of partitioning, transformation, and bioaccumulation, PCB mixtures in the environment do not resemble the commercial products. About half of the 209 possible congeners account for most of the environmental contamination. Based on toxicity, prevalence, and relative abundance, less than 40 congeners are most commonly found in the environment.. Twenty-five of these account for 50-75% of the total PCBs in biological tissues (McFarland *et al.* 1989).

In Washington and elsewhere, PCBs with three to six chlorines (tri- through hexachlorobiphenyls) are the dominant compounds found in environmental samples. Less chlorinated compounds are more volatile and more readily metabolized and eliminated from organisms. Highly chlorinated compounds are relatively less abundant, more tightly bound to sediment particles, and taken up poorly by fish and other aquatic animals.

Twelve PCBs have a co-planar configuration that imparts dioxin-like toxicity (Tables 20 and 25). These compounds are frequently detected in Washington's environment. PCB-118 is the co-planar most often encountered in the highest concentrations (Cleverly *et al.* 1996, Ecology 2011i) most toxic co-planar, PCB-126, is typically present at the lowest concentrations.

Although their toxicity is low relative to dioxin - a tenth or less – these PCBs can impart a significant fraction of the total dioxin toxicity equivalents (TEQ), particularly in higher animals. Co-planar PCBs accounted for up to 89% of the total TEQ in harbor seal pups collected from Puget Sound in 2009 (Ecology 2011i). PCB-118, -105, and -156, in that order, were the major contributors to the TEQ. Cullon *et al.* (2009) reports that PCBs explained the majority of the TEQ in adult salmon from British Columbia and Puget Sound waters. In contrast, the PCB TEQ in Washington freshwater fish is typically much lower than the dioxin TEQ, by an order of magnitude or more in most cases (CH2MHill 2007, USDOE 2010, Ecology 2010c).

PCB-11, a non-legacy PCB, has been identified in Columbia River water and clams (Ecology 2005, McCarthy 2007). In some samples, PCB-11 was either the most or second-most abundant congener detected. PCB-11 is neither associated with historical commercial PCB products nor a breakdown product of the commercial mixtures. The source has been traced to pigments currently used in paint (Hu and Hornbuckle, 2010). Reports of PCB-11 in environmental samples have become widespread in North America (Litton 2006, Grossman 2013). PCB-11 is considered a significant source of contamination to air, soil, and water (Hornbuckle and Robertson 2010).

Model Predictions

Ecology modeled the long-term fate and bioaccumulation of PCBs in Puget Sound (Ecology 2009b). Pertinent findings from Ecology's box model include the following:

- Approximately 97% of the total mass of PCBs in the aquatic ecosystem of Puget Sound is in the active sediment layer (top 10 cm), <1% is in the water column, and <3% is in the biota.
- Decreases in PCBs in sediment and biota are possible by the year 2020 in the urban bays due to burial and transport of sediments.
- Increases in PCBs in sediment and biota are possible by the year 2020 in the larger basins.
- Considering the wide range of uncertainty in loading from outside of the Puget Sound basin, it is possible the mass of PCBs in the aquatic ecosystem of Puget Sound may either increase or decrease over time at the current loading levels.

Ecology is currently re-evaluating this model using more recent data.

A delayed response to environmental declines in PCB levels is predicted for long-lived species like killer whales (~50-year lifespan). According to an individual-based model, Southern Resident killer whales may not fall below PCB effects thresholds for several more generations (Mongillo *et al.* 2012, Hickie *et al.* 2007).

Food web models for Lake Washington and the Spokane River conclude that PCB residues in fish are driven mainly by levels in the sediments in Lake Washington and are an important factor in the Spokane River (Ecology. 2010a and 2011c). Thus, recovery in these water bodies may respond slowly to reductions in external PCB loading.

Results of a mass balance model for the Willamette River basin in Oregon demonstrated that the PCB levels observed in fish could be due entirely to atmospheric deposition from global legacy sources (Hope 2008). In this analysis, PCB sources within the Willamette basin were assumed to be insignificant. Portland was discounted because it occupies a short segment of the lower river isolated by Willamette Falls.

Local Hazard Assessments

Spokane River

The Spokane River has elevated levels of PCBs in Washington. Ecology calculated hazard quotients (HQs) for different endpoints and receptors in six different parts of the river for aquatic life and fish-eating wildlife (Ecology 2001). HQs are ratios of the level of PCBs in the environment and the level at which no adverse effects are expected. If the HQ is greater than 1, then adverse health effects are possible, but do not necessarily occur.

The primary ecological hazards identified were:

1. Possible adverse effects on the sustainability of salmonid populations and fish-eating mammals, primarily in the reach between Trentwood and Nine-Mile Dam.

PCB levels in salmonid fish tissue were high compared to the National Marine Fisheries Service (NMFS) effects threshold for sublethal effects (HQs of 2.2-4.1).

The levels of PCBs in water were high compared to the Great Lakes criterion for reproductive effects on fish-eating mammals (HQs of 4.5-17). Also the PCB levels in fish tissue were high when compared to the British Columbia guideline for reproduction in fish eating wildlife (HQs of 2-6) and compared to the lowest observable effects levels (LOEL) for mink and otter reproduction (HQs of 1.5-2.4).

2. Possible adverse effects on benthic invertebrates in the Trentwood to Monroe Street Dam reach in areas where PCBs have been concentrated in fine-grained sediments, such as behind Upriver Dam. The levels of PCBs in sediment were high compared to the threshold effect for abundance and diversity of benthic invertebrates (HQs of 2.5-9.8)

Puget Sound

As part of the larger, multi-year, multi-agency, project to study toxic chemicals in Puget Sound, the Assessment of Selected Toxic Chemicals in the Puget Sound Basin, 2007-2011 (Ecology 2011a) included a hazard evaluation to estimate the relative hazard posed by the 17 chemicals of concern assessed in the Puget Sound studies. This was not a risk assessment, but part of the effort to prioritize efforts on pollutants in Puget Sound. The hazard evaluation was for the entire Sound, not for hot spots where there are higher levels of contamination, such as in cleanup sites. PCBs were ranked as having the highest level of concern for a range of media and receptors in both the freshwater and marine aquatic environments.

PCBs were found to be at the highest level of concern (Priority 1) for the five categories assessed. The category and the reason PCBs were placed in Priority one is given below for each.

- Aquatic life through surface water exposure. The 90th percentile of observed concentrations of Aroclors was above the chronic Water Quality Standard (WQS) for aquatic species in freshwater.
- Benthic organisms through sediment exposure. The 90th percentile of the observed concentrations exceeds the Sediment Quality Standard for Aroclors for freshwater (FP-SQS) and offshore marine sediment (SQS).
- Tissue Residue Effects. The 90th percentile of observed concentrations was above the 10th percentile of the effects concentration for non-decapod invertebrates for both Aroclors and total congeners.
- Wildlife through seafood consumption. Using Great Blue Heron, Osprey, River Otter, and Harbor Seal as representative species, the daily dose was more than the lowest effect dose divided by 10.
- Human health through seafood consumption. The 90th percentile of observed tissue concentrations was above National Toxics Rule (NTR) water quality criteria for freshwater, nearshore marine, and offshore marine for both Aroclors and congeners for bivalves, fish and invertebrates. Tissue criteria were back calculated from the NTR based water quality criteria.

Environmental data from January 2000 to July 2010 were collected from a variety of sources, and the largest source of data was Ecology's Environmental Information Management (EIM) system. Information on effects levels were found in the scientific literature and regulatory benchmarks. Comparisons to effects levels, criteria, and guidelines were done separately for both PCB Aroclor and congener data. Box Plots showing these comparisons can be found in the Assessment report Appendices D3-D7

<https://fortress.wa.gov/ecy/publications/summarypages/1103055.html>).

Human Health Effects of PCBs

Introduction

There is a very large body of toxicological and epidemiological research on the health effects of PCBs. Research conducted in experimental animals has shown that PCBs can cause a wide variety of adverse health effects including, immune suppression, adverse reproductive effects, abnormal motor and cognitive development, injury to the liver and other internal organs, changes in the endocrine system, and cancer. Epidemiological studies have found evidence of similar adverse effects on human development and behavior, reproduction, immune function, and cancer (ATSDR 2000). The International Agency for Research on Cancer (IARC) recently changed their classification of PCBs and dioxin-like PCBs from “probable human carcinogens” to “human carcinogens” to recognize that there is now sufficient evidence in humans and animals. (Lauby-Secretan *et al.* 2013).

The primary historic uses of PCBs were banned in 1979 but existing electrical equipment and other closed systems containing PCBs were permitted to remain in use (40 CFR part 761). Caulk, joint sealant, paint, and other building materials sold before 1979 may have contained PCBs and could still be in place. PCBs have continued to slowly escape from these historic sources with rapid releases during leaks, fires, and building demolition.

Historically, PCB oils and equipment containing those oils have been disposed in ways that allowed PCB release into the environment. A number of waste sites in Washington have been identified as contaminated with PCBs. Many have been cleaned up but additional clean-up remains. Because many PCBs are persistent and bioaccumulative, these legacy sources of PCBs continue to cycle through air, water, soil, sediments, and biota. Although general environmental levels have dropped dramatically since 1979, human exposure to legacy PCBs in fish, other foods, and air will continue into the future.

In addition, PCBs are inadvertently formed during current production of certain pigments and ink (Hu and Hornbuckle 2010). These PCBs have been detected in colored papers, cardboard, plastics, and textiles and may be released to the environment during manufacturing, use, disposal, or recycling of consumer products (Litten *et al.* 2002, Rodenburg *et al.* 2010). PCB 11 has emerged as a useful indicator of these new sources of exposure since commercial PCBs mixtures did not contain more than trace amounts of PCB 11 (Grossman 2013).

There are 209 possible configurations of chlorine substitutions of the biphenyl molecule. Each possible configuration (called a congener) is assigned a number and most can now be quantified analytically. Because congeners vary in their toxicity and their resistance to metabolism, risk assessment of PCB mixtures is complex. One of the earliest discoveries in the search for common mechanisms of toxicity was that certain congeners have dioxin-like ability to bind to

the aryl hydrocarbon (Ah) receptor. Dioxin-like PCBs are planar or nearly planar in structure (Van den Berg *et al.* 1998). Their interaction with the Ah receptor is dose-dependent, saturable, and induces hepatic enzymes, including aryl hydrogen hydroxylase (also called cytochrome p450 CYP1A1) and 7-ethoxyresorfin *O*-deethylase (CYP4501A2) (Seegal 1996). These enzymes metabolize (or breakdown) a number of environmental chemicals but also act on important endogenous chemicals such as hormones, retinoids, and neurotransmitters (ATSDR 2000).

Several toxic responses have been well correlated with the Ah-receptor binding affinity, including body weight reduction, hepatotoxicity, and thymic atrophy (Seegal 1996). Laboratory animals exposed solely to coplanar PCBs have shown reproductive problems, increases in brain levels of biogenic amines including dopamine, alterations in fetal and neonatal plasma thyroid hormone levels, and neurobehavioral effects (Brouwer *et al.* 1995). Available evidence in lab animals suggests that the maturation of the immune system is especially vulnerable to adverse effects of dioxin-like compounds (Holladay and Smialowicz 2000). Toxic equivalency factors (TEF) for 12 PCB congeners have been developed to facilitate human health risk assessment of mixtures of dioxin-like chemicals (Van den Berg *et al.* 1998, 2005, see Table 24 and Table 29).

EPA and ATSDR have established health recommendations concerning oral intake and inhalation of PCBs. These screening levels help public health agencies and communities identify exposures of concern. The three primary pathways of current PCB exposure for the U.S. general public are diet, indoor air, and ambient air. In addition, ingestion of PCB residues in house dust could be a significant contributor to exposures in toddlers (ATSDR 2000, Harrad *et al.* 2009). Although background exposures in the U.S. population appear to have dropped below levels of concern, special populations at higher risk for exposure exist and require attention. These include people who work around PCB contaminated equipment or materials, who consume fish and seafood from contaminated waters, or who live or work in a building with PCBs in building materials or fluorescent light ballasts.

Historical Episodes of PCB Poisoning

Acute poisoning to PCBs has been documented in people following accidental food contamination and workplace accidents. These incidents underscore why people must be protected from direct contact with concentrated PCB liquids or materials during source removal, transport, and disposal. There have been two episodes of mass human poisoning by inadvertent community-wide consumption of PCB contaminated rice oil. One occurred in Japan in 1968 and the other in Taiwan in 1978-79. Affected people in Japan were diagnosed with “Yusho” which means “the oil disease” and in Taiwan with “Yu-Cheng,” the term for “oil disease” in Taiwanese. About 1700 adults were acutely affected in the Japanese incident. Exposure of adults resulted in increased skin pigmentation, severe acneform eruptions, swelling of the meibomian gland with eye discharge, thickening of the nail bed, numbness in extremities, and respiratory disease (Urabe and Asahi 1985, Ikeda 1996, Nakanishi *et al.* 1985). Affected women who were

pregnant at the time gave birth to children with physical abnormalities (dental disorders, hyperpigmentation of skin) and severe neurodevelopmental problems (Seegal 1996). Exposure monitoring for PCBs in blood of Yusho patients did not begin until five years after the onset of disease.

About 2000 persons were initially affected with illness in the Taiwan incident. Symptoms included hyperpigmentation, acneform eruptions, swelling of eyelids and increased discharge from the eyes, as well as systemic complaints (Lu and Wu 1985). Women who were pregnant at the time of exposure gave birth to children who showed hyperpigmentation, nail deformities, conjunctival discharge and swelling. Eight of the 39 infants born with hyperpigmentation during the four years following the incident died (Hsu *et al.* 1985). A cohort of most of the Taiwanese children ($n = 118$) born to affected mothers up to six years past the incident has been followed and tested annually for cognitive deficits. A comparison population with the same number of children was matched on maternal age, child's birthdate, gender, and neighborhood of residence. Blood PCB levels of Yu Cheng patients were measured early in the disease outbreak and were high (44.4% of 613 patients sampled had blood levels of PCBs between 51-100 ppb). The highest value reported was 1156 ppb (Hsu *et al.* 1985). Yu-Cheng offspring have been shown to have persistent cognitive deficits, lower IQ, and higher rates of problem behaviors compared to neighborhood controls (Lai *et al.* 2002).

Immune effects were also reported in both groups of poisoned people including an increase in respiratory and skin infections and changes in immune parameters such as immunoglobulins and T cells (Lu and Wu, 1985). Studies also detected depressed responses to tuberculin tests (Lu and Wa 1985, Nakanishi *et al.* 1985). Infants born to mothers who had Yu-Cheng disease had more episodes of bronchitis or pneumonia during their first six months of life and had higher frequencies of ear infection and respiratory tract infection in a six-year follow-up (Yu *et al.* 1998).

There is debate about the degree to which these two mass poisonings are relevant to current assessments of PCB exposure (Schantz 1996, Seegal 1996). The levels of PCB intake were very high compared to environmental sources. PCBs in both incidents had been repeatedly heated to high temperatures in a heat exchanger before contamination of rice oil occurred. The high temperatures changed the chemical composition of the oil creating high concentrations of polychlorinated dibenzofurans (PCDF) and other toxic compounds. Many of the developmental and physical effects seen in these populations, however, are also observed in monkeys dosed with pure PCB mixtures.

Developmental abnormalities have also been observed in occupationally exposed populations. A seven-year follow-up study of capacitor manufacturing workers in Japan and their children evaluated effects on children born to mothers who had PCB blood and breast-milk levels that were 10-100 times the normal background and markedly higher than the blood of Yusho

patients. Forty children were examined once a year for five years and none were diagnosed with PCB poisoning. Some of the children were found to have decay of nails, gingival pigmentation, mottled enamel, and dental caries that were typical symptoms in Yusho but were less serious in this study population (Hara 1985).

Endpoints of Human Health Concern

Cancer

There is clear evidence that commercial PCB mixtures cause cancer in animals in a dose-dependent manner (EPA 1996b, ATSDR 2000). Cancers observed primarily involve thyroid and liver tissue. Studies of workers exposed to commercial PCB mixtures found increases in liver and bile-duct cancers and malignant melanoma across multiple human studies (NTP 2011, Lauby-Secretan *et al.* 2013).

EPA and NTP consider PCBs to be probable human carcinogens and recently International Agency for Research on Cancer (IARC) strengthened its classification of PCBs to “human carcinogens” based on new evidence of melanoma in epidemiological studies (Lauby-Secretan *et al.* 2013). EPA concluded that the types of PCBs likely to be bioaccumulated in fish and bound to sediments are likely to be the most carcinogenic PCB mixtures (EPA 1996b).

PCB mixtures and individual congeners can act as tumor promoters (ATSDR 2000, WHO 2003, EPA 1996b). Tumor promotional activity has been observed by congeners that are aryl hydrocarbon agonists (dioxin-like congeners), that induce cytochrome P450 1A and 2B isozymes, and induce P450 CYP2 and CYP3 families of enzymes and have a phenobarbital pattern of enzyme induction (ortho-substituted congeners). Oxidative stress and disruption of intercellular communication have also been proposed as mechanisms for cancer promotion (EPA 1996b, WHO 2003).

Certain PCB congeners have been shown to be direct tumor inducers as well. In a series of recent investigations, the National Toxicology Program (NTP) demonstrated that dioxin-like congeners, PCB 118 and PCB 126, were able to induce lung, liver, bile duct, oral, and uterine cancers in rodents (NTP 2006). Certain non-dioxin-like congeners that are likely to be in air, such as PCB 3, also appear to undergo metabolic activation in rodents to reactive species that are genotoxic and can initiate DNA and chromosomal damage (Xie *et al.* 2010; Ludewig and Robertson, 2013). Few studies of genotoxicity in humans have been conducted but these have been negative for environmental PCB exposures (Ludewig and Robertson, 2013).

Immune Effects

Numerous immune effects have been measured in laboratory animals exposed to PCBs (ATSDR 2000). Changes in the immune system were selected by both ATSDR and EPA as the most sensitive non-cancer endpoint for chronic exposure to PCBs. In the critical study chosen by these

agencies (Tryphonas *et al.* 1989, 1991a, 1991b), PCB-treated rhesus monkeys had a dose-related reduction in antibody response to an injected antigen (sheep red blood cells). The diminished production of immunoglobulins IgM and IgG, in response to antigen was statistically-significant at two time points during the study (27 months and 55 months) at the lowest dose of Aroclor 1254 tested (5 µg/kg/d). No differences in baseline serum concentrations of IgG, IgM, or IgA were evident. Both EPA's Reference dose for chronic exposure and ATSDR's minimal risk level were derived from findings of this study at the 5 ug/kg/d dose level (EPA 1994, ATSDR 2000). Body burdens after 25 months of dosing at 5 µg/kg/d were reported to be 10.3 ppb in blood (8.4 ppm in blood when expressed on a lipid basis) and 2.2 ppm in adipose tissue (7.5 ppm in adipose when expressed on a lipid basis) (Arnold *et al.* 1993a, 1993b).

The experiment above continued into a breeding phase to measure reproductive and developmental outcomes in the rhesus monkeys. Female monkeys treated for 37 months with Aroclor 1254 were bred to unexposed males. Among other things, offspring were tested for immunological function. A reduction in IgM titres to sheep red blood cells were statistically significant for the 5 µg/kg/d dose level at multiple post-natal time points (Arnold *et al.* 1999).

Statistically significant but clinically mild developmental abnormalities were observed in offspring at the 5 µg/kg/d dose level including nail and nail bed changes, and inflammation and/or enlargement of the tarsal glands. There were also adverse reproductive effects that were elevated but did not reach statistical significance at the 5 µg dose (Arnold *et al.* 1999).

A number of epidemiological studies have reported immune effects associated with human environmental exposures to PCBs. Inuit children with high exposure to PCBs and other organochlorines, were reported to have higher incidence of ear infection and lower (but not upper) respiratory tract infection during the first five years of life (Dallaire *et al.* 2006). Early life exposures to PCBs have also been associated with reduced response to childhood vaccinations in European children (Weisglas-Kuperus *et al.* 2000, Heilman *et al.* 2006) and reduced size of the thymus (Park *et al.* 2008).

Neurological and Neurodevelopmental Effects

Extensive animal research on neurologic impacts of PCB shows adverse effects in adults and the young with fetal and early postnatal periods being the most sensitive in producing adverse effects in rodents and monkeys (Brouwer *et al.* 1995). Hyperactivity and learning and memory impairments are very sensitive to developmental PCB exposure in non-human primates (Bowman *et al.* 1978, Schantz *et al.* 1991). ATSDR based their health advice for oral PCB exposure over intermediate durations on learning and memory impairments observed after postnatal exposure to a PCB in male rhesus monkeys (ATSDR 2000). In this study, Rice *et al.* created a congener mixture that represented 80% of the congeners present in breast milk in Canadian women and administered it for 20 weeks post-natally at a dose estimated to be equivalent to nursing from a mother with 50 ppb PCB in breast milk (7.5 µg/kg/d). Behavioral

tests were conducted 3-5 years later. Treated monkeys were slower to learn new responses, adapt to new response patterns, and inhibit a response that was previously rewarded (Rice 1999). This study also measured effects at the lowest and only dose tested.

A number of studies have reported developmental effects in children although PCB levels in cord blood at birth or in the mothers were significantly higher than current body burdens in most populations (Jurewicz *et al.* 2013). Some studies, such as the Michigan Maternal/Infant Cohort and the Oswego Newborn and Infant Development Project, compared pregnant women who consumed Great Lakes fish to mothers who did not. Other studies, such as the North Carolina Breast Milk and Formula Project and the Dutch PCB/Dioxin Study, focused on mothers in the general population. These studies reported a range of subtle neurobehavioral effects such as abnormal newborn reflexes, cognitive and memory deficits including decreased IQ and changes in physical activity that were associated primarily with *in utero* not lactational PCB exposure (Jacobson and Jacobson 1996, Stewart *et al.* 2008, Brouwer *et al.* 1995). Although some studies have measured effects of lactational exposure to PCBs via breast milk, breast feeding appears to have a net positive effect on children with regard to mental and physical development (Anderson *et al.* 1999, Boersma and Lanting 2000, Pan *et al.* 2009). Fish consumers had higher proportions of PCB congeners with 7-9 chlorines and, in one analysis, these congeners were shown to be more closely associated with the neurobehavioral effects observed (Stewart *et al.* 1999). In another study, maternal body burden of dioxin-like mono-ortho substituted congeners (PCBS 118 and 156) were most strongly associated with neurobehavioral outcomes in children (Park *et al.* 2010).

Several researchers have proposed potency schemes for neurotoxicity of PCB mixtures that include both dioxin-like and non-dioxin-like PCB congeners. One neurotoxicity equivalency scheme is based on congener potency in interfering with intracellular signaling pathways and calcium ion modulation in the nervous system (Simon *et al.* 2007). Another is based on congener potency in altering brain dopamine and blood thyroid hormone levels (Yang *et al.* 2009). Although these schemes are not sufficiently developed for risk assessment, they point to the need to expand beyond TEQ of dioxin-like congeners when assessing potential neurotoxicity of PCB mixtures.

Reproductive Effects, including Birth Defects

Reproductive effects of PCBs have been demonstrated in a variety of animal species including non-human primates (ATSDR 2000). Oral PCB exposures reduced birth weight, conception rates and live birth rates of monkeys exposed during preconception and gestation (Arnold *et al.* 1995). Similar results have been observed in rodents. Developmental exposures in rodents resulted in lasting changes in reproductive tissue that were measurable at puberty and into adulthood (WHO 2003).

Investigations of reproductive effects have also been carried out in human populations exposed to PCBs. Longer time-to-pregnancy for couples trying to get pregnant has been reported to correlate with higher levels of certain PCB congeners (Axmon *et al.* 2005, Buck Louis *et al.* 2013). Obvious growth retardation was observed in offspring following the Yusho and Yu-Cheng incidents. Children born to women who worked with PCBs in factories showed decreased birth weight and a significant decrease in gestational age with increasing exposures to PCBs (Taylor *et al.* 1989, Hara 1985). Studies in fishing populations believed to have high exposures to PCBs also suggest similar decreases in either birth weight or gestational age or both (Fein *et al.* 1984, Rylander *et al.* 1995). Govarts *et al.* 2012 reported that birth weight decreased with increasing cord serum concentration of PCB-153 after adjustment for potential confounders in 12 of 15 study populations in Europe. Several studies have observed persistent deficits in physical growth into childhood following prenatal exposure to PCBs, particularly in girls (Jacobson and Jacobson 1997, Lamb *et al.* 2006, Blanck *et al.* 2002). Other investigations did not detect lower weight or shorter gestation times in other populations, including fish consumers (Rogan *et al.* 1986, Patandin 1999, Dar *et al.* 1992, Buck *et al.* 2013, Cupul-Uicab *et al.* 2013).

Endocrine Effects

There has been significant discussion and research on the effects of PCBs on the endocrine (or hormone) system. A number of PCB congeners and their metabolites display weak estrogenic, antiestrogenic effects, or antiandrogenic effects (Goncharov *et al.* 2009, Hamers *et al.* 2011, Brouwer *et al.* 1999, Birnbaum 1994). Certain PCBs and their metabolites appear able to directly interfere with estrogen or androgen receptors and bind directly to the estrogen receptor while others may act indirectly by inducing enzymes that then change estrogen metabolism (Brouwer *et al.* 1999, Kester *et al.* 2000, Hamers 2011).

The strongest evidence is for disruption of thyroid hormone levels. Hydroxylated PCB metabolites are structurally similar to the thyroid hormone thyroxine (T₄) and may interfere with hormone receptor binding directly. They have been shown to competitively displace binding of thyroid hormone (T₄) to transthyretin in rodents and to disrupt the normal delivery of thyroid hormone from maternal plasma to the rodent fetus *in vivo* (Porterfield 2000, Brouwer *et al.* 1999). In addition, PCBs and their metabolites may act indirectly by interfering with thyroid hormone metabolism. For example, activation of the Ah receptor by dioxin-like PCBs, induces production of the enzyme uridine diphosphoglucuronyl transferase that metabolizes T₄ and may accelerate T₄ clearance from the liver (Porterfield 2000, Koopman-Esseboom *et al.* 1994). Thyroid hormones are essential for regulating metabolism and normal growth and brain development. They also promote normal cardiovascular, reproductive and nervous system functioning.

Dioxin-like PCBs have been associated with changes in thyroid hormone levels in infants (Koopman-Esseboom *et al.* 1994, Nagayama *et al.* 1998, Pluim *et al.* 1992). A more recent study

by Wilhelm *et al.* 2008 looked for but did not find any decrease in thyroid hormones related to dioxin-like PCBs or total TEQ at current exposure levels in Germany. Chevrier *et al.* 2008 reported that blood concentration of thyroid stimulating hormone in newborns was associated with non-dioxin like PCB congeners (PCBs 99, 138, 153, 180, 187, 194, and 199). Similar results, higher TSH and lower free T4 levels with increasing PCB levels, were reported in adolescents, although only in the group that had not been breast-fed (Schell *et al.* 2008).

Established Health Guidelines for PCB Mixtures

EPA's approach to cancer risk assessment of PCB mixtures

EPA uses a tiered approach to cancer risk assessment for PCB exposure. EPA recognized that selective bioaccumulation in the environment creates dietary PCB mixtures that differ markedly from Aroclor mixtures produced commercially. The tiers attempt to address the likely differences in toxicity and persistence of PCB mixtures. The tiers also reflect that PCB mixtures comprised mostly of congeners with more than four chlorines are more persistent and more carcinogenic than more lightly-chlorinated, less persistent congeners.

EPA recommends that risk assessors use a cancer slope factor of 2.0 per mg/kg/d for PCB mixtures present in the food chain. This most potent assumption should also be applied to protect all early life exposures. A less potent assumption of 0.4 per mg/kg-d can be used in assessments of ingestion of water soluble congeners and inhalation of evaporated congeners. A third tier (cancer slope equal to 0.07 per mg/kg-day) is provided for assessment of exposure to PCB mixtures with less than one half percent congeners of four or more chlorines. (Cogliano 1998)

Dioxin-like congeners and Toxic Equivalency (TEQ) approach.

Mixtures of PCBs congeners that have dioxin-like toxic effects can be evaluated by their toxicity relative to the most toxic dioxin, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Dioxins and dioxin-like compounds have a common mechanism of action mediated by the aryl hydrocarbon receptor (AhR) but differ in their potency. Their potency relative to TCDD is reflected in their Toxic Equivalent Factor (TEF) developed by the World Health Organization for 7 dioxins, 10 dibenzofurans, and 12 PCB congeners. TEFs for PCBs are shown in Table 29 (Van den Berg *et al.* 2006). The most potent PCB congener has a TEF =0.1 which means that it is 1/10 as toxic as TCDD. The TCDD Toxicity Equivalent (TEQ) of a mixture can be calculated by summing the individual congener concentration and their TEFs as shown in the equation below.

$$\text{TEQ} = \sum (\text{TEF}_i \cdot C_i)$$

Where:

TEQ = TCDD toxicity equivalence

TEF_i = Toxicity equivalency factor for an individual congener

C_i = Concentration of individual congener

Table 29. Toxicity Equivalence Factors for PCB Congeners

Class	Congener	Mammal Toxicity Equivalence Factor (TEF)
Co-planar PCBs	3,3',4,4'-TCB (77)	0.0001
	3,4,4',5-TCB (81)	0.0003
	3,3',4,4'-5-PeCB (126)	0.1
	3,3',4,4',5,5'-HxCB (169)	0.03
Mono-ortho PCBs	2,3,3',4,4'-PeCB (105)	0.00003
	2,3,4,4',5-PeCB (114)	0.00003
	2,3',4,4',5-PeCB (118)	0.00003
	2',3,4,4',5-PeCB (123)	0.00003
	2,3,3',4,4',5-HxCB (156)	0.00003
	2,3,3',4,4',5'-HxCB (157)	0.00003
	2,3',4,4',5,5'-HxCB (167)	0.00003
	2,3,3',4,4',5,5'-HpCB (189)	0.00003

Source: TEFs recommended by World Health Organization (Van den Berg et al. 2006).

The EPA recently set the daily level of exposure considered safe for humans over a lifetime (also known as the Reference Dose or the RfD) at 0.7 picograms per kilogram of body weight of TCDD or toxicity equivalent as calculated by the equation above (EPA 2012d). This number is believed to protect against the most sensitive non-cancer endpoints observed. It is based on observations of health effects at 20 pg/kg/d in two studies conducted after an industrial accident in Seveso, Italy. The follow-up studies detected reduced sperm counts in men exposed in childhood and increased thyroid hormones in infants of mothers exposed during pregnancy (Mocarelli *et al.* 2008, Baccarelli *et al.* 2008). An earlier health guideline for acceptable daily intake of dioxin-like compounds, set by the World Health Organization/United Nations in 2001, was based on older data. The newer EPA RfD is three times lower (see Table 30). EPA is currently developing its health guidance for dioxin cancer assessment.

Other Health Guidance

There are a number of health standards that address exposures to PCBs in people. For assessment of dietary intake, the Washington State Department of Health (Health) uses the EPA RfD and TEFs as described in WHO 2005 for non-cancer endpoints and an upper bound cancer slope factor of 2.0 per mg/kg/d for cancer.

The EPA standard for PCBs in drinking water is 0.5 µg/L and the FDA adopted the same standard for bottled water (see Table 30). The FDA has also set residue limits for PCBs in various foods to protect against harmful health effects including a maximum of 0.2 mg/kg in infant and junior foods, 0.3 mg/kg in eggs, 1.5 mg/kg in milk and other dairy products (fat basis), 2 mg/kg in fish and shellfish (edible portions), and 3 mg/kg in poultry and red meat (fat basis). The FDA regulatory action level for PCBs in fish is much higher than human health risk levels established under the National Toxics Rule or used by Health to assess fish. The FDA action level reflects FDA's higher tolerance for PCBs in food and the agency's emphasis on the net benefit to consumers of eating fish, despite contamination.

The National Toxics Rule sets water quality criteria for PCBs to protect human health over a lifetime of drinking water and eating fish from surface water. The NTR includes an equivalent fish tissue criteria (5.3 ppb) for PCBs. This serves as an "equivalent" measure of water quality in that fish living in water at the surface water criteria (0.00017 µg/L) should not exceed 5.3 ppb PCB in tissue. While Health supports Ecology's use of the NTR criteria for identifying problems and controlling water pollutant sources, Health does not use the NTR criteria to establish fish consumption advisories.

Health establishes fish advisory screening levels for mercury, PCBs, and other contaminants by using an approach similar to that outlined in EPA's Guidance for Assessing Chemical Contaminant Data for use in Fish Advisories Vol. 1-4 (EPA 2000b). This guidance provides a framework for state development of fish consumption advisories, based on best available science, and established procedures in risk assessment, risk management, and risk communication. Health's current screening level for PCBs also incorporates recommendations from the American Heart Association that people should consume two meals of fish per week to gain the known health benefits associated with fish consumption. The Health screening value of 23 ppb is derived from assumptions of two meals/week consumption rate, average body weight of a person, and EPA's RfD for protection of human health effects. Health uses this value to identify populations of local fish that may need a fish advisory. This is a starting point for state advisories which need to balance the many health benefits of fish with the possible risks of PCB ingestion. More on information about how Health develops PCB fish advisories is at: <http://www.doh.wa.gov/AboutUs/ProgramsandServices/EnvironmentalPublicHealth/EnvironmentalHealthSafetyandToxicology/FishAdvisories>.

For inhaled PCBs, EPA calculated indoor air guidance for schools ranging from 0.07-0.60 µg/m³ depending on the age of the children (see Table 30). These EPA calculations account for additional average exposures through diet, water, air and other sources and would maintain children’s exposure levels below the RfD of 0.02 µg/kg/d (EPA 2012c). Residential indoor air levels would need to be lower to reflect the longer hours spent at home.

Public health guidance for PCBs in ambient air are lower still and assume exposure 24 hours a day and seven days a week. For inhalation of evaporated congeners, EPA IRIS assessment considers a concentration of 0.01µg/m³ to be conservative protection against cancer risk (EPA 1997b). A variety of higher occupational inhalation exposure limits were established more than 10 years ago, assume exposures to adults only, and assume exposure during a standard work week (see Table 30).

Table 30. Established health regulations/guidance for PCBs

	Exposure Limits	Agency	Reference
Total oral daily intake-chronic	Oral Reference dose (RfDs) 0.07 µg/kg/day (Aroclor 1016) 0.02 µg/kg/day (Aroclor 1254)	EPA, 2000	EPA, IRIS http://www.epa.gov/iris/subst/0462.htm http://www.epa.gov/iris/subst/0389.htm
Total daily intake of dioxin-like chemicals (TEQ)	0.7 pg/kg/day	EPA, 2012	EPA, Dioxin Assessment http://www.epa.gov/iris/subst/1024.htm
Total daily intake of dioxin-like chemicals (TEQ)	2.3 pg/kg/day	WHO 2001	World Health Organization, Joint Expert Committee on Food Additives
Minimal Risk Level for chronic oral intake	MRL is 0.02 µg/kg/d (based on Aroclor 1254)	ATSDR, 2000	Toxicological Profile for PCB http://www.atsdr.cdc.gov/toxprofiles/tp17.pdf
PCBs in specific foods	0.2-3.0 ppm in various categories of food.	FDA 1996	21 CFR 109
PCBs in edible fish entering interstate commerce	2.0 ppm	FDA, 2011	http://www.fda.gov/downloads/Food/GuidanceRegulation/UCM251970.pdf
PCBs in fish	Screening level of 23 ppb in fish tissue (fillet)	DOH	See DOH website http://www.doh.wa.gov/CommunityandEnvironment/Contaminants/PCBs
PCBs in fish	5.3 ppb Fish tissue equivalent for	NTR, 1999	National Toxics Rule 64 FR 61182 http://www.gpo.gov/fdsys/granule/FR-1999-11-09/99-25559

	surface water quality criteria		
Drinking water	MCL is 0.5 µg/L (or 500 ppt). The MCL Goal is set at zero.	EPA1992 (reviewed 2010)	http://water.epa.gov/drink/contaminants/basicinformation/polychlorinated-biphenyls.cfm
Bottled water	0.5 µg/L	FDA, 1999	21 CFR 165.110
Ambient Air	0.01 µg/m ³ based on cancer risk of 1 in 1,000,000	EPA, 2000	EPA IRIS http://www.epa.gov/iris/subst/0294.htm
Indoor air – schools*	0.07-0.60 µg/m ³ depending on age of children present.	EPA	http://www.epa.gov/pcbsincaulk/maxconcentrations.htm
Occupational air	1.0 µg/m ³	NIOSH, 2000	http://www.cdc.gov/niosh/npg
Occupational air	1,000 µg/m ³ (Aroclor 1254); 500 µg/m ³ (Aroclor 1242)	OSHA	1998-29 CFR 1910.10003

PCB Exposures in People

PCBs are absorbed primarily from the diet and air, accumulate in fatty tissues, and are excreted, often very slowly, from the human body. PCBs are readily absorbed from the gastrointestinal tract. Absorption efficiency across the gut is higher with more chlorinated congeners. Once in the blood stream, PCBs are rapidly cleared and initially accumulate in liver and muscle tissue. In general, PCBs then redistribute to adipose tissue and skin but this varies depending on the congener (ATSDR 2000). For instance, PCB 126 is a coplanar PCB and binds very tightly to CYP1A2 and subsequently concentrates in the liver of rodent. Other highly persistent PCBs (e.g., PCB 153) are stored primarily in the adipose tissue and skin. There are also gender differences in storage of PCBs (Feeley and Jordan 1998). Metabolism of PCBs involves metabolic enzymes called cytochrome P₄₅₀ enzymes (CYP). Specific subtypes involved in PCB metabolism are CYP1A1 and 1A2, CYP2B1 and 2B2, and CYP3A. Metabolism can lead to biologically active arene oxides and hydroxylated and methysulfonyl metabolites. Elimination of PCBs from the body is largely dependent on biotransformation of congeners to more polar metabolites. Half-lives for PCBs congeners in humans are estimated at 1.4-4.9 years for lightly chlorinated PCB 28 and 10-15 years for the more chlorinated congeners such as PCB 153, 170, and 180 (Ritter *et al.* 2011). Longer half-life estimates have also been reported (ATSDR 2000, Milbrath *et al.* 2009). Because PCBs are more readily absorbed than excreted, they accumulate in the body over time.

PCB Body Burden in the General U.S. Population

PCBs are widely detected in adipose tissue and blood of people (Lordo *et al.* 1996, CDC 2009). PCB in serum is a common indicator of body burden since there is a dynamic equilibrium

between PCBs stored in fat and PCBs circulating in blood. Most studies of PCBs in serum report lipid-adjusted measurements to correct for short-term fluctuation in circulating lipids.

Since the 1980s, body burdens of PCBs in the U.S. have declined by more than 80% and continue to decrease (CDC 2009, Longnecker *et al.* 2003, Woodruff *et al.* 2011, Xue *et al.* 2014). Recent estimates of body burden of PCBs in the U.S. general population are available from the National Health and Nutritional Examination Study or NHANES (CDC 2009). This survey sampled serum for 34 PCB congeners in 2001-2002 and added four dioxin-like PCB congeners in 2003-2004 for a total of 38 congeners. In the 2003-2004 survey, 100% of the 1866 participants sampled had detectable levels of PCBs in their serum (Patterson *et al.* 2009). The primary congeners detected were PCB 153, 180, and 138/158. PCB 28, 74, 118, 170, and 187 were also frequently detected (Table 31 lists NHANES results). The sum of 35 PCB congeners in participants had a mean of 134.4 ng/g blood lipid (0.820 ng/g whole weight blood). Five percent of the participants sampled had a sum of PCB in blood higher than 530.7 ng/g lipid weight (3.531 ng/g whole weight) (Patterson *et al.* 2009). The TEQ of total dioxins, furans and dioxin-like PCB in the NHANES 2001-2002 survey was calculated to be 30.4 pg/g lipid for the general population. The nine PCB congeners with dioxin-like properties contributed 38-41% of the TEQ depending on the age of the participant (Ferriby *et al.* 2007). Both studies showed that increasing PCB body burden is strongly associated with increasing age.

Table 31. Sum of 35 PCB congeners in 2003-04 NHANES survey (Patterson *et al.* 2009)

Age of participant	50 th percentile for population (CI)	95 th Percentile for population (CI)	Population sample size
12-29 years	51.2 (48.2-56.1)	139.0 (110.8-164.3)	585
20-39 years	75.4 (71.2-81.7)	226.5 (170.6-300.5)	452
40-59 years	174.4 (159.9-201.9)	470.7 (373.5-650.9)	383
60+ years	334.5 (308.7-351.8)	929.4 (752.2-1167.9)	446
Total (all ages)	131.8 (121.8-145.5)	530.7 (498.4-570.2)	1866

Serum levels in ng/g blood lipid

CI is the 95% confidence interval for the estimate of percentile in the study population.

Greater body burdens of PCB congeners that readily bioconcentrate have been observed in avid consumers of seafood or land and marine mammals that eat a diet rich in fish. (Dewailly *et al.* 1993; Ayotte *et al.* 1997, Muckle *et al.* 1998, Fångström *et al.* 2002, Grandjean *et al.* 2001).

Lightly chlorinated PCB congeners (congeners 1-52) may be elevated in people exposed to PCBs in ambient or indoor air. Disposal and recycling workers may have elevated exposures to the full spectrum of PCB congeners in the initial Aroclor mixtures.

PCB Exposures to Developing Children

Fetal and early life are considered the most sensitive life stage for PCB toxicity so it is important to understand early life exposure to PCBs. PCBs cross the placenta of experimental animals and humans. When PCB level is adjusted for percent lipid in the blood, there is no difference between PCB blood levels in maternal serum and cord blood at the time of birth (Jacobson *et al.* 1984).

PCBs stored in fat and fatty tissues are mobilized as serum lipids increase during the normal course of pregnancy. Median concentration of total serum lipids increased 43% and median serum levels of PCBs increased 34% between the first and third trimesters in a study of 67 women. The increase was completely explained by the increase in lipids; when results were lipid normalized there was no difference in $\mu\text{g PCB/g serum lipid}$ (Longnecker *et al.* 1999).

The body burden of PCBs accumulated over a lifetime is thought to be the primary determinant of circulating levels of PCB during pregnancy; however, a study reported by Humphrey in 1989 demonstrated that a single meal could conceivably expose a fetus to a transient peak of PCBs. In his measurements following a meal of Great Lakes fish (fish contained 4-10 ppm PCB) he observed a short-term spike of 250-500% above serum baseline in healthy volunteers. Most fish consumed in the U.S. today are about 1000 times less contaminated than the fish used in Humphrey's experiment.

Breast milk has healthy fat to support the rapid growth of babies. PCBs can accumulate in fat and be transferred to babies during nursing. The PCB body burden of children at four years old is strongly related to the level of contamination in milk and duration of lactation (Swain 1991, Patandin *et al.* 1999, Walkowiak *et al.* 2001). Blood levels of PCBs in Japanese children of occupationally-exposed parents also showed a strong correlation with length of lactation (Hara 1985). By some estimates, human infants can receive up to 10-12% of their lifetime dose from nursing (Birnbaum and Slezak, 1999). Breast milk samples from 40 first-time mothers from the Pacific Northwest of the U.S. and Canada were analyzed for PBDEs and PCBs (She *et al.* 2007). Total PCBs were calculated by summing values of 82 separate PCB congeners and ranged from 0.049 to 0.415 mg/kg lipid. This is 10-100 times lower than the levels documented in breast milk in the 1980s in a North Carolina study and further evidence that PCBs in U.S. breast milk have declined since PCB production ceased (Pan *et al.* 2009, Zietz *et al.* 2008). PCB in breast milk should not deter women from nursing because studies have shown that even breast milk with PCBs has a net benefit on cognitive and motor development of children compared to formula-fed children (see DOH Recommendation for Breast Feeding).

Sources and Pathways of Human Exposure

PCBs in Food

PCBs in food are the most significant source of exposure for most people. Recent studies on fish indicate concentrations of PCBs can be in the 10 to 100 parts per million in fish (especially freshwater fish). High levels are typically found in top predator fish, in bottom-feeding fish such as carp and large scale suckers, and in fish living near known sources of PCB contamination. Meat and dairy products are generally much lower in PCBs with concentrations in the low parts per billion (see Table 34). A recent analysis of 2001-2004 NHANES data looked at food consumption patterns in a general U.S. population relative to 30 PCB congeners measured in their serum (Xue *et al.* 2014). The study found a strong correlation between serum PCB and reported fish consumption but no measurable correlation with consumption of meat or milk.

PCBs in Freshwater Fish Species from Washington State

PCBs can be highly concentrated in the fish of waters contaminated with even low levels of PCBs. The Washington State Department of Ecology routinely conducts fish tissue monitoring as part of its Washington State Toxics Monitoring Program (WSTMP). Between these two programs, thousands of fish have been sampled from hundreds of sites across Washington State. Figure 27 displays the distribution of total PCB tissue concentrations from fish collected across Washington State from several sources.

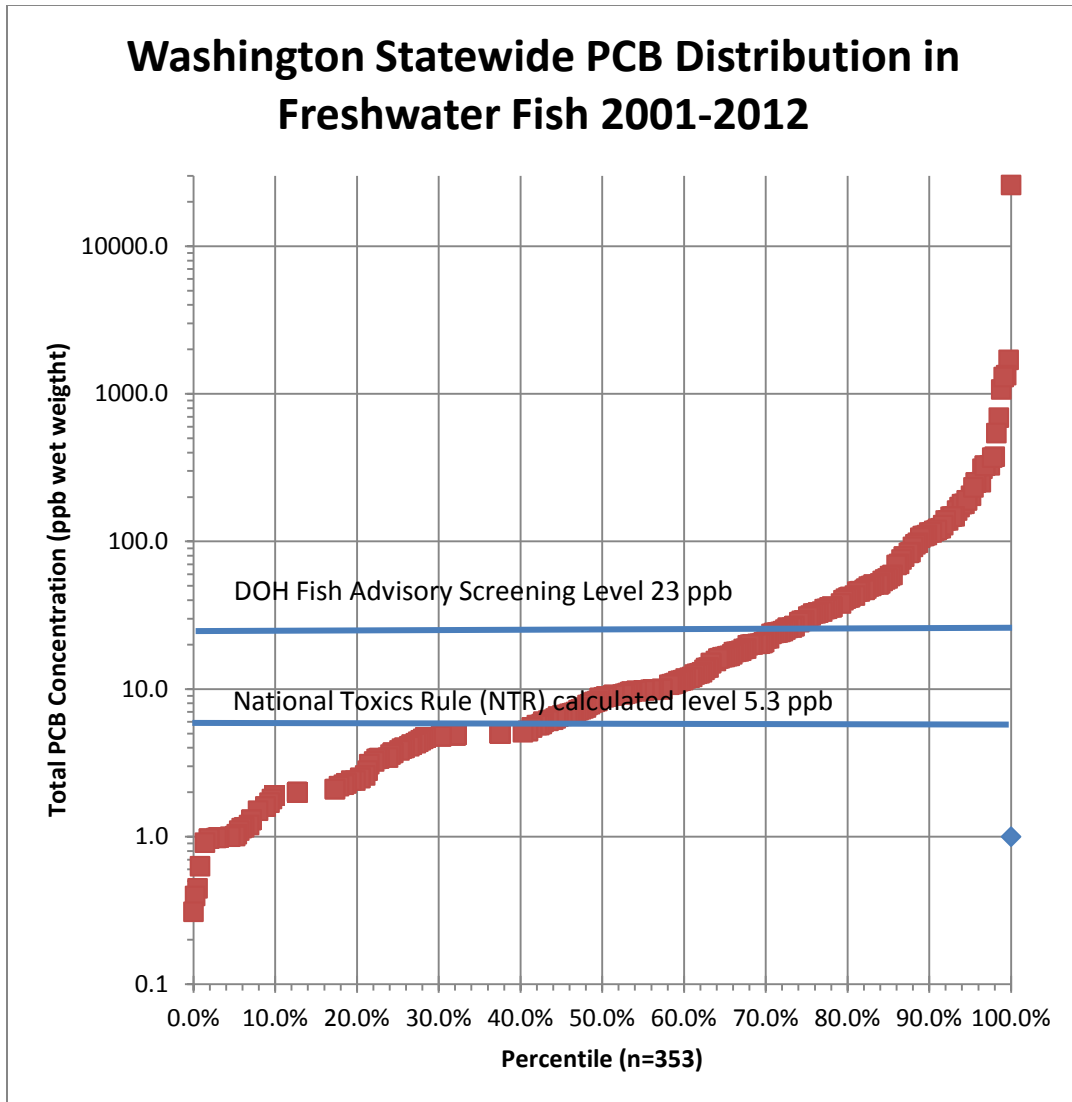


Figure 27. Washington Statewide PCB Distribution in Freshwater Fish Fillets 2001-2012. Data sources: 2001-2010 total PCB fish tissue concentrations extracted from Ecology’s EIM database (Seiders 2012), EPA’s Upper Columbia River site investigation as reported by Health (WDOH 2012), U.S Department of Energy’s 2012 assessment of contaminant data in the Mid-Columbia River, and fish tissue data provided to Health by the U.S. Army Corps of Engineers near Bradford Island and the Bonneville Dam on the Columbia River (unpublished data). NTR and Health screening levels for PCB concentration in fish tissue are displayed for reference.

The data set displayed in Figure 27 includes 353 total PCB values that range from non-detects to greater than 26,000 ppb, with a median of 8.7 ppb. The maximum detection is from a single bass collected near the Bonneville Dam in the Columbia River.

PCBs in Commercially Available Fish in Washington State

Limited data on PCBs in commercially available fish are also available for Washington State. The primary source of this data is a Washington Department of Health 2005 study of contaminants in canned tuna and other frequently consumed store bought fish purchased in

Washington State grocery stores (McBride *et al.* 2005). In this study, PCBs (based on Aroclors concentrations) were detected in store-bought halibut, red snapper, and salmon in at least 10% of the samples collected. Salmon had the highest average PCB concentrations (31.5 ppb PCBs, total Aroclors). Additional data from the Washington State Department of Fish and Wildlife on PCB levels in Puget Sound Chinook and coho salmon were also included for this assessment (WDOH 2006). A comparison of PCB concentrations in store bought and Puget Sound commercially available fish can be seen in Figure 28. Of all fish species, PCB concentrations were highest in Chinook salmon collected in Puget Sound. PCB levels in Chinook salmon returning to Puget Sound waters typically have higher concentrations than coastal salmon or Alaskan Chinook. The higher concentration in Puget Sound Chinook and resident Blackmouth is believed to be due to residence time in areas such as Puget Sound that have greater PCB loads. DOH recommends that women of childbearing age and young children should eat no more than one meal per week of Puget Sound Chinook salmon. Most fish species collected from grocery stores were below Health’s general screening level of 23 ppb.

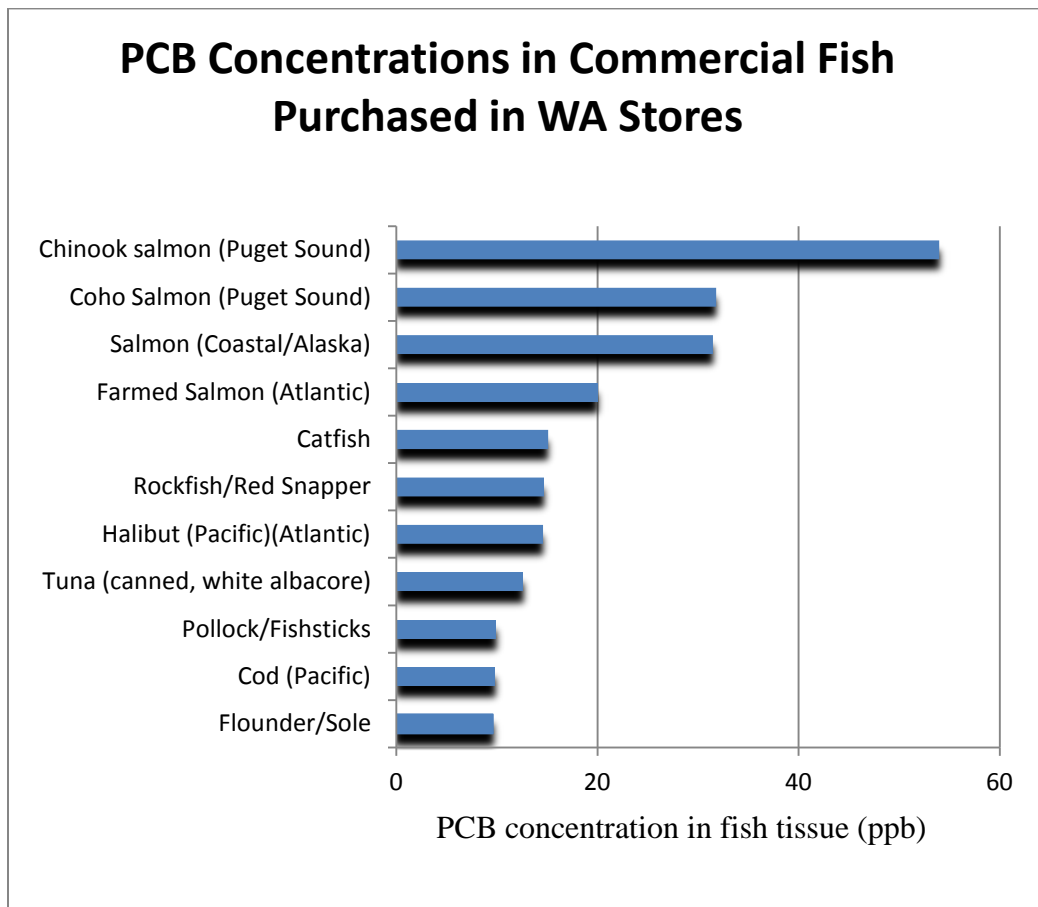


Figure 28. Mean PCB concentrations (total Aroclors) in fish collected from markets and grocery stores in Washington State and from Puget Sound. Data Source: McBride et al. 2005.

Other Dietary Sources of PCBs

Humans may be exposed to small but detectable quantities of PCBs in meat, dairy products, and other foods. PCB concentrations in fish, meat, and dairy products vary widely depending on where they are grown and how they are processed or cooked. Sampling for PCB concentrations in FDA's Market Basket studies between 1991 and 2003 showed PCB levels are far below FDA limits in a variety of prepared dishes. This section summarizes the limited data available from various U.S. and international sources.

The Total Diet Study (TDS), sometimes called the market basket study, is an ongoing FDA program that determines levels of various contaminants and nutrients in foods.

<http://www.fda.gov/downloads/Food/FoodScienceResearch/TotalDietStudy/UCM184304.pdf>. A unique aspect of the TDS is that foods are prepared as they would be consumed (table-ready) prior to analysis, so the analytical results provide the basis for realistic estimates of the dietary intake of these analytes. TDS Market Basket surveys are generally conducted four times each year, once in each of four geographic regions of the countries. Food samples are purchased from supermarkets, grocery stores, and fast food restaurants in three cities in the region and are shipped to a central laboratory. The foods are then prepared table-ready and the three samples are combined to form a single analytical composite for each food. For each survey, samples of food are collected over a 5-week period. Table 32 presents data collected from 1991 through 2004 for PCBs in 26 separate food items. Total PCB concentrations are expressed as Aroclor equivalents, rather than as the sum of congener-specific measurements. Mean PCB concentrations ranged from 0.09 ppb for chicken potpie to 24.4 ppb for salmon.

PCB concentrations in foods from the market basket survey are much lower than previously reported by the Puget Sound Action Team in 2007 and cited by Ecology's Toxics Cleanup Program (Ecology 2012d). PCB levels in foods reported by the Puget Sound Action Team were based on very small sample sizes of one or two. FDA data presented in Table 32 are based on average samples sizes of 40 resulting in more robust, representative PCB levels. The state of origin of the food sampled is not available.

Table 32. Measured PCB Levels as Reported by U.S.FDA

Food Description	Sample Size	Results		
		Concentration (ppb)		Detection Frequency %
		Mean	Maximum	
Chicken potpie, frozen, heated	44	0.09	4	2.3
Candy, caramels	40	0.15	6	2.5
Beef roast, chuck, oven-roasted	44	0.23	10	2.3
Pork roast, loin, oven-roasted	44	0.23	10	2.3
Lamb chop, pan-cooked w/ oil	44	0.23	10	2.3
Chicken, drumsticks and breasts, breaded and fried, homemade	40	0.23	9	2.5
Corn/hominy grits, enriched, cooked	44	0.23	10	2.3
Cornbread, homemade	44	0.23	10	2.3
Biscuits, refrigerated-type, baked	44	0.23	10	2.3
Raisins	44	0.23	10	2.3
English muffin, plain, toasted	44	0.23	10	2.3
Veal cutlet, pan-cooked	40	0.25	10	2.5
Crackers, butter-type	44	0.25	11	2.3
Pork chop, pan-cooked w/ oil	44	0.45	20	2.3
Meatloaf, beef, homemade	44	0.45	20	2.3
Beef (loin/sirloin) steak, pan cooked with added fat	40	0.5	20	2.5
Pancakes made from mix with addition of egg, milk, and oil	40	0.5	20	2.5
Baby food, vegetables and chicken	44	0.68	30	2.3
Brown gravy, homemade	40	0.75	30	2.5
Tuna, canned in oil, drained	40	1.0	40	2.5
Eggs, fried with added fat	40	1.23	39	5.0
Chicken breast, oven-roasted (skin removed)	44	1.36	30	4.5
Popcorn, popped in oil	40	1.7	30	10.0
Butter, regular (salted)	44	3.18	120	4.5
Catfish, pan-cooked w/ oil	4	4.25	17	25.0
Salmon, steaks/filletts, baked	24	24.38	55	91.7

Table 32 summarizes PCB analytical results of food from the Food and Drug Administration's Total Diet Study program. The information pertains to Total Diet Study market baskets 1991-93 through 2003-04. Statistics were calculated using value of zero for results below the detection limit. This document is available on the internet at: <http://www.cfsan.fda.gov/~comm/tds-res.html>.

In addition to the U.S.FDA information, Arnold Schecter and colleagues at the University of Texas in Dallas have analyzed PCB concentrations in foods in the U.S. over the past 15 years. These studies have focused on common foods in the American diet that were collected throughout the country. The following summarizes those individual studies and a compilation of the data is presented in Table 33.

- Schecter *et al.* (1997) pooled food samples collected from grocery stores across the U.S. and measured 15 different PCB congeners, including eight coplanar PCBs, three mono-ortho PCBs, and four di-ortho PCBs. A total of 90 individual food specimens were pooled into 12 different food types (e.g., cheese, beef) and analyzed for dioxins, dibenzofurans, and PCBs. Based on a conversion of the measured congeners, the authors conclude that PCBs contribute significantly to total TEQ values in eight out of 12 sample types.
- Schecter and Li (1997) measured dioxin-like PCBs in U.S. fast food purchased at five cities across the US. Samples were pooled by type and tested for seven mono- and di-ortho PCBs. Total PCB levels ranged from 0.957 ppb (McDonald's Big Mac) up to 1.180 ppb (Pizza Hut Personal Pan Supreme with anchovies). The authors estimate that fast food accounts for roughly 16.7-52.7% of the total daily TEQ of dioxin-like compounds.
- Schecter *et al.* (1998) analyzed both cooked and uncooked samples of beef, bacon, and catfish from a supermarket in Binghamton, New York. A total of five cooked, and four uncooked samples of each type of meat were analyzed for dioxins, dibenzofurans, and three dioxin-like PCBs (77, 126, 169). Total PCB concentration for each food type ranged from 1.028 ppb (wet weight) (uncooked hamburger) to 5.370 ppb (cooked bacon). Broiling each type of sample resulted in a 50% decrease on average in total PCDD, PCDF, and coplanar PCB TEQ. However, broiling of hamburger resulted in an increase of total coplanar PCB concentration of 10.4%; broiling bacon resulted in an increase of 75.7% of total coplanar PCB concentration. The authors conclude that final concentrations (pg TEQ/kg) of PCDDs, PCDFs, and coplanar PCBs in broiled foods cannot be accurately predicted from raw samples due to variances in cooking method.
- Schecter *et al.* (2002) analyzed a total of 72 meat baby food samples purchased from grocery stores across the U.S. (Illinois, Nebraska, California, Georgia, New York, Pennsylvania, and Maryland). Three to six samples (200 g each) were purchased from each state, and analyzed for dioxins and three coplanar PCB congeners (77, 126, and 159). Total PCBs for each food sample type range from 0.579 ppb (wet weight) (lamb) to 2.280 ppb (chicken). Converted TEQ concentration for total PCBs for each food type ranged from 17.6 (lamb) to 95.9 (beef). The authors note that for the turkey, beef, lamb, and ham samples, total PCBs contributed more to total TEQ values than did the PCDD/PCDF values.

- Schechter *et al.* (2010) study expanded their previous studies of persistent organic pollutants contamination, including PCBs in composite U.S. food samples collected in Dallas, Texas. The study showed that PCBs were not detected by congener analysis in any meats except hamburger, in any fish except salmon and canned sardines, or in any dairy products or eggs.

Overall, Schechter and colleagues have shown that the PCB levels in foods common in the U.S. are typically low relative to freshwater fish species collected in Washington State. PCB levels in foods other than fish are generally in the low single digit parts per billion range whereas freshwater and marine fish species are generally one, two, and sometimes three orders of magnitude higher. Even when beef, chicken, and pork consumption rates are greater than fish consumption rates, dietary exposure to PCBs is dominated by the consumption of fish.

Table 33. Level of PCBs in U.S. Foods (1994 – 2009)

Location (date)	Type of Sample	PCB congeners	Food (sample size)	Total PCB concentration ppb (wet weight)	Reference
Across U.S. (1995)	Grocery Stores	15 total, including 8 coplanar, 3 mono-ortho, and 4 di-ortho PCB congeners	Beef (5 pooled)	Total coplanar 0.0428 ng/g; mono-ortho 0.344 ng/g; di-ortho 0.593 ng/g Total 0.980 ppb	Schechter et al. 1997
			Chicken (4 pooled)	Total coplanar 0.132 ng/g; mono-ortho 0.403 ng/g; di-ortho 0.505 ng/g Total 1.04 ppb	
			Pork (5 pooled)	Total coplanar 0.182 ng/g; mono-ortho 0.375 ng/g; di-ortho 0.322 ng/g Total 0.879 ppb	
			Hot dog/bologna (2 pooled)	Total coplanar 0.156 ng/g; mono-ortho 1.500 ng/g; di-ortho 1.871 ng/g Total 3.027 ppb	
			Eggs (3 pooled)	Total coplanar 0.0006 ng/g; mono-ortho 0.064 ng/g; di-ortho 0.147 ng/g Total 0.212 ppb	
			Cheese (5 pooled)	Total coplanar 0.0017 ng/g; mono-ortho 0.240 ng/g; di-ortho 0.342 ng/g Total 0.584 ppb	
			Butter (2 pooled)	Total coplanar 0.004 ng/g; mono-ortho 1.150 ng/g; di-ortho 2.080 ng/g Total 3.23 ppb	
			Ice cream (5 pooled)	Total coplanar 0.0001 ng/g; mono-ortho and di-ortho ND Total 0.0001 ppb	
			Milk (5 pooled)	Total coplanar 0.0004 ng/g; mono and di-ortho ND Total 0.0004 ppb	
			Vegan diet (1 pooled)	Total coplanar 0.0002 ng/g; mono-ortho 0.015 ng/g; di-ortho 0.144 ng/g Total 0.159 ppb	
Across U.S. (1995)	Fast Food Restaurants	PCBs 105, 118,156,128,138,153, 180	Hamburger, McDonalds Big Mac (5)	mono & di-ortho total 0.957 ppb	Schechter and Li 1997
			Pizza, Pizza Hut Supreme (5)	mono & di-ortho total 1.180 ppb	
			Chicken, KFC Original Recipe (5)	mono & di-ortho total 1.170 ppb	
Binghamton, NY (1996)	Grocery Stores	Coplanar PCBs 77,126, 169	Hamburger, cooked (5)	Mean 1.401; range 1.204-1.601 ppb	Schechter et al. 1998
			Hamburger, uncooked (4)	Mean 1.270; range 1.028-1.736 ppb	
			Bacon, cooked (5)	Mean 2.734; range 1.722-5.370 ppb	
			Bacon, uncooked (4)	Mean 1.556; range 1.205-1.971 ppb	
			Catfish, cooked (4)	Mean 3.188; range 1.945- 3.963 ppb	
			Catfish, uncooked (4)	Mean 4.691; range 2.200-6.387 ppb	
Across U.S. (IL, NE, CA, GA, NY, PA, MD) (1998)	Baby Food Grocery Stores	PCBs 77, 126, 159	Chicken	Range 0.883-0.228 ppb	Schechter et al. 2002
			Turkey	Range 0.144-0.160 ppb	
			Beef	Range 0.150-0.225 ppb	
			Lamb	Range 0.579-0.844 ppb	
			Ham	0.771 ppb	
Dallas, TX (2009)	Supermarkets	PCBs, 52, 101, 118, 138, 153, 180	Hamburger	PCB-153 1.2 ppb; PCB-180 0.21 ppb	Schechter et al. 2010
			Salmon	PCB-52 0.28 ppb; PCB-101 0.51 ppb; PCB-118 0.43 ppb; PCB-138 0.93 ppb; PCB-153 1.21 ppb; PCB-180 0.44 ppb	
			Canned Sardines	PCB-52 0.28 ppb; PCB-101 0.67 ppb; PCB-118 0.80 ppb; PCB-138 1.80 ppb; PCB-153 1.83 ppb; PCB-180 0.49 ppb	
			Bacon	Non-detected	
			Turkey	Non-detected	
			Sausages	Non-detected	
			Ham	Non-detected	
			Chicken breast	Non-detected	
			Roast beef	Non-detected	
			Canned chili	Non-detected	
			Catfish fillet	Non-detected	
			Tilapia	Non-detected	
			Cod	Non-detected	
			Frozen fish sticks	Non-detected	
			Butter	Non-detected	
			American cheese	Non-detected	
			Other cheese	Non-detected	
			Whole milk	Non-detected	
			Yogurt	Non-detected	
			Cream cheese	Non-detected	
Eggs	Non-detected				

PCB Contribution to Dioxin TEQ in Food

Coplanar PCB congeners act toxicologically like dioxins and contribute to the total dioxin TEQ in foods. The National Academies of Science provided a comprehensive compilation of data on dietary exposure to dioxin and dioxin-like compounds including PCBs (NAS 2003). Estimates of exposure are based on concentrations of dioxins and dioxins-like compounds measured in foods and dietary consumption habits of those foods. The dioxin and PCB food concentration data were based on the U.S. Food and Drug Administration’s Total Diet Study (FDA 2006). The NAS report identifies that dietary sources of animal fat are by far the largest source of dioxin exposure to the general population, with 90% of total exposure being due to consumption of food – namely animal products and their associated animal fats (beef, pork chicken, fish, fats (butter), and dairy products. The NAS reported that estimates of the contribution of PCBs to dietary dioxin TEQ range from 37-57% and concluded that 50% was a reasonable estimate (NAS 2003).

EPA’s 2000 Draft Dioxin Reassessment (EPA 2000a) summarized the available data on background concentrations in foods for the United States. Using that data and standard assumptions for intake, they developed an estimate of general background exposure to coplanar PCBs. The estimates assume concentrations in food reported as nondetected are present at ½ the detection limit. EPA estimated background exposure to adults in the general population to be 0.64 pg/kg/day for dioxins and furans and 0.34 pg/kg/day for dioxin-like PCBs. Based on EPA’s analysis, coplanar PCBs account for approximately one-third of total dioxin-TEQs (Smith and Frohberg, 2008). See Table 34.

Table 34. Estimates of Background Dietary Exposure to Dioxins and Coplanar PCBs on a Toxic Equivalents (TEQs) Basis.

Chemical	Estimated Exposure Assuming NDs = 0 (pg/kg/day)	Estimated Exposure Assuming NDs = 1/2 DL (pg/kg/day)
Dioxins/Furans TEQs	0.38	0.64
Coplanar PCB TEQs	0.34	0.34
Total TEQ	0.72	0.98
% Contribution of Coplanar PCBs to Total TEQs	47%	35%
EPA RfD for dioxin (non-cancer endpoints)	0.7 pg/kg/d	0.7 pg/kg/d

(Source: Smith and Frohberg, 2008)

ND = non-detected, DL= Laboratory detection limit

In summary, food and especially fish appear to be major contributors to PCB exposure in the U.S. population. With few exceptions, freshwater fish species have the highest PCB levels. Mean PCB concentration of all Washington state freshwater fish for which Health has issued fish consumption advisories is over 150 times higher than the mean PCB concentration reported in other common food items. Freshwater fish species in Washington are over ten times higher than

PCB concentrations measured in commercially available fish in Washington State stores. Commercially purchased fish PCB levels are also greater than mean PCB concentrations of other non-fish foods tested by a factor of ten (Figure 29). Such comparisons illustrate the relative contribution of freshwater fish species to an individual's dietary PCB exposure, particularly for high fish consumers. Those individuals or groups that rely on freshwater fish species as an important component of their diet are potentially at greater exposure to PCBs and correspondingly at greater health risk.

Dioxin-like PCBs are significant contributors to dietary dioxin burden in the U.S. and the total dioxin burden appears to be at the EPA reference dose for dioxin TEQ.

The PCBs in fish are relatively well studied and this source of exposure has a robust health literature pointing to adverse health impacts. The most vulnerable lifestage to PCB exposure appears to be fetal development. Although U.S. exposures have dropped dramatically since the 1980s, Avid consumers of Puget Sound salmon, freshwater sports fish like bass, and other fish from contaminated waters are still at risk for elevated exposure. Reducing PCB exposure in people will require efforts to reduce PCB levels in freshwater and some marine fish and to mitigate the sources of PCB loading to the waters where they live.

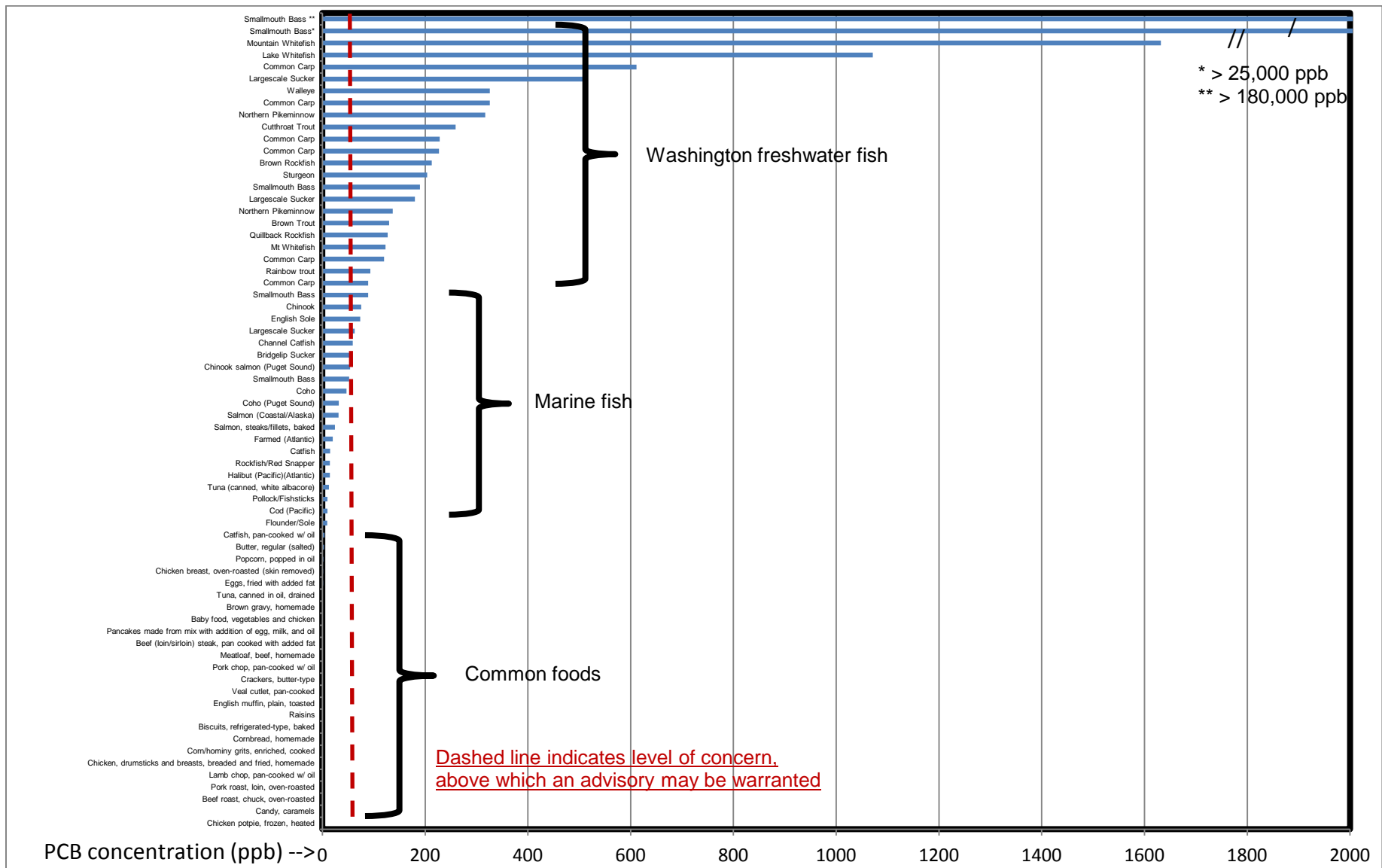


Figure 29. PCB Concentrations (ppb) in Sportcaught Fish Collected in Washington, Commercial Fish Purchased in Washington, & Common Foods
Data sources: WA freshwater fish data 2001-12 in Ecology EIM database, U.S. Dept. of Energy, WA Dept of Health commercial fish study (McBride et al.,2005), FDA Total Diet Study 1991-2006. Only a subset of the state's freshwater fish PCB data are shown to represent those species associated with Health fish advisories based on PCB levels.

PCBs in Ambient Air

PCBs with fewer chlorines can volatilize from water, soil, or contaminated materials and effect local air concentrations (ATSDR 2000, Carlson and Hites 2005, Du *et al.* 2009). They can also be transported long distances by global air currents and have been detected polar research stations where no local sources exist (Choi *et al.* 2008). Heavier PCBs are not volatile but can contaminate air when adhered to demolition dust, wind-blown dust, and airborne particulate. Inhalation was thought to be the primary pathway of occupational exposure to PCBs historically but was largely ignored for general population exposures until recently. PCB air monitoring started in Chicago in 1995 and found surprising PCB concentrations in urban air. Hu *et al.* 2008 analyzed for 209 PCB congeners in Chicago area air and reported an annual average of $0.000835 \mu\text{g}/\text{m}^3$ (range 0.000075 to $0.0055 \mu\text{g}/\text{m}^3$). Similar air concentrations results have been reported from the Philadelphia, PA (Du *et al.* 2009) and Cleveland, OH (Basu *et al.* 2009). Air levels at least an order of magnitude lower have been detected in polar regions (Choi *et al.* 2008) and in various remote locations around the Great lakes region (Basu *et al.* 2009).

Only limited air sampling for PCBs has been conducted in Washington State. Bulk air deposition samplers have been used to estimate the load to Puget Sound soils and water surfaces (Ecology 2010d). These results are not adequate for estimating inhalation exposure for health risk assessment because the lighter gas phase PCBs would be largely missed by these samplers.

One EPA pilot study analyzed air samples collected in year 2000 from rural areas of the U.S. for six PCBs that are considered dioxin-like. This study included one site on the Olympic Peninsula in Washington. PCB 118 was the most common dioxin-like PCB detected ($0.337 \text{ pg}/\text{m}^3$). PCB 105 was detected at $0.115 \text{ pg}/\text{m}^3$, PCB 156/7 were detected at $19.7 \text{ fg}/\text{m}^3$, 77 was detected at $16 \text{ fg}/\text{m}^3$, and PCB 126 and 169 were detected at $1 \text{ fg}/\text{m}^3$ or less (EPA 2007).

The reported levels of PCBs in ambient air are generally well below EPA level of human health concern. The maximum PCB levels reported on hot summer days in Chicago was $0.0055 \mu\text{g}/\text{m}^3$ which is still below the EPA “de minimus” cancer risk estimate for chronic inhalation of evaporated PCB congeners ($0.01 \mu\text{g}/\text{m}^3$).

Congener profiles of PCBs in ambient air differ both from profiles of commercial Aroclors and from congeners that partition to fish. Although the full spectrum of congeners has been detected in ambient air, lightly chlorinated congeners predominate (PCBs 1-52). Lighter congeners are more quickly eliminated from the body and their toxicological properties are less studied. This introduces uncertainty in the exposure and toxicity assessment of the mixture. Norström *et al.* 2010 conducted modelling to predict the contribution to PCB body burden from breathing urban air contaminated with a profile of PCBs similar to those detected in Chicago air. Their model suggests that urban air would not significantly impact the body burden of congeners associated with dietary uptake such as PCB 153, 180, and 183 but could contribute to human body burden of PCB 28, 33, and 52 by as much as 30% depending on the congener (Norström *et al.* 2010).

The toxicological relevance of inhaling congeners in urban air was investigated by Hu *et al.* 2012. They conducted a subchronic rodent inhalation assay with a cocktail of PCBs representing urban air and observed for immune responses, microsomal enzyme induction, cellular toxicity and histopathologic abnormalities. The minimal effects detected are suggestive of mild oxidative stress during the course of treatment.

The toxicological relevance of lighter chlorinated congeners must also consider the impact of metabolites produced once these lighter PCBs are absorbed into the body. For example, some PCB 3 metabolites are genotoxic and have been shown to cause point mutations in rodents (Xie *et al.* 2010, Robertson and Ludewig 2011). There is also limited evidence of tumor initiating activity of PCB 3, 15, 52 and 77 in a rodent model (Espandiari *et al.* 2004). Congeners like PCB 11 may be transformed into metabolites that contribute to oxidative stress and cellular damage (Zhu *et al.* 2013). This is an active area of research and more study is needed to understand the potential toxicity of lower chlorinated PCBs and their metabolites.

PCBs in Indoor Air (Caulk, Joint Sealants, Lamp Ballasts)

PCBs were used as plasticizers and flame retardants in building materials such as some elastic caulks, joint sealing compounds for brick and masonry buildings, exterior paints, window glazing, ceiling tile coatings, and some floor finishes sold in the 1950-1970s. PCBs were also widely used in fluorescent lighting ballasts installed during this same period. In different investigations since 1980, these materials have been identified as sources of elevated PCB levels in air in schools, office buildings, large apartment complexes, and other buildings. A few examples are listed below.

EPA investigated PCB levels at six unoccupied schools in New York that were scheduled for major renovation or demolition and were suspected of containing PCB sources (EPA 2012c). EPA measured PCBs in air and surface wipes in the buildings and estimated student exposures before and after PCB remediation. EPA estimated doses for an average student were 0.022 $\mu\text{g}/\text{kg}/\text{day}$ before remediation and 0.007 $\mu\text{g}/\text{kg}/\text{d}$ after. Estimates of higher student exposure scenarios were 0.041 $\mu\text{g}/\text{kg}/\text{day}$ before remediation and 0.012 $\mu\text{g}/\text{kg}/\text{day}$ after. PCB light ballasts and caulk were considered the primary PCB sources in the schools and inhalation the primary exposure route. Remediation reduced estimated exposure by approximately two thirds. EPA conducted congener specific PCB analysis in one of the six schools. Average indoor air concentration of total PCBs in air was 0.50 $\mu\text{g}/\text{m}^3$, the average TEQ of dioxin-like congeners in air was 0.788 pg/m^3 . (EPA 2012c). EPA research associated with this project confirmed that caulk with high levels of PCBs caused elevated PCB in the surrounding air, that light ballasts emit PCBs at normal operating temperatures even when there was no visible liquid leaking, that caulk with low levels of PCBs can be encapsulated to reduce emissions, and that a special treatment system can be effective in removing PCBs from thin surfaces such as wall paint (EPA 2013h). In December 2010, EPA released national guidance recommending that schools remove

all PCB-containing lighting ballasts.

<http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/ballasts.htm>

Elastic joint sealants containing PCBs were found to be the source of elevated PCBs in indoor air at 29 sampling sites in various public buildings in Switzerland (Kohler *et al.* 2002). In most cases the indoor air levels of PCBs were below $1.50 \mu\text{g}/\text{m}^3$ but levels up to $4.20 \mu\text{g}/\text{m}^3$ were detected. As a comparison, this study reported air levels of $13.0 \mu\text{g}/\text{m}^3$ PCB at an industrial building that formerly produced transformers. PCB congeners 28 and 52, used as indicators for the more volatile PCBs, predominated in all air samples. Dioxin-like PCBs were also measured (primarily PCB 118 and 105) and the TEQ was calculated using WHO 1998 TEFs. Emissions from joint sealants had a consistent ratio of dioxin-like PCBs to total PCBs. Air levels of $1.0 \mu\text{g}/\text{m}^3$ total PCBs corresponded to a $1.2 \text{ pg}/\text{m}^3$ of dioxin-like PCBs. (Kohler *et al.* 2002).

Joint sealants were also the source of PCB contamination in a public building in Germany (Schettgen *et al.* 2012). Investigations included air measurements and biomonitoring of people who worked in the building. Workers from an uncontaminated building served as controls. Median air levels for total PCBs were reported as $1.74 \mu\text{g}/\text{m}^3$ with a maximum of $4.28 \mu\text{g}/\text{m}^3$. Exposed workers had significantly higher blood levels of the more volatile PCBs (28, 52, 101 and the dioxin-like congeners 105 and 118) but not heavier PCBs which constitute the bulk of human body burden and are taken up primarily in the diet (PCB 138, 153, or 180). The calculated TEQ for dioxin-like congeners did not differ statistically between the groups. Follow-up monitoring of three people who were removed from the building demonstrated that levels of PCB 28, 52, and 101 declined steadily after removal and that the biological half-lives were 4.5 ± 0.9 years for PCB 28, 1.3 ± 0.1 years for PCB 52, and 2.8 ± 0.7 years for PCB 101 (Schettgen *et al.* 2012). Longer retention of PCB 28 in the body may explain why PCB 52 predominated in air samples but PCB 28 predominated in serum samples.

Liebel *et al.* 2004 reported significantly higher median serum concentrations for PCBs 28, 52, and 101 in 377 children from the contaminated school in Germany compared to 218 students attending an uncontaminated school. There was a significant positive association between years spent at the contaminated school and serum levels of the combined lower chlorinated congeners. Air levels measured in multiple locations over two years in the school building ranged $0.004\text{--}0.600 \mu\text{g}/\text{m}^3$ for PCB 28, $0.038\text{--}2.300 \mu\text{g}/\text{m}^3$ for PCB 52, and $0.003\text{--}1.100 \mu\text{g}/\text{m}^3$ for PCB 101. Very little PCB 138, 153 or 180 were detected in air sampling. The authors estimated total PCB in air over the two-year period to be $0.690\text{--}20.80 \mu\text{g}/\text{m}^3$ (mean $2.044 \mu\text{g}/\text{m}^3$) based on measurement of six indicator congeners. When PCB congeners associated with dietary intake were considered, there was no statistically significant difference between overall PCB body burden in students from the two schools. Nor was there a detectable difference in a survey of children's subjective symptoms.

Frederiksen *et al.* 2012 reported that mean PCB air levels in Danish multiunit housing was $1.03 \mu\text{g}/\text{m}^3$ (range $0.168\text{-}3.843 \mu\text{g}/\text{m}^3$) in apartments that contained PCB in elastic sealants versus a mean of $0.006 \mu\text{g}/\text{m}^3$ in apartments sealed with PCB-free sealants. PCB sealants contained up to 20% (221,680 ppm) PCB and were the primary determinant of indoor PCB levels. A survey of residents about their adherence to advice about minimizing their exposure showed that frequent ventilation, vacuuming, dusting, and floor washing were associated with lower indoor air levels.

In 2009, PCBs were discovered in chipping exterior paint on the former Rainier Brewery in Seattle at concentrations over 10,000 ppm PCB. This 4.5 acre site now houses mixed residential, restaurant, and business spaces. Paint chips were suspected to be the source of elevated PCBs in a nearby stormwater collection area. In 2010, sampling by EPA detected PCBs in indoor air in some office areas ($0.010\text{-}0.028 \mu\text{g}/\text{m}^3$) and in an outside stairwell that had been enclosed with the exterior paint intact ($0.052 \mu\text{g}/\text{m}^3$). Sampling also detected PCBs in vacuum dust at concentrations between 1.4-15.6 ppm in residential and office spaces, 3.4-36 ppm in storage and warehouse areas, and 470 ppm in stairwell dust. DOH concluded that there was a very low to insignificant increase in cancer risk associated with the levels detected. Recommendations for mitigation included removing all paint with more than 50 ppm PCB (as required by law), warning occupants to avoid regular use of the external stairwell until remediation could take place, and adopting cleaning techniques that would reduce potential for human exposure (WDOH 2013b).

PCBs can bind to indoor dust and present an inhalation or ingestion pathway for people. Dust intake is associated with higher molecular weight PCBs than air exposures. A 2006 survey of PCBs in residential settings reported median dust concentrations to be $0.200 \mu\text{g}/\text{kg}$ dust (ppb) in 20 Texas homes and $0.260 \mu\text{g}/\text{kg}$ in ten Toronto homes (Harrad *et al.* 2009). Maximum detected was $0.820 \mu\text{g}/\text{kg}$ PCBs in dust. While ingestion of house dust was a minor contributor to adult exposures, it contributed 1-20% of total PCB exposure to toddlers in exposure modelling (Harrad *et al.* 2009). Homes built before 1980 had higher PCB loading in house dust than more recently constructed homes in a large sampling of 415 homes in California (Whitehead *et al.* 2013). A recent study in China reported that house dust levels of PCBs were associated with subtle neurodevelopmental effects in pre-school aged children (Wang *et al.* 2015).

It appears that PCBs in older building materials can elevate PCBs in indoor air and dust and cause higher body burden of certain PCB congeners in the bodies of people living or working in these buildings. In some cases the detected air concentrations were high enough to exceed residential or occupational health guidelines. In the EPA investigation into older schools in New York, indoor air levels frequently exceeded EPA health guidance for schools of $0.70\text{-}0.60 \mu\text{g}/\text{m}^3$ depending on the age of the children present. EPA requires caulk with more than 50 ppm of PCBs to be removed. PCB containing fluorescent light ballasts that remain in service are

generally more than 30 years and have exceeded their expected life-span. They are at high risk for over-heating and failing and should be removed and properly disposed.

PCBs in Pigments and Dyes

Residual PCBs in dyes and pigments have been detected in ambient air, food, water, and consumer products. Air monitoring studies of urban air and remote polar air detect PCB 11, occasionally as a major component (Hu *et al.* 2008, Du *et al.* 2009, Basu *et al.* 2009, Choi *et al.* 2008). Consumer product testing has measured residual amounts of PCB 11 and other congener in a variety of colored paper, cardboard, and plastic packaging. (Hu and Hornbuckle 2010, Rodenberg *et al.* 2010). In Washington, PCBs associated with pigments and dyes have been identified in Columbia River water and clams and in a majority of fish sampled in a recent study in the Mid-Columbia. River (McCarthy 2007, Ecology 2005, U.S. Department of Energy 2010)

There is only limited investigation of absorption of PCB 11 into people. In rats, PCB 11 was rapidly absorbed via inhalation, distributed to tissue, and eliminated with half-lives in lung, liver and serum of approximately two hours. A hydroxylated metabolite of PCB 11 was also detected in the rodent liver (Hu *et al.* 2013). Biomonitoring for PCB congeners unique to dyes and pigments (PCB 11) has detected PCB 11 in people. In a recent study, 65% of 85 women in a mid-West had traces of PCB 11 in their blood (Marek *et al.* 2013). Three potentially toxic metabolites of PCB 11 have also been detected in human serum (Zhu *et al.* 2013).

There is only limited toxicity information specific to PCB 11. Zhu *et al.* 2013, tested PCB 11 and the 4-hydroxymetabolite detected in human serum for toxicity *in vitro*. In this study, the PCB 11 metabolite suppressed cell growth, created oxidative stress, and resulted in cytotoxicity. Co-administration of antioxidants partially protected against the observed effects. PCB 11 had no effect in the test (Zhu *et al.* 2013). Further study is needed to understand the magnitude of human exposure to PCB 11 and its metabolites as well as their toxicity.

Other Environmental Exposures

Small amounts of PCBs can be found in almost all soil surfaces and sediments. Most soil levels of PCBs are less than 0.010-0.040 $\mu\text{g}/\text{kg}$ (ppb) but soil at hazardous waste sites may be much higher. In water, a small amount of PCB may remain dissolved but most tends to stick to organic particles and sediments or evaporate from the water surface (ATSDR 2000).

Direct contact with PCB in old paint, caulk or fluids leaking from capacitors can lead to skin absorption or ingestion of PCBs. It is important to wear protective clothing gloves and respiratory protection if repairing or handling equipment like light ballasts that may have PCBs in them.

Occupational Exposures

Current occupational exposures can come from exposure to leaking electrical equipment made before 1979, from PCB abatement programs, or during demolition or recycling of PCB-contaminated structures and equipment.

Herrick *et al.* (2007), conducted biomonitoring for 54 PCB congeners in a small group of construction workers with a history of removing PCB caulk from buildings in the greater Boston area. The workers had higher proportions of lighter PCB congeners (PCBs 6-74) in their serum than a reference population of men who sought health care in the Boston area. The construction workers as a group had more than five times more PCB 6, 16, 26, 33, 37, 41, 70, 97, and 136 than the referent population. One worker, who was actively involved with removal of PCB products at the time of blood collection, had 25% of his body burden comprised of the lighter PCBs compared to 7% of the PCB serum levels in the referent population.

Wingfors *et al.* 2006 collected blood samples from 36 workers directly involved in abating PCB sealants in Sweden. These were compared in a biomonitoring study to 33 age- and sex-matched construction workers who did not work in the abatement program. The exposed workers had PCB serum levels (sum of 19 congeners) that were twice as high as the controls (mean of exposed workers were 575 ng/g lipid compared to 267 ng/g for the controls). The PCB congener patterns also differed between the workers and the controls, with much higher levels of many less chlorinated PCBs in the exposed workers, compared to the controls. The authors concluded that PCBs 56/60 and 66, were good markers of general occupational exposure; PCB 44, 70, and 110 were good markers for recent occupational exposures; and PCB 153 and 180 reflected background (dietary) exposure. Follow-up samples taken 10 months later showed that serum concentrations of rapidly excreted congeners (PCB 52, 44, 70, and 110) declined after workers were given information about protecting themselves from exposure.

Adequate safeguards are also important during recycling and disposal of PCB containing materials. Electronic waste recycling and disposal practices in China have resulted in elevated exposures in workers, PCB release into nearby soils and rivers, and subsequent contamination of staple foods grown in surrounding areas. (Yang *et al.* 2013, Tue *et al.* 2013, Labunska *et al.* 2015).

Existing Washington State Health Advice

Fish consumption is the primary exposure pathway that most Washingtonians have to many Persistent, Bioaccumulative Toxics (PBTs). Many PBTs such as PCBs, DDT, and mercury are linked to a variety of adverse health effects (e.g. neurological, developmental, immunological, and cancer). The paradox of consuming fish is that it also known to be one of the healthiest forms of protein due in part to the high levels of omega-3 fatty acids that have been associated with a variety of positive health outcomes (e.g. prevention of heart disease, inflammation, arteriosclerosis, and cognitive development). Results from the most recent Behavioral Risk Factor Surveillance System (BRFSS) conducted by DOH indicate that nearly three quarters of the adult general population in Washington State consume fish. Washington State is also the home of numerous federally recognized tribes whose fish consumption rates are often well above that of the general population (Ecology 2013b). Additionally, there are other high fish consuming populations within the state including Asian and Pacific Islanders and sports fishers.

Because of potential exposure to PBTs to fish consuming populations, DOH collaborates with numerous state and federal agencies on the collection and analysis of contaminants in fish. DOH's role is to evaluate fish contaminant levels in fish tissue for potential public health impacts and to convey information on risks and benefits to fish consumers by way of fish advisories. Currently, Washington State has thirteen waterbody specific fish advisories based on PCB levels in tissue. PCBs account for the greatest number of waterbody specific advisories in Washington State and across the country (WDOH 2013a, EPA 1999b).

Table 35 lists those waterbodies and fish species that currently have a fish advisory due to elevated PCB levels.

Table 35. Washington State PCB Fish Advisories

Water Body/Location	Fish Species	Advisory
Green Lake	Common Carp	1 meal per month
Lake Roosevelt	Largescale Suckers	2 meals per month
Lake Washington	Common Carp	Do not eat
	Northern Pikeminnow	Do not eat
	Cutthroat Trout	1 meal per month
	Yellow Perch	1 meal per week
Lower Duwamish River	Resident fish	Do not eat
	Shellfish	Do not eat
	Crab	Do not eat
Lower Columbia – (Bonneville Dam)	Resident fish	Do not eat
Bonneville Dam to McNary Dam	Resident fish	1 meal per week
Okanogan River	Common Carp	1 meal per month
Puget Sound	Chinook	1 meal per week
	Chinook (Blackmouth)	2 meal per month
	English Sole/Flatfish	Varies by location
	Rockfish	Varies by location
Spokane River		
Idaho Border to Upriver Dam	All species	Do not eat
UpRiver Dam to Nine Mile Dam	All species*	1 meal per month
	* Exception: Largescale Suckers	Do not eat
Long Lake (Lake Spokane)	Largescale Suckers, Brown Trout	1 meal per week
	Mountain Whitefish	1 meal per month
Walla Walla River – Lower	Carp	1 meal per month
Walla Walla River – Lower & Upper	Northern Pikeminnow	Do not eat
Wenatchee River	Mountain Whitefish	Do not eat
Yakima River	Common Carp	1 meal per week
Pending Advisories*		
Mid-Columbia	Lake Whitefish	1 meal per month
	Largescale Suckers	2 meals per month
	Sturgeon	2 meals per month
	Common Carp	1 meal per month
	Walleye	2 meals per month
	Bass	2 meals per month
Snake River	Channel Catfish	2 meals per month
	Common Carp	2 meals per month
* preliminary assessment, meal recommendations may change Fish advisories apply to all individuals. Women of childbearing age and young children should pay particular attention.		

Food Preparation and Cooking Advice to Reduce Exposure

Chemical contaminants are not distributed uniformly in fish. Fatty tissues typically concentrate organic chemicals such as PCBs and dioxins more readily than lean muscle tissue (ATSDR 2004). To reduce the level of PCBs in fish, remove the fish skin and visible fat before cooking. Do not use the fat for gravy or sauces. For further information on reducing contaminants such as PCBs in fish, visit

<http://www.doh.wa.gov/CommunityandEnvironment/Food/Fish/ReduceContaminantExposure>.

Benefits of Fish Consumption

The primary health benefits of eating fish are well documented for children and adults. Dietary fish is associated with reduction of cardiovascular disease (Yuan *et al.* 2001, Rodriguez *et al.* 1996, Hu *et al.* 2002, Marckmann and Gronbaek 1999, Mozaffarian *et al.* 2003, Simon *et al.* 1995, Burr *et al.* 1989, 1994, Singh *et al.* 1997, and Harrison and Abhyankar 2005) and positive pregnancy outcome (Jorgensen *et al.* 2001, Olsen *et al.* 1992, Olsen *et al.* 1995, Olsen and Secher 2002, Carlson *et al.* 1993, 1996, Fadella *et al.* 1996, San Giovanni *et al.* 2000, and Helland *et al.* 2003). Limited data also show a link between fish consumption and a decrease in development of some cancers (SACN 2004, IOM 2007). Additionally, eating fish has been associated with impacts on brain function, including protection against cognitive decline (SACN 2004, IOM 2007).

At present, we know that fish is an excellent protein source that is low in saturated fats, rich in vitamin D, omega-3 fatty acids, and other vitamins and minerals. The health benefits of eating fish are associated with low levels of saturated versus unsaturated fats. Saturated fats are linked with increased cholesterol levels and risk of heart disease while unsaturated fats (e.g., omega-3 polyunsaturated fatty acid) are an essential nutrient. Replacing fish in the diet with other sources of protein may reduce exposure to contaminants but could also result in increased risk for certain diseases (Pan *et al.* 2012). For example, replacing fish with red meat could increase the risk of cardiovascular disease due to the fact that red meat has higher levels of saturated fat and cholesterol (Law, 2000).

DOH fish advisories work to be protective of human health while acknowledging the benefits of eating fish. This is done by recommending decreased consumption of fish known to have high concentrations of contaminants in favor of fish that are lower in contaminants. DOH supports the American Heart Association and the U.S. Food and Drug Administration recommendation of consuming at least two servings (12 oz.) of fish per week as part of a healthy diet.

Health benefits of eating fish deserve particular consideration when dealing with groups that consume fish for subsistence. Removal of fish from the diet of subsistence consumers may have serious health, social, cultural, and economic consequences. In order to decrease the potential risks of fish consumption, these populations are encouraged to consume a variety of fish species,

to fish from locations with low contamination, and to follow recommended preparation and cooking methods.

Recommendation for Breast-feeding

DOH recommends that babies be breast fed because breast feeding has many demonstrated health benefits for the developing child and the mother. (Washington State Department of Health website <http://www.doh.wa.gov/YouandYourFamily/WIC/BreastfeedingSupport.aspx>)

Many investigations have looked for adverse effects associated with PCBs in breast milk and duration of breast feeding. Most studies have shown that prenatal, not postnatal PCB exposure correlates with neurobehavioral effects (Michigan, NC, Patandin *et al.* 1999, Darvill *et al.* 2000). Breast feeding appears to have a net positive effect on neurobehavioral test performance regardless of PCB concentration of the milk (Jacobson *et al.* 1990b).

A Dutch study on PCB and dioxin exposures to children recently found that PCB body burden at 42 months is associated with possible immune deficits. However, when the researchers controlled for length of breast feeding, they found that the negative effect of higher postnatal PCB exposure was counteracted by the positive effect of longer duration of nursing in infancy (Weisglas-Kuperus *et al.* 2000). Using this same cohort, other researchers conducted neurological and cognitive assessments at 42 months and found that breast-fed children performed better than their formula fed counterparts despite higher prenatal and postnatal exposure to PCBs (Lanting *et al.* 1998, Patandin *et al.* 1997 and 1999). Follow-up with these children at 6.5 years showed that effects of prenatal exposure to PCBs on cognitive and motor abilities were still measureable in the formula fed group and not measurable in the breast-fed group (Vreugdenhil *et al.* 2002). Analysis of parental and home characteristics suggested that an advantaged home environment contributed significantly to the resilience of the breast-fed group (Vreugdenhil *et al.* 2002).

Current Regulatory Approaches for PCBs

This chapter describes the existing regulations relevant to PCBs and the activities that generate them at the federal, state, and international levels. It includes a brief summary of many laws and regulations directly related to management of processes that produce PCBs, the production, use, and disposal of products that contain PCBs, and exposure limits and cleanup levels for PCBs themselves. This chapter is not an exhaustive review of all of the regulations pertinent to PCBs.

In many instances, federal laws and regulations delegate the authority for implementing these laws and regulations to state or Tribal governments. In some cases, states adopt laws and promulgate regulations that are more stringent than their federal partners.

Federal Laws & Regulations

Toxic Substances Control Act

15 USC 2601 et seq., Toxic Substances Control Act

The Toxic Substances Control Act (TSCA) of 1976 (15 USC 2601 et seq.) gives EPA the authority to regulate new and existing substances. TSCA gives EPA the authority to require reporting, record-keeping and testing requirements, and restrictions relating to chemical substances and/or mixtures. Certain substances are generally excluded from TSCA, including, among others, food, drugs, cosmetics, and pesticides.

TSCA is the primary federal law pertinent to PCBs in the United States. PCBs are regulated by Title I Section 6 of the Act and by EPA implementing regulations, Title 40, Part 761 of the Code of Federal Regulations (CFR). Section 6(e)(2)(A) of TSCA states that "...effective one year after January 1, 1977, no person may manufacture, process, or distribute in commerce or use any polychlorinated biphenyl in any manner other than in a totally enclosed manner." Section 6 of TSCA further prohibited the manufacture of all PCBs by 1979, but allowed the EPA administrator to authorize certain processing, distribution in commerce, and use of PCBs manufactured before 1979 if the Administrator determined that such activity did not present an unreasonable risk of injury to health or the environment. Table 37 summarizes several subparts of TSCA and their contents

Table 36. Subparts of TSCA

Subpart A	General regulations governing PCBs including definitions
Subpart B	Manufacturing, processing, distribution in commerce and use of PCBs and PCB items Prohibitions and exceptions Authorizations including: <ul style="list-style-type: none">• Totally enclosed uses (e.g. transformers, capacitors)• Non-totally enclosed uses (including requirements for servicing PCB-containing equipment)• Other uses (carbonless copy paper, research and development, scientific instruments, continued use of porous surfaces contaminated with PCBs)
Subpart C	Marking of PCBs and PCB items
Subpart D	Storage and disposal, including: <ul style="list-style-type: none">• PCB disposal requirements• Remediation waste disposal and cleanup levels• Bulk product waste• PCB household waste storage and disposal• PCB decontamination standards and procedures• Storage for disposal
Subpart E	Manufacturing, processing, and distribution in commerce exemptions, including: <ul style="list-style-type: none">• Research and development for disposal technologies• Analytical reference samples• 5 ml or less PCB fluids from electrical equipment for analysis•
Subpart F	Transboundary shipments of PCBs for disposal
Subpart G	PCB spill cleanup policy
Subpart J	General records and reports
Subpart K	PCB waste disposal records and reports
Subparts M-R	Sampling requirements for various media and disposal authorizations
Subpart S	Double wash/rinse method for decontaminating non-porous surfaces
Subpart T	Comparison study for validating a new performance-based decontamination solvent

Continued use and disposal of existing PCBs is governed by a framework of controls driven by the form the PCBs take (liquid form, non-liquid form, or multi-phasic, meaning a combination of liquid and non-liquid forms), the amount of PCBs in each form, and the original source of PCBs for media contaminated by a release.

While not a complete summary of all sections in TSCA that pertain to PCBs: below are some important requirements:

- Prohibits of manufacture, sale, and distribution, with exceptions.
- Mandates proper disposal for any PCBs unauthorized for use.
- Does not require testing to find PCB sources, but does require proper use and disposal of identified PCB contaminated items.
 - Many unauthorized uses are therefore not found until a release to the environment has occurred.
- Limits use of PCBs to certain “totally enclosed” uses, such as transformers and capacitors, or concentrations below 50 ppm in bulk product. Various other levels exist for remediation waste and other limited uses, typically with EPA approval.
- Requires that by December 1998, all known transformers containing PCBs >500 ppm be registered with EPA.
 - There is no requirement to determine if transformers contain >500 ppm PCBs, only to register it if it is known to be a PCB Transformer (>500 ppm PCBs).
- Allows many forms of PCB waste to be disposed of as municipal solid waste, which does not require PCBs to be listed on a manifest. Examples include:
 - Small non-leaking PCB capacitors.
 - Plastics (such as plastic insulation from wire or cable; radio, television and computer casings; vehicle parts; or furniture laminates); preformed or molded rubber parts and components; applied dried paints, varnishes, waxes or other similar coatings or sealants; caulking; Galbestos; non-liquid building demolition debris; or non-liquid PCB bulk product waste from the shredding of automobiles or household appliances from which PCB small capacitors have been removed (shredder fluff).
 - Any of these may also be disposed as landfill daily cover or as roadbed under asphalt.
 - Other PCB bulk product waste that leaches PCBs at <10 µg/L of water measured using a procedure used to simulate leachate generation.
 - PCB bulk product waste other than those materials listed above if:
 - The PCB bulk product waste is segregated from organic liquids disposed of in the landfill unit.
 - Leachate is collected from the landfill unit and monitored for PCBs.
- Requires labels identifying electrical equipment containing over 500 ppm PCBs.
- Requires quarterly inspections of PCB transformers containing more than 60,000 ppm PCBs. Transformers with less than 60,000 ppm PCBs and those with appropriate secondary containment must be inspected for leaks at least annually.

- Requires removal or reclassification of high-voltage network PCB-containing transformers to prevent fires. Requires enhanced electrical protection be added on many types of PCB transformers in, or within 30 meters of, commercial buildings.¹²
- Requires EPA authorization for commercial storage of PCBs. Non-Commercial storage does not always require EPA oversight.

TSCA Rules

Under TSCA EPA has promulgated 29 rules for the regulation of PCBs. A list of rules, with the associated notices, drafts, etc. can be found on the EPA website at <http://www.epa.gov/wastes/hazard/tsd/pcbs/pubs/laws.htm>. The current regulations can all be found in the Federal Code of Regulations (CFR) part 761. In general, each rule addresses a specific portion of managing PCBs, such as labeling and spills. Below is some information on three specific regulations.

1. 44 FR 31514 PCBs; Manufacturing, Processing, Distribution in Commerce and Use Bans.

This 1979 rule implemented the ban on PCBs and established 50 ppm PCBs as the general regulatory limit.

2. 49 FR 28172 Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions; Exclusions, Exemptions, and Use Authorizations

EPA promulgated a rule in 1984 for inadvertent generation of PCBs that are not in closed or controlled manufacturing processes (49 FR 28172). EPA found the societal benefit of these products and the cost of not producing PCBs outweighed the risks to human health and the environment from these sources of PCBs. The rule was based on a consensus proposal from the Environmental Defense Fund, Natural Resources Defense Council, and Chemical Manufacturers Association (now known as the American Chemistry Council). It requires that the concentration of inadvertently generated PCBs in products, including recycled paper, must have an annual average of < 25 ppm, with a maximum of 50 ppm. Detergent bars are treated differently as they are consumer products with a high potential for exposure, and are limited to 5ppm (soap and deodorant are regulated by the FDA).

There were several additional criteria in the rule:

- Releases to ambient air must be less than 10ppm.
- Discharges to water must be less than 0.1ppm, except from recyclable paper the limit is 3 ppb total Aroclors.

¹² Panero, M., Boheme, S., and Muñoz, G. Pollution Prevention and Management Strategies for Polychlorinated Biphenyls in the New York/New Jersey Harbor. February 2005. New York Academy of Sciences, New York, NY. Available at: <http://www.nyas.org/WhatWeDo/Harbor.aspx>

- All wastes must be disposed of properly. Process wastes with PCB levels > 50 ppm must be disposed of in accordance with TSCA.
- The concentration of monochlorinated biphenyls is discounted by a factor of 50 and dichlorinated biphenyls are discounted by a factor of 5.
- Certification, reporting, and records maintenance.

The numerical limits in the law were set at the Limits of Quantification (LOQs) at the time.

The rule clarifies some overlap between TSCA with the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and Federal Food Drug and Cosmetic Act (FFDCA). If a chemical is solely manufactured for a use that is regulated by FIFRA or FFDCA, then that substance is not regulated under TSCA. If only some uses are regulated under FIFRA, then the chemical is regulated under TSCA until it becomes part of an identified pesticide product. However, chemicals used in FDA-regulated products under FFDCA (like a food, food additive, drug, cosmetic, or medical device) are excluded from TSCA jurisdiction.

In 2013 EPA clarified the definition of “excluded PCB Products” to generally allow for the recycling of plastic separated from shredder residue containing < 50 ppm PCBs under specific conditions. The voluntary procedures to prevent the introduction of PCBs in shredder residue are (1) documented source control programs and (2) documented output control. The review was done at the request of the Institute of Scrap and Recycling Industries to clarify whether the plastic material should be managed as an Excluded PCB Product or as a PCB Remediation Waste. This interpretation reiterates EPA’s “generic exclusion for processing, distribution in commerce, and use, based on the Agency’s determination that the use, processing, and distribution in commerce of products with less than 50 ppm concentration will not generally present an unreasonable risk of injury to health or the environment” (FR Vol. 78, No. 66, April 5, 2013).

3. Several rules on transformers and other electrical equipment have been promulgated. The current regulations are in CFR part 761.

The regulations include several important definitions:

- PCB Transformer (≥ 500 ppm) *PCB Transformer* means any transformer that contains ≥ 500 ppm PCBs.
- PCB contaminated (50-500 ppm) *PCB-Contaminated* refers to liquid and non-liquid material containing PCBs at concentrations ≥ 50 ppm but < 500 ppm, and non-porous surface having a surface concentration $> 10 \mu\text{g}/100 \text{ cm}^2$ but $< 100 \mu\text{g}/100 \text{ cm}^2$.

The definitions specifically mention electrical equipment with a very similar definition. *PCB-Contaminated Electrical Equipment* means any electrical equipment including, but not limited to, transformers (including those used in railway locomotives and self-propelled cars), capacitors, circuit breakers, reclosers, voltage regulators, switches (including

sectionalizers and motor starters), electromagnets, and cable, that contains PCBs at concentrations of ≥ 50 ppm and < 500 ppm in the contaminated fluid. In the absence of liquids, electrical equipment is PCB-Contaminated if it has PCBs at $> 10 \mu\text{g}/100 \text{ cm}^2$ and $< 100 \mu\text{g}/100 \text{ cm}^2$.

- Non-PCB Transformer (< 50 ppm) *Non-PCB Transformer* means any transformer that contains less than 50 ppm PCB.

Owners of PCB transformers (≥ 500 ppm) were required to register their transformers with the EPA by Dec. 28, 1998. Some important points about this requirement:

- There is no requirement to test a transformer to determine if it is a PCB Transformer.
- There is no requirement to register a transformer if the owner takes ownership after 1998.
- There is no requirement to register a PCB-contaminated transformer (50-500ppm PCBs)
- There is no requirement to request a registered transformer be removed from the database if it is physically removed from service.
- Other equipment, such as bushings with ≥ 500 ppm PCBs, are not required to be registered.

While testing for PCBs is not required, the regulations do include PCB concentration assumptions that are based on the age and size of the equipment. The assumptions include:

- Transformers with < 3 pounds (1.36 kilograms (kgs)) of fluid, circuit breakers, reclosers, oil-filled cable, and rectifiers whose PCB concentration is not established contain PCBs at < 50 ppm.
- Mineral oil-filled electrical equipment that was manufactured before July 2, 1979, and whose PCB concentration is not established is PCB-Contaminated Electrical Equipment (i.e., contains ≥ 50 ppm PCB, but < 500 ppm PCB). All pole-top and pad-mounted distribution transformers manufactured before July 2, 1979, must be assumed to be mineral-oil filled.
- Electrical equipment manufactured after July 2, 1979, is non-PCB (< 50 ppm PCBs).
- If the date of manufacture of mineral oil-filled electrical equipment is unknown, any person must assume it to be PCB-Contaminated.
- A transformer manufactured prior to July 2, 1979, that contains 1.36 kg (3 pounds) or more of fluid other than mineral oil and whose PCB concentration is not established, is a PCB Transformer (i.e., ≥ 500 ppm). If the date of manufacture and the type of dielectric fluid are unknown, any person must assume the transformer to be a PCB Transformer.
- A capacitor manufactured prior to July 2, 1979, whose PCB concentration is not established contains ≥ 500 ppm PCBs.
- A capacitor manufactured after July 2, 1979, is non-PCB (i.e., < 50 ppm PCBs).
- If the date of manufacture is unknown, any person must assume the capacitor contains ≥ 500 ppm PCBs.

Water Regulations

33 USC 1251 et seq., The Clean Water Act (CWA)

EPA has established water quality criteria for certain compounds that define levels to protect human health and aquatic life. The Clean Water Act and its amendments prohibit discharging pollutants from a point source without a National Pollutant Discharge Elimination System (NPDES) permit. These permits include conditions to protect water quality. EPA authorizes states to issue and monitor compliance with these permits. The Clean Water Act also directs EPA to establish technology-based standards, known as Best Available Technology (BAT) requirements to prevent discharges of harmful amounts of pollutants.

Stormwater from certain industries and municipalities is also considered a point source of pollution that requires NPDES permitting¹³. PCBs from various sources that are deposited on land and washed into storm drains would be regulated under these stormwater permits. EPA's stormwater regulations establish two phases for the stormwater permit program:

- Phase I stormwater permits cover discharges from certain industries, construction sites involving five or more acres, and municipalities with a population of more than 100,000.
- Phase II stormwater permits cover all municipalities located in urbanized areas and construction sites between one and five acres. The EPA rule also requires an evaluation of cities outside of urbanized areas that have a population over 10,000, to determine if a permit is necessary for some or all of these cities.

National Recommended Water Quality Criteria¹⁴

PCBs are a Priority Pollutant under the CWA. EPA has national recommended water quality criteria for the protection of aquatic life and human health in surface water for about 150 pollutants. These criteria are published pursuant to Section 304(a) of the Clean Water Act and provide guidance to states. For aquatic health the chronic freshwater criterion is 0.014 ug/L and 0.03 ug/L for saltwater. For human health the criteria are 0.000064 ug/L both for the consumption of water and organism and for the consumption of organism only.

National Toxics Rule (40 CFR 131.36).¹⁵

The National Toxics Rule promulgated chemical-specific numerical criteria for priority toxic pollutants for 14 states to bring them into compliance with requirements of section 303(c)(2)(B)

¹³ Department of Ecology. How is Stormwater Regulated? Available at: <http://www.ecy.wa.gov/programs/wq/stormwater/municipal/howregulated.html>

¹⁴ US EPA. National Recommended Water Quality Criteria. Available at: <http://water.epa.gov/scitech/swguidance/standards/current/index.cfm> (accessed 9 June 2011).

¹⁵US EPA. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliances. 57 FR 60848. Available at: <http://water.epa.gov/lawsregs/rulesregs/ntr/index.cfm> (accessed 21 Oct 2013).

of the CWA. This rule became effective in 1993. The criterion for PCBs for both freshwater and marine water is 0.00017 ug/L, which has a fish tissue equivalent of 5.304 ug/kg.

42 USC 300f et seq., Safe Drinking Water Act (SDWA)

The Safe Drinking Water Act specifies water quality standards for drinking water. The National Primary Drinking Water regulations under the SDWA apply to public water systems with at least 15 service connections or more than 25 individuals for more than 60 days per year.

The SDWA sets two drinking water standards. The Maximum Contaminant Level Goal (MCLG) is a non-enforceable health goal. The Maximum Contaminant Level (MCL) is the legally enforceable standard. Water systems must reduce levels of the contaminant as close to the MCLG as feasible, considering technology, treatment techniques, and costs. For PCBs the MCLG is zero and the MCL is 0.0005 mg/L (ppm)¹⁶

Air Regulations

42 USC 7401, Clean Air Act and Amendments

PCBs are regulated under Section 112 of the Clean Air Act as Hazardous Air Pollutants (HAPs).

Regulation under Section 112 of the Clean Air Act requires major sources of HAPs to meet standards based on Maximum Achievable Control Technology (MACT). These standards must require the maximum degree of emission reduction that the EPA determines to be achievable by each particular source category. Different criteria for MACT apply for new and existing sources. For existing major sources, MACT is defined as the technology used to control emissions at the top 12% of facilities within the same source category. Eight to nine years after MACT is implemented, EPA is required to conduct a residual risk analysis. If the "residual risk" for a source category does not protect public health with "an ample margin of safety," the EPA must promulgate health-based standards for that source category to further reduce HAP emissions.

PCBs are one of several substances listed in Section 112(c)(6) of the Clean Air Act, which requires EPA to "list categories and subcategories of sources assuring that sources accounting for not less than 90 per centum of the aggregate emissions of each such pollutant are subject to standards." EPA published this listing in a Federal Register notice in June 1997.¹⁷ Various forms of waste incineration were identified as the primary industrial source categories emitting PCBs.

¹⁶ US EPA. List of Contaminants & their MCLs. Available at: <http://water.epa.gov/drink/contaminants/index.cfm#List> (accessed 9 June 2011).

¹⁷ Notice of draft source category listing for section 112(d)(2) rulemaking pursuant section 112(c)(6) requirements. 62 FR 119 (20 June 1997). p. 33625 - 33638.

Waste, Hazardous Substance & Cleanup Regulations

42 USC 6901 et seq., Resource Conservation and Recovery Act (RCRA)

Under the authority of the Resource Conservation and Recovery Act of 1976, EPA implements regulations pertaining to solid waste, hazardous waste and underground storage tanks (40 CFR parts 239-299).

Hazardous wastes are managed under RCRA from their point of generation to their proper disposal or treatment. There are three means under RCRA of identifying if a waste is hazardous: (1) if the waste is specifically listed as hazardous, (2) if it exhibits hazardous characteristics, as determined by a Toxicity Characteristic Leaching Procedure (TCLP) test or 3) exhibits the characteristics of ignitability, corrosivity or reactivity.

Wastes are given waste codes based on their sources or specific properties. D codes are for characteristic wastes. P and U waste codes are assigned to discarded chemical products. F codes are for non-specific and K codes are for specific industrial sources.

Standards for the Management of Used Oil (40 CFR Part 279)¹⁸ include management standards for generators, transporters, processors, burners, and marketers of used oil containing PCBs at less than 50 ppm. Used oil containing more than 50 ppm is regulated under TSCA (40 CFR part 761).

RCRA allows EPA to permit facilities to Treat, Store and Dispose of hazardous waste. Additionally, RCRA grants EPA the authority to require cleanup of any releases of hazardous waste to the environment from a permitted or interim status facility through the RCRA Corrective Action Program. RCRA cleanup sites regularly also have PCB contamination. Generally these sites come under both programs for approval of the waste cleanup.

42 USC Part 103, Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

CERCLA, passed in 1980, is the primary federal authority used to regulate and cleanup historic hazardous waste sites. The statute and implementing regulations establish procedures for the long-term remediation of such sites, but also provides authority to clean up hazardous waste sites in need of immediate action. The law has subsequently been amended, by the Superfund Amendments and Reauthorization Act of 1986 (SARA), and the Small Business Liability Relief and Brownfields Revitalization Act of 2002.

Under CERCLA Section 103, releases of hazardous substances are required to be reported to the National Response Center if they exceed the Reportable Quantity (RQ) for that substance, which

¹⁸ US EPA. Standards for the Management of Used Oil. [40 CFR Part 279](http://www.access.gpo.gov/nara/cfr/waisidx_07/40cfr279_07.html). Available at: http://www.access.gpo.gov/nara/cfr/waisidx_07/40cfr279_07.html (accessed 10 June 2011).

is 1 pound for PCBs.¹⁹ CERCLA implements TSCA as an Applicable or Relevant and Appropriate Requirements (ARAR), without need for separate approval under TSCA for PCB waste disposal.

42 USC Part 116, Emergency Planning and Community Right-to-Know Act (EPCRA)

EPCRA, or SARA Title III, is intended to protect public health and the environment from hazards posed by toxic chemicals by providing information about the presence of toxic chemicals in communities. The Act, passed in 1986, creates the annual hazardous chemical inventory as well as the toxics release inventory (TRI).

Under Section 302 of EPCRA, facilities that manufacture, process or use chemicals on the list of Extremely Hazardous Substances (EHSs) must report the presence of those chemicals above a certain quantity, known as the Threshold Planning Quantity (TPQ).

Section 313 of EPCRA establishes the Toxics Release Inventory (TRI). Under the TRI, the release or waste management of toxic chemicals by certain industries must be reported if the quantity of a chemical that is manufactured, processed, or otherwise used during the calendar year exceeds the reporting threshold. For most TRI chemicals, the thresholds are 25,000 pounds manufactured or 10,000 pounds otherwise used.²⁰ The reporting threshold for PBTs is lower and is 10 lbs for PCBs.

Worker & Product Safety Regulations

84 USC 1590 et seq., Occupational Safety and Health Act (OSHA)

The Occupational Safety and Health Act allows the Occupational Safety and Health Administration (OSHA) to set protective regulatory limits on the amount or concentration of a substance in the air in workplaces. These limits, called Permissible Exposure Limits (PELs) are based on an average exposure over an 8 hour workday, or a Time-Weighted Average (TWA).²¹ OSHA's PEL is 1,000 $\mu\text{g}/\text{m}^3$ for PCBs containing 42% chlorine (CAS 53469-21-9) and 500 $\mu\text{g}/\text{m}^3$ for compounds containing 54% chlorine (CAS 11097-69-1). The PELs include "skin" to refer to the contribution to overall exposure through skin. These are based on the prevention of liver injury in exposed workers.

The National Institute for Occupational Safety and Health (NIOSH) recommends a 10-hour TWA of 1 $\mu\text{g}/\text{m}^3$ based on the minimum reliable detectable concentration and the potential

¹⁹ US EPA. List of Lists: Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the Clean Air Act. EPA 550-B-01-003. October 2012. Available at: <http://www.epa.gov/emergencies/tools.htm#lol> (accessed 21 October 2013).

²⁰ US EPA. List of Lists: Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the Clean Air Act. EPA 550-B-01-003. October 2012. Available at: <http://www.epa.gov/emergencies/tools.htm#lol> (accessed 21 October 2013).

²¹ Occupational Safety and Health Administration. Permissible Exposure Limits (PELs). Available at: <https://www.osha.gov/dsg/topics/pe/> (accessed 21 October 2013).

carcinogenicity of PCBs.²² The NIOSH Recommended Exposure Limit (REL) was based on reproductive effects in animal models, carcinogenic effects, and prevention of liver injury. NIOSH also recommends that all workplace exposures be reduced to the lowest feasible level.

Washington State Laws and Regulations

Water Regulations

Chapter 90.48 RCW Water Pollution Control

Chapter 173-200 WAC Water quality standards for groundwaters of the state of Washington.

This regulation is intended to protect current and future beneficial uses of groundwater from deleterious effects, prevent degradation of waters of outstanding value, and actively maintain the higher quality of waters that exceed water quality criteria.

Chapter 173-201A WAC Water quality standards for surface waters of the state of Washington.

This regulation institutes narrative and numeric criteria for surface water quality, an anti-degradation policy, and use-based protection measures.

Chapter 70.142 RCW Chemical Contaminants and Water Quality

This law allows the State Board of Health to establish standards for allowable concentrations of chemical contaminants in public water supplies.

Chapter 246-290 WAC Water quality standards for groundwaters of the state of Washington

This regulation establishes regulatory requirements applicable to public drinking water supplies.

Multiple Statutes – Chapters 90.48, 70.105D, 90.70, 90.52, 90.54 and 43.21 RCW

Chapter 173-204 WAC, Sediment Management Standards

Enacted in 1991, this chapter establishes marine, low salinity and freshwater surface sediment management standards. The purpose of this chapter is to reduce health threats to humans and biological resources resulting from surface sediment contamination.²³

Air Regulations

Chapter 70.94 RCW Washington Clean Air Act

The Washington Clean Air Act authorizes the Department of Ecology to develop and implement regulations that are needed to control air pollution.

²² Polychlorinated Biphenyls (PCBs). Current Intelligence Bulletin 45 (1986) <http://www.cdc.gov/niosh/docs/86-111/> (accessed 21 October 2013)

²³ WAC 173-204-320. Table 1, Marine Sediment Quality Standards. Available at: <http://apps.leg.wa.gov/wac/default.aspx?cite=173-204-320> (accessed 10 June 2011).

Chapter 173-460 WAC Controls for new sources of toxic air pollutants

Under this chapter, Ecology reviews new sources of toxic air pollutants and establishes emission control requirements that are needed to prevent air pollution that may impact human health and safety. This chapter, enacted in 1991, requires new sources to implement Best Available Control Technology for toxics (BACT). The owner or operator of a new toxic air pollutant source must also conduct an Acceptable Source Impact Level (ASIL) analysis for toxic air pollutants. When performing these assessments, the owner/operator must quantify the amount of toxic air pollutant likely to be emitted from the new source and estimate ambient air concentrations that might result from those emissions. Ambient air concentrations are estimated using air quality models. The model air concentrations are then compared to regulatory screening values (ASIL). If the modeled concentration exceeds the ASIL screening levels, the owner/operator must perform a comprehensive review using a more sophisticated model and, if necessary, apply additional emission controls. Violators may be subject to enforcement actions, civil penalties and/or criminal charges such as gross misdemeanor. Twelve PCB congeners and general PCBs (CAS 1336-36-3) are regulated as Toxic Air Pollutants (TAPs).²⁴

Waste, Hazardous Substance & Cleanup Regulations

Multiple Statutes - Chapter 70.105 RCW and parts of chapters 70.105A, 70.105D and 15.54 RCW

Chapter 173-303 WAC, Dangerous Waste Regulations

These regulations meet the requirements of the Federal Resource Conservation and Recovery Act (RCRA) and the Department of Ecology is authorized by the US EPA to implement RCRA within the state. Therefore, all the requirements identified under RCRA are also part of the state's dangerous waste regulations. In addition, this chapter also contains specific state-only dangerous waste requirements for any waste generated or disposed of within the state. The dangerous waste regulations require a generator of dangerous waste to designate that waste according to the regulations and follow the associated requirements for waste of that designation.

Washington State has specific requirements that pertain to toxicity and persistent criteria. Halogenated organic compounds like PCBs are considered persistent in the dangerous waste regulations.

WAC 173-303-100(5) requires waste to be evaluated for mammalian and aquatic toxicity and WAC 173-303-100(5)(b)(i) provides a process to designate a specific waste stream based upon the toxicity of the individual components. In this evaluation, toxicity must be considered with other waste constituents to determine if the waste stream designates as a state-only toxic waste

²⁴ WAC 173-460-450. Table of ASIL, SQER and de minimis emission values. Available at: <http://apps.leg.wa.gov/WAC/default.aspx?cite=173-460-150> (accessed 10 June 2011).

and assigned the waste codes of WT02 as dangerous waste or WT01 as EHW (extremely hazardous waste).

In Washington State, PCB waste may be regulated as a state criteria dangerous waste or as a state listed dangerous waste. The Washington dangerous waste regulations separate wastes into four categories:

- Characteristic wastes.
- Criteria wastes.
- Discarded chemical products.
- Non-specific and specific industrial sources.

Wastes are given waste codes based on their sources or specific properties as discussed in the Federal Regulations section on RCRA. W codes are for state-only wastes.

PCBs as a state criteria dangerous waste

Since PCBs meet the definition of Halogenated Organic Compound (WAC 173-303-040), wastes containing PCBs (other than state listed PCB wastes discussed below) must be evaluated for state persistence. This requirement has been in place since early adoption of the State's Dangerous Waste Regulations in 1982. At 100ppm PCB, a waste would be considered a persistent dangerous waste (waste code WP02). A few examples of PCB persistent waste include: caulking, tar and rubber stripping at airport runways. If the PCB concentration exceeds 10,000 ppm (waste code WP01), the waste is recognized as an extremely hazardous waste pulling on additional requirements and/or prohibitions on the management of that waste.

PCBs as a state listed dangerous wastes

To address the management of the most problematic PCB wastes- liquid PCBs in transformers, bushings and capacitors- RCW 70.105.105 gives the authority to Ecology to regulate PCBs as a dangerous waste. In 1985, Ecology amended its Dangerous Waste Regulations to include certain PCB wastes (waste code WPCB). This is a source specific group of waste products that only applies to discarded transformers, capacitors or bushings containing 2 ppm PCB or greater (except when drained of all free flowing liquid) and to the following wastes generated from the salvaging, rebuilding, or discarding of transformers, capacitors or bushing at 2 ppm PCB or greater: cooling and insulation fluids, cores, and core papers.

Exclusions

- 1) -071(3)(k). PCB exclusion. One may manage a state only PCB waste under specific TSCA regulations instead of the state Dangerous Waste regulations. The waste would become excluded from the state Dangerous Waste regulations. Often, listed-WPCB dangerous wastes are managed under this exclusion.

- 2) -073 “Special waste exclusion”. If the waste meets the definition of special waste (WAC 173-303-040), then some listed WPCB wastes and some state only persistent criteria waste (due to PCB) can be managed this way.

Chapter 70.95I RCW Used oil recycling

Used oil is conditionally regulated under the dangerous waste regulations as long as 1) it is not contaminated with chlorinated solvents or PCBs and 2) it is managed appropriately. If used oil is not contaminated, it may be recycled or burned for energy recovery. Used oil with 2 ppm or greater PCBs is prohibited from being managed as used oil under the Dangerous Wastes used oil regulations when burned for energy recovery. WAC 173-303-515 contains management standards for used oil.

This statute requires local governments to include an element in their hazardous waste plans enumerating how they will collect used oil. It also requires used oil recycling containers and educational information about used oil to be provided at any business that sells above 1,000 gallons of lubricating oil to consumers (500 gallons in a city with an approved used oil recycling element in their hazardous waste plan).

Chapter 70.105D RCW Hazardous Waste Cleanup – Model Toxics Control Act

Chapter 173-340 WAC, Model Toxics Control Act – Cleanup

Chapter 70.105D RCW establishes the framework and authority for the development of a program dealing with the cleanup of sites contaminated with toxic chemicals. The MTCA Cleanup Regulation, issued in 1991, establishes procedures and standards for the identification, investigation and cleanup of facilities contaminated with hazardous wastes.

MTCA provides several methods for setting cleanup standards. Under MTCA Method A, pre-calculated protective cleanup levels are available in tables within the regulation for use at relatively simple sites.

Method B is the universal method for determining cleanup levels for all media at all sites. A target cancer risk level of one in one million (10^{-6}) is used when calculating cleanup levels under Method B. Toxicity equivalency factor (TEF) methodology (Van Den Berg *et al.* 2006) may also be used to evaluate the toxicity of PCBs, where the mixture is considered a single hazardous substance.²⁵

Method C cleanup levels are established when cleanup levels established under Method A or B may be impossible to achieve or may cause greater environmental harm.

²⁵ Department of Ecology. Evaluating the Toxicity and Assessing the Carcinogenic Risk of Environmental Mixtures Using Toxicity Equivalency Factors. Available at: <https://fortress.wa.gov/ecy/clarc/FocusSheets/tef.pdf> (accessed 16 June 2011).

Chapter 173-360 WAC, Underground Storage Tank Regulations

The Department of Ecology implements Chapter 90.76 RCW, Underground Storage Tanks, in order to protect human health and the environment from leaking underground storage tanks containing petroleum and other regulated substances. No underground storage tank systems, within the parameters of this chapter's scope, may operate without a valid permit. This chapter sets forth performance standards for underground storage tanks. Tanks must be monitored and owners and operators are required to comply fully with testing and inspection. Releases into the surrounding environment must be immediately reported to Ecology and appropriate cleanup and containment measures must be taken. Under most circumstances, MTCA cleanup standards apply to the remediation of releases from leaking underground storage tanks. This chapter was adopted in 1990 and violators face fines of up to \$5,000 dollars per day per violation.

Worker & Product Safety Regulations

Chapter 49.17 RCW Washington Industrial Safety and Health Act

Chapter 296-841 WAC Airborne Contaminants

This chapter specifies Permissible Exposure Limits (PELs) of 1,000 $\mu\text{g}/\text{m}^3$ for PCBs containing 42% chlorine (CAS 53469-21-9) and 500 $\mu\text{g}/\text{m}^3$ for compounds containing 54% chlorine (CAS 11097-69-1) that mirror the federal OSHA requirements (see Federal Regulations).

They also specify Short-Term Exposure Limits (STEL) of 3,000 $\mu\text{g}/\text{m}^3$ for PCBs containing 42% chlorine (CAS 53469-21-9) and 1,500 $\mu\text{g}/\text{m}^3$ for compounds containing 54% chlorine (CAS 11097-69-1). STELs refer to 15 minute exposure periods.

Taxes

Chapter 82.21 RCW Hazardous substance tax – model toxics control act

Chapter 458-20-252 WAC Hazardous substance tax and petroleum product tax

PCBs are taxed under the Hazardous Substance Tax.

This law places a tax on the first possession of hazardous substances in Washington. The Department of Ecology determines which substances are subject to the tax. The tax applies to petroleum products, pesticides, and certain chemicals. There are currently over 8,000 different hazardous substances identified as being subject to the tax. The tax rate is .007 of the wholesale value of the product. Funds are distributed to the Department of Ecology to help clean up, manage and prevent solid and hazardous waste in the state of Washington.²⁶ The tax does not apply to components or contaminants, such as inadvertently generated PCBs in other products.

²⁶ Washington State Department of Revenue. Hazardous substance tax. Available at: http://dor.wa.gov/content/findtaxesandrates/othertaxes/tax_hazard.aspx

The tax applies to

- Petroleum products.
- Substances designated as hazardous under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA – see Federal Regulations).
- Any pesticide product required to be registered under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA – see Federal Regulations).
- Other substances or categories of substances designated by Ecology.

Select Regulations in Other US Jurisdictions

Maine

<http://www.mainelegislature.org/legis/statutes/38/title38sec419-B.html>

This law requires public utilities to remove transformers with more than 50 ppm PCBs. There are earlier deadlines for transformers within 100 feet surface water, elementary school or secondary school.

Select International Regulations

Most countries have prohibited the commercial manufacturing of PCBs.

Stockholm Convention²⁷

The Stockholm Convention on Persistent Organic Pollutants is a global treaty that aims to protect human health and the environment from the effects of persistent organic pollutants. The Convention has a range of control measures to reduce and, where feasible, eliminate the release of POPs. The Convention also aims to ensure the sound management of stockpiles and wastes that contain POPs.

The Convention was signed in 2001 and entered into force in 2004. The US is a signatory, but has not ratified the Convention, so is not a Party to it.

PCBs are one of the 12 initial POPs under the Stockholm Convention. The parties to the Convention are required to eliminate the use of PCBs in existing equipment by 2025 and ensure environmentally sound waste management of them by 2028. Each country is expected to develop inventories and identify contaminated sites. To help stakeholders achieve the goals in the Stockholm Convention they created the PCB Elimination Network (PEN) as a voluntary

²⁷<http://chm.pops.int/Home/tabid/2121/mctl/ViewDetails/EventModID/871/EventID/407/xmid/6921/Default.aspx>

collaborative arrangement to promote and facilitate information exchange to support the obligations of Stockholm Convention on environmentally sound management of PCBs. Canada

Sweden

In addition to banning the use of PCBs, Sweden has required inventorying buildings with PCB-contaminated materials, such as caulk, and removing them²⁸. The initial program in 1980 was voluntary, with information to homeowners and voluntary work by the Ecocycle Council to inventory and remediate buildings. In 2007 an ordinance passed to make owners required to inventory and remediate structures built or renovated between 1956 and 1973 (when PCBs in open applications were banned in Sweden). Working at the local city level, the inventories have mostly been completed and the remediation is expected to be finished by 2016.

Canada

PCBs were never manufactured in Canada and most PCBs used in Canada were imported from the US. Like the US, Canada banned the import, manufacture, and sale of PCBs in 1977 and allowed PCB equipment to be used until the end of its service life in the original regulation. The release of PCBs to the environment was made illegal in 1985.

One significant difference between US and Canada regulations is that Canada does not regulate mono- and di-chlorinated biphenyls²⁹. PCBs with more than 2 chlorines are on Schedule 1 of the Toxics Substances list in Canada.

The Canadian Environmental Protection Act (CEPA) covers PCB Regulations.³⁰ Many of the regulations are similar to TSCA, such as a general limit of 50 ppm. One major difference is the Canadian regulations set deadlines for the phase-out of PCBs in use:

- Dec. 31, 2009 for equipment containing more than 500 ppm PCBs
- Dec. 31, 2009 for equipment containing 50-500 ppm PCBs within 100 meters of a drinking water plant, food or feed processing plant, school, hospital, or care center
- Dec. 31, 2025 for other equipment containing 50-500 ppm PCB
- Dec. 31, 2025 for light ballasts and pole-top electrical transformers

²⁸ Johansson, Niklas. PCBs in Schools: International Experience: Inventory, Remediation, and Outcomes. EPA webinar series PCBs in Schools Session II. April 28, 2014.

²⁹ <http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=0DA2924D-1&wsdoc=4ABEFFC8-5BEC-B57A-F4BF-11069545E434> (accessed 13 July 2014).

³⁰ SOR/2008-273 available at <http://www.ec.gc.ca/bpc-pcb/default.asp?lang=En&n=663E7488-1> (accessed 21 October 2013).

Economic analysis

Cost Estimates of Various PCB Reduction Methods

Chapter 173-333 WAC, the Persistent Bioaccumulative Toxic Chemical rule, requires Ecology to follow a specific process while developing Chemical Action Plans (CAPs). Specifically, Chapter 173-333-420(1) (f) (iii) (B) requires Ecology to consider the potential economic and social impacts of implementing the recommendations within the CAPs. In this section, we present estimates for the likely costs associated with the recommendations within the polychlorinated biphenyls (PCBs) CAP. The majority of the initial costs would accrue to Ecology because of the amount of scoping and research necessary to grasp the extent of PCB contamination in the state of Washington.

Economic analysis, like all analytical exercises, depends on the quantity and quality of data. As described throughout the document, PCBs are ubiquitous in the environment, which dictates that the scope of activities taken to reduce PCBs involve the combined efforts of public and private actors across numerous sectors of the economy throughout Washington. To the greatest extent possible given data limitations, we estimated costs to Ecology and the entities directly impacted by the recommended actions.

As expected, we lack data on various processes involved in remediating PCB-contaminated buildings, equipment, and habitats. In some cases, representative data is not available. In other cases, we determined that systemic attributes of entities affected by the recommendations, especially public and quasi-public entities, hindered our ability to reasonably assume that past costs serve as a basis for future costs. We determined that a scarcity of data in some areas required us to consider certain figures as anecdotal that fail to describe what an average entity in Washington affected by the recommendations might face. When we faced questions concerning the availability or reliability of data, we proceeded with a qualitative analysis. That is, we focused more on identifying the variables that drive the costs to those affected by recommendations.

As evident from the recommendations below, we anticipate building databases concerning PCBs based upon data submitted from entities and collected by Ecology. This new data would enable us to revisit the qualitative cost estimates presented in this section. Accordingly, it is important to remember that qualitative analysis is suggestive as opposed to representative.

The economic analysis section proceeds with a statement of each recommendation, specific goals, related background, and analysis of likely costs.

Historic PCB-Containing Building Materials

1. Identify PCB-containing lamp ballasts in schools and other public buildings. Encourage replacement with more energy efficient PCB-free fixtures.

Goal: Remove remaining PCB lamp ballasts from schools and other publicly owned buildings.

Prior to 1979, PCBs were widely used in fluorescent lamp ballasts, including those in use at schools and other public buildings. The pre-1979 ballasts have likely outlived their useful lives and are at high risk for failing (dripping, smoking, and catching fire). Ballast failures can expose children and others that frequently use public school buildings to concentrated PCB oils and elevated PCBs in the air.

There is no easily accessible source of information on how many buildings are of the age and construction type likely to have PCB-containing light ballasts. Because children are more sensitive to PCBs and school buildings are typically publicly owned, Ecology recommends prioritizing public schools. The first step towards implementing this recommendation is to conduct a survey of the 295 school districts in Washington to identify how many of the approximately 9,000 school buildings are likely to have PCB-containing light ballasts. Other public buildings will be surveyed as time and resources allow. Ecology would use the survey results to construct a database with information on construction and renovation dates and activities of schools (and other public buildings if possible). Ecology would first use the database to identify schools where PCB-containing light ballasts are likely still in use. Lamp ballasts with PCBs can then be identified through visual inspection.

Ecology anticipates that this recommendation would require an additional FTE at Environmental Specialist 3 (ES3) level. One FTE at ES3 level would cost \$90,931 annually. We employed Washington State employee pay grades at step H (DOP, 2014) and standard overhead cost assumptions used for legislative fiscal notes and related estimation (Ecology, 2013). Wages include the following adjustments for overhead expenses (per FTE):

- Benefits of 33.0 percent of salary
- Goods and services of \$5,709 annually, or \$2.74 per hour
- Travel costs of \$1,394 annually, or \$0.67 per hour
- Equipment costs of \$1,131 annually, or \$0.54 per hour
- Agency administrative overhead of 32.25 percent of salaries and benefits (Agency administrative overhead FTEs are included at 0.15 FTE per direct FTE, and are identified as Fiscal Analyst 2 and IT Specialist 2.)

Ecology envisions this person would split time between working towards this recommendation (0.75 FTE) and working towards Recommendation 5 (0.25 FTE). Because the staff person would

work on two goals, we estimate the cost based on the time spent (.75 FTE) on this recommendation as \$68,198 annually. Ecology anticipates that work on this recommendation could span two years (FY2016- FY2017) for a total estimated cost of \$136,396.

We do not have confident cost estimates for replacing light ballasts in schools or other public buildings. Estimating the cost of replacing the light ballasts to school districts is not possible without knowing how many schools might contain PCB-containing light ballasts, the condition of the light ballasts, and the extent of the problem within each building. However, replacing old, potentially dangerous light ballasts not only reduces the risk of exposure for children and others that use the school buildings frequently, it also reduces energy costs. Accordingly, it makes sense to combine PCB removal with initiatives to increase energy efficiency rather than create a new program just for removal of PCB-containing ballasts.³¹

Public money should be used to remove PCB-containing lamp ballasts from schools and other public buildings. Schools with PCB-containing lamp ballasts will be provided with information about the importance of removing these ballasts and referred to the Office of the Superintendent of Public Instruction (OSPI) (or Washington State Department of Health and other available resources) to replace these fixtures with more energy-efficient lighting. Ecology has requested \$200,000 in public money to assist with some of this work.

2. Develop and promote best management practices to contain PCBs in building materials currently in use and those slated for remodel or demolition.

Goal: Reduce exposure to people from PCBs in historic building materials and prevent PCBs in building materials from getting into stormwater.

Historically, PCBs were used at high levels in some caulks and paints. Studies in other areas have shown the widespread occurrence of PCB-containing caulk in buildings from about 1950-1980, especially masonry buildings. Smaller sampling efforts in Washington support this conclusion.³² Accordingly, developing best management practices and other materials to provide guidance for renovation and demolition of buildings that contain PCB materials would help to prevent the release of PCBs into the environment.

³¹ Since 2009, the Legislature has provided money to the Office of the Superintendent of Public Instruction (OSPI) and the Department of Commerce to support energy efficiency measures in schools and other public buildings. If the grant programs are not funded, the legislature could establish a fund to help offset the costs of replacing PCB-containing lamp ballasts.

³² For example, studies suggest that buildings with PCB-containing materials exist in the Duwamish basin. In addition, source tracing from cleanup efforts in Tacoma revealed PCBs in sidewalk and building caulk.

The first step toward preventing PCBs in building materials from getting into the environment is to compile, compose, and distribute information concerning best management practices for containment of PCB-containing materials. Based on available data in Washington, other government programs, and scientific literature, Ecology would develop BMPs for containing PCBs to prevent exposure during the life of the building and during remodeling or demolition. Ecology should also provide education and outreach on BMPs to local governments and those in the building trades.

Ecology estimates that developing BMPs would require an additional FTE of an Environmental Specialist 3 (ES3) for a three-year period. We employed Washington State employee pay grades at step H (DOP, 2014) and standard overhead cost assumptions used for legislative fiscal notes and related estimation (Ecology, 2013). One FTE at ES3 would cost \$90,931 annually. Wages include the following adjustments for overhead expenses (per FTE):

- Benefits of 33.0 percent of salary
- Goods and services of \$5,709 annually, or \$2.74 per hour
- Travel costs of \$1,394 annually, or \$0.67 per hour
- Equipment costs of \$1,131 annually, or \$0.54 per hour
- Agency administrative overhead of 32.25 percent of salaries and benefits (Agency administrative overhead FTEs are included at 0.15 FTE per direct FTE, and are identified as Fiscal Analyst 2 and IT Specialist 2.)

While working on the BMPs, Ecology would also work to compile existing information into a PCB Source Control Guidance Manual to aid Local Source Control work. A number of urban waters programs around the northwest have performed PCB source identification work. However, to date, the lessons learned from each of these programs have not been synthesized and summarized for the benefit of future pollution prevention efforts at the state and local levels.

Ecology estimates that work on the best management practices and source control manual would last approximately three years (FY2016-FY2018) and result in total staff costs of \$272,793.

3. Assess schools and other public buildings for the presence of PCB-containing building materials.

Goal: Reduce children's exposure to PCB-containing building materials.

Goal: Prevent PCBs in building materials from getting into stormwater.

Many buildings constructed prior to the ban of PCBs include materials, such as caulk, paint, and light ballasts that often contain high levels of PCBs. Industrial buildings, including schools, are more likely to contain PCB-contaminated materials than residential buildings. Other states have found high levels of PCB contamination in schools. Because children are more sensitive to PCBs

and school buildings are typically publicly owned, Ecology recommends assessing public schools for possible PCB contamination first and expanding the effort to include other buildings, as appropriate.

To our knowledge, school districts in Washington have not systematically tested schools for PCBs. Schools built prior to 1980 are more likely to contain material with PCBs. The first step in assessing public school buildings that contain PCB material is to construct a centralized database based on information provided by school districts. The database would contain information on the date of construction and dates of renovation for each school building in Washington. The database would serve as a mechanism to identify schools, based on construction date, that require testing for PCBs. Initial testing would include visual inspections and then physical testing where appropriate. Ecology would use the database and test results to determine the scope of the problem in Washington and plan accordingly. A similar approach would be used to assess other public buildings once the assessment of schools is complete, and as resources allow.

Ecology estimates that the person retained to compile information on PCB light ballasts in schools would compile the database for building materials, as well. Ecology anticipates that two Environmental Specialist 3 (ES3) positions in other recommendations will merge tasks in FY2018:

- The 0.75 FTE at Environmental Specialist 3 (ES3) level at \$68,198 annually would spend two years (FY2016-FY2017) focusing on light ballasts (Recommendation 1).
- The 0.25 FTE at the ES3 level at \$22,733 annually would spend two years (FY2016-2017) focusing on electrical equipment (Recommendation 5).
- These positions would shift their database efforts to include other building materials at schools.

Ecology anticipates that work on this recommendation could span four years (FY2018- FY2021) for a total estimated cost of \$363,724.

We employed Washington State employee pay grades at step H (DOP, 2014) and standard overhead cost assumptions used for legislative fiscal notes and related estimation (Ecology, 2013). Wages include the following adjustments for overhead expenses (per FTE):

- Benefits of 33.0 percent of salary
- Goods and services of \$5,709 annually, or \$2.74 per hour
- Travel costs of \$1,394 annually, or \$0.67 per hour
- Equipment costs of \$1,131 annually, or \$0.54 per hour
- Agency administrative overhead of 32.25 percent of salaries and benefits (Agency administrative overhead FTEs are included at 0.15 FTE per direct FTE, and are identified as Fiscal Analyst 2 and IT Specialist 2.)

Ecology understands the time and budget constraints facing school districts across the state. However, this recommendation would not require school districts to generate new reports or information. We assume that school districts have information concerning construction and renovation of school buildings from routine recordkeeping, operations, and maintenance documents. Therefore, we do not expect a cost to school districts to submit documents to Ecology for the database beyond minimal expenditures of time and resources to submit records to Ecology.

After compiling the database and conducting initial testing, Ecology would work with school districts to plan and coordinate remediation efforts at schools that have PCB-contaminated materials. There is no one size fits all approach to remediation projects for buildings containing PCBs (Environmental Health & Engineering, 2012). Depending on the extent of contamination, schools decide whether to pursue abatement (reducing the amount of PCBs in building materials permanently) or mitigation (controlling exposure) procedures. Regardless of the remediation technique, schools would need to work with local health agencies, Ecology, and EPA to meet removal criteria and follow hazardous waste regulations.

Estimating the cost of remediating school buildings in Washington is not possible without knowing the scope (number of schools and extent of remediation needed) of the problem. The number of school buildings and extent of work necessary to bring a building in compliance would determine bids from contractors and others involved in remediation activities. In addition, remediation activities generally involve mandated testing procedures, extensive planning, feasibility studies, and permitting requests. School districts might also have to explore temporarily relocating students during the initial testing/cleanup stage (depending on age of building and likelihood of PCB contamination). Because of the extensive nature of remediation projects, we feel that a database is appropriate to enable Ecology and school districts to narrow the scope, identify economies of scale, and prioritize remediation projects.

As mentioned above, systemic attributes of public entities make some estimates less reliable. We consider the process school districts use to price construction projects such a structural constraint. Generally, available data suggests that the cost of remediating PCB-contaminated school buildings depends on the extent of contamination and approach used by schools (abatement or mitigation) to address the problem. To our knowledge, no state has addressed PCB contamination in schools in a comprehensive manner. It appears that most schools learn of PCB contamination by miscellaneous tests conducted prior to unrelated renovation work, and must react quickly to bring exposure levels below EPA guidelines. This creates immediate financial stress on local/state agencies responsible for public health, school facilities, etc. Further, school districts face unique budget constraints and absorb costs differently than owners of private buildings.

Schools generally face administrative procedures (feasibility studies, budget requests, and limited window for large remediation projects) that increase the overall cost of projects. However, it is difficult to compare how school districts determine costs for certain projects, especially when comparing school districts in different regions or states. School districts in Washington form cost estimates based on the needs of schools here in Washington. In sum, existing estimates of remediation projects based solely on PCB contamination are too limited to provide a meaningful basis for comparison, at this point.

Acknowledging the above limitations, though, illustrates the need for Ecology to identify the scope of the problem here in Washington. We found estimates for remediation work at five schools in New York and two schools in Massachusetts. Estimates from remediation projects at the five public schools in New York City ranged from \$3.2 million to \$3.6 million (2014\$) per school depending on the techniques (abatement or mitigation) used to address the PCB-contaminated areas (TRC, 2011). In 2010, an elementary school in Lexington, MA found PCB-contaminated material. The school had to close for a week while workers performed testing required by the EPA and performed preliminary cleanup work. Feasibility studies suggested that officials faced temporary solutions ranging from \$3.0 million to \$4.6 million (2014\$) to relocate students while remediating the school (Goddard, 2010). Ultimately, officials decided to replace the school with a new \$40 million building (Parker, 2014). A different school in Westport, MA also found PCB material and encountered initial costs in excess of \$3 million (Wagner, 2014). Currently, the school faces additional costs ranging from \$1.8 million to \$7.75 million (2014\$) (CGKV Architects, 2013) to remediate the PCB-contaminated material. Again, we consider the estimates from New York and Massachusetts more suggestive than representative. That said, the expenses incurred by the school districts in New York City and Massachusetts, along with the extent of activity required to remediate the structures, indicate a need to determine the scope of the problem by compiling construction dates and preliminary testing of high risk schools here in Washington.

Current Manufacturing Processes

4. Learn more about what products contain PCBs and promote the use of processes that don't inadvertently generate PCBs.

Goal: Reduce newly generated PCBs in manufacturing processes.

Unpermitted non-point releases, such as from consumer products, are becoming increasingly important to control in order to reduce total PCB delivery. In 1982, EPA identified 70 manufacturing processes that are likely to inadvertently generate PCBs, but little else is known about this potentially large source of uncontrolled PCBs. More information is known about PCBs in pigments and dyes, which are a known source of PCBs in the environment and a problem for

paper recyclers in Washington. Ecology recommends adding additional staff and funding to determine the extent of inadvertently generated PCBs in consumer products.

To accomplish the goal of reducing newly generated PCBs in manufacturing processes, Ecology would work with EPA, manufacturers, and other partners to identify products that inadvertently contain PCBs and explore available alternatives. Ecology would test identified products, and provide relevant results to the Department of Enterprise Services (DES) to assist with implementing new purchasing policies that provide a preference for products that do not contain PCBs. Ecology would also work with the Department of Health and DES to develop a focus sheet to educate purchasers and vendors in the state supply chain about the prevalence and incidence of products that inadvertently contain PCBs and concisely outlines the problem and its potential impacts.

Learning more about processes that inadvertently generate PCBs would require 1 FTE of a Natural Resource Scientist 3 (NRS3) at \$116,641. We employed Washington State employee pay grades at step H (DOP, 2014) and standard overhead cost assumptions used for legislative fiscal notes and related estimation (Ecology, 2013). Wages include the following adjustments for overhead expenses (per FTE):

- Benefits of 33.0 percent of salary
- Goods and services of \$5,709 annually, or \$2.74 per hour
- Travel costs of \$1,394 annually, or \$0.67 per hour
- Equipment costs of \$1,131 annually, or \$0.54 per hour
- Agency administrative overhead of 32.25 percent of salaries and benefits (Agency administrative overhead FTEs are included at 0.15 FTE per direct FTE, and are identified as Fiscal Analyst 2 and IT Specialist 2.)

Ecology anticipates that the NRS3 would test approximately 100 products a year. Ecology anticipates that the employee retained to perform the product testing would continue to work on this issue on an ongoing basis, with costs from FY2016 through FY2021 totaling \$699,846. Additionally, at \$1,000 per test, Ecology estimates annual testing costs of \$100,000.

In addition to testing for PCBs, we also estimated the cost of investigating alternate processes in chemical manufacturing, to prospectively replace processes that produce PCBs as a byproduct. Specifically, we estimated the cost of initiating an alternatives assessment process for pigments and dyes, based on the Interstate Chemicals Clearinghouse (IC2) Alternatives Assessment Guide.

Ecology anticipates that producing such an “Alternatives Assessment” would cost \$470,000 in FY2016, which includes hiring a consultant. Ecology plans to engage business and other concerned stakeholders to participate in the alternatives assessment process. If there are currently

no alternatives that do not generate PCBs, Ecology would engage Green Chemistry Northwest or a similar institution to develop alternative processes.

Historic Electrical Equipment

5. Survey owners of historic electrical equipment, including transformers and large capacitors.

Goal: Confirm estimates of EPA-regulated electrical equipment with more than 500 parts per million (ppm) PCBs, learn what is known about electrical equipment with the PCBs greater than 2 ppm, and find out when such electrical equipment is estimated for replacement.

Electrical equipment, such as transformers and capacitors, used by utility and large non-utility industrial sites are the primary historical use of PCBs. Concentrations of PCBs in many pieces of electrical equipment are high compared to other sources, so relatively rare leaks and spills can release a significant amount of PCBs into the environment. Ecology recommends a survey of the 61 utilities and other sites that provide electricity to construct a recent and relevant database of electrical equipment that contains PCBs in Washington.

We anticipate that this recommendation would most likely affect utilities and large non-utility entities that provide electrical transmission (operate transformers or large capacitors) on site. The nature of electricity and the regulatory status of utilities presents unique challenges regarding this recommendation. Electricity is difficult to store, impossible to substitute, and a necessity to most consumers and businesses. Accordingly, each utility in the state enjoys a natural monopoly in the transmission of electricity to end users within a defined area. In exchange for monopoly status, various regulatory agencies set prices administratively based on costs incurred by utilities. The process of setting prices administratively makes it difficult, if not impossible, for us to determine the cost of individual projects and to determine how the utilities absorb costs. Regulations also require utilities to provide electricity on demand that makes a recommendation to test all existing equipment difficult to undertake without potentially disrupting service. In sum, from a practical perspective, a recommendation for further testing could prove cost prohibitive to utilities and consumers.

Prior to the ban on PCBs, manufacturers of transformers, capacitors, and other electrical equipment used oil-containing PCBs as a coolant within the housing of utility equipment. Since the ban on PCBs took effect in the United States, utilities and owners of electrical equipment have worked to identify and replace equipment that contains PCBs. According to a report submitted by the Utility Solid Waste Activities Group (USWAG, 2010) to the EPA, utilities across the country have reduced the use of equipment containing PCBs through normal maintenance and replacement procedures. A similar statement by the Northwest Public Power

Association (2010), extensive discussions with representatives from various utilities, and local news reports (Kramer, 2014), suggest that utilities across Washington have also replaced many units that contain PCBs. Currently, however, no reporting requirement exists to verify the claims of utility and a non-utility users of electrical equipment concerning retirement of equipment that contains PCBs.

Ecology believes that surveying the state's utilities and compiling a centralized database based on past, present, and future efforts by owners of electrical equipment is within reason and at minimal cost to the owners of electrical equipment. Because electrical equipment that might contain PCBs are part of a complex transmission system that requires significant time and resources to maintain, Ecology assumes that owners of electrical equipment maintain records that form the basis of routine maintenance schedules. Over the past 15 years, increased demand for energy and the interconnectedness of the electrical grid has changed the regulatory environment in such a way that providers of electricity at all levels of the transmission process must maintain certain levels of service at all times. In addition, utilities upgrade old and inefficient transmission equipment (often the equipment that might also contain PCBs) to increase efficiency and output. The need to maintain a consistent supply of energy and increase profitability, where possible, necessitates that utilities maintain extensive records. Therefore, we assume that utilities and other large non-utility owners know which pieces of equipment have PCBs or may have PCBs based on the age of the equipment.

Because the utilities have taken action to address the use of equipment that contains PCBs, Ecology believes establishing a database of current equipment containing PCBs would require minimal effort and cost to Ecology and users and electrical equipment. The survey of electrical equipment would not include small capacitors. The survey would not require additional testing or disposal of equipment by a certain date. The survey would ask owners to report what they know about detectable levels of PCBs in their equipment, using the industry standard detection level that is currently 2 parts per million (ppm), and detail when they expect all the equipment to be replaced based on their current maintenance practices. A statewide inventory will allow the state to confirm current inventories and target efforts to prevent releases of PCBs from this equipment.

Ecology anticipates that the FTE assigned to collect data on PCBs in public schools (Recommendation 1) would also assemble and enter data on electrical equipment. Ecology envisions this person would split time between working towards this recommendation (.25 FTE on this goal) and working towards Recommendation 1.

One FTE at Environmental Specialist 3 (ES3) level would cost \$90,931 annually. We employed Washington State employee pay grades at step H (DOP, 2014) and standard overhead cost assumptions used for legislative fiscal notes and related estimation (Ecology, 2013). Wages include the following adjustments for overhead expenses (per FTE):

- Benefits of 33.0 percent of salary
- Goods and services of \$5,709 annually, or \$2.74 per hour
- Travel costs of \$1,394 annually, or \$0.67 per hour
- Equipment costs of \$1,131 annually, or \$0.54 per hour
- Agency administrative overhead of 32.25 percent of salaries and benefits (Agency administrative overhead FTEs are included at 0.15 FTE per direct FTE, and are identified as Fiscal Analyst 2 and IT Specialist 2.)

Because the staff person would work on two goals, we estimate the cost based on the time spent (.25 FTE) on this recommendation as \$22,733 annually. Ecology anticipates that work on this recommendation could span two years (FY2016-FY2017) for a total estimated cost of \$45,466.

Multi-Source

6. Expand environmental monitoring to identify any new areas requiring cleanup.

Goal: Find areas with highly concentrated PCBs and clean them up to prevent the wider release of PCBs.

Goal: Find out more about the distribution of PCBs in Washington to prioritize future actions.

Ecology should expand environmental monitoring of water, fish tissue, and sediment to identify PCB hot spots, such as the recently found historical landfill of electrical equipment on Bradford Island in the Columbia River. Historical disposal practices at Bradford Island near Bonneville Dam on the Columbia River contaminated resident fish with high levels of PCBs. Levels were high enough to prompt Oregon and Washington to issue a joint fish consumption advisory for select species from Bonneville Dam upstream to McNary Dam. A number of fish sampling efforts in the Columbia basin (CRITFC, Hanford Corridor Study and Ecology's Freshwater Fish Contaminant Monitoring Program) found other areas (mid-Columbia and Snake River) with elevated levels of PCBs and a number of hydroelectric facilities.

To our knowledge no work has been done to identify sources of contaminants in these areas. The proposed monitoring would conduct sampling to determine if contaminant sources exist in areas with a focus on hydroelectric facilities. Ecology may also use mapping and historical information on the location of potential sites, such as landfills, industrial sites, railroad switching yards, etc., to find potential sites. Newly identified sites would receive priority for clean up using existing procedures. In addition to identifying new hot spots, Ecology would continue its trend monitoring to show changes in PCBs in the environment and biota over time.

Air deposition is a potentially significant pathway for PCBs to move into the environment. Ecology proposes to investigate monitoring air deposition to assess the relative importance of this pathway.

Ecology estimates that the workload generated by Recommendation 6 would require the addition of three FTE. Ecology estimates that it would take 1 FTE Natural Resource Scientist 3 (NRS3) to identify new hot spots and implement necessary testing procedures. In addition, Ecology estimates that effectively monitoring hot spots would require an Environmental Specialist 2 (ES2) FTE to provide support for testing. The addition of one FTE at NRS3 level would cost \$116,641 annually, and one FTE at the ES2 level would cost \$79,513 annually. To monitor air deposition, Ecology would require an additional FTE at the Environmental Specialist 3 (ES3) level to conduct the air monitoring tests. The ES3 would cost \$90,931 annually.

We employed Washington State employee pay grades at step H (DOP, 2014) and standard overhead cost assumptions used for legislative fiscal notes and related estimation (Ecology, 2013). Wages include the following adjustments for overhead expenses (per FTE):

- Benefits of 33.0 percent of salary
- Goods and services of \$5,709 annually, or \$2.74 per hour
- Travel costs of \$1,394 annually, or \$0.67 per hour
- Equipment costs of \$1,131 annually, or \$0.54 per hour
- Agency administrative overhead of 32.25 percent of salaries and benefits (Agency administrative overhead FTEs are included at 0.15 FTE per direct FTE, and are identified as Fiscal Analyst 2 and IT Specialist 2.)

Ecology anticipates that the work of the NRS3 toward this recommendation would take 3 years, with assistance from the ES2 for 2 years. Ecology anticipates that testing to identify potential hot spots would result in lab costs of \$87,192 annually for two years. Ecology anticipates that the work of the ES3 to monitor air disposition would take two years, and anticipates testing costs of \$37,967 annually for two years to monitor air deposition.

Table 37 summarizes the costs associated with this recommendation.

Table 37. Summary of the costs associated with Recommendation 6.

	FY 2016	FY 2017	FY 2018
Hot spot monitoring			
1 FTE NRS3	\$116,641	\$116,641	\$116,641
1 FTE ES2	\$79,513	\$79,513	
Hot spot testing	\$87,192	\$87,192	
Air monitoring			
1 FTE ES3	\$90,931	\$90,931	
Air testing	\$37,967	\$37,967	

7. Conduct a public educational campaign.

Goal: Provide information to residents about ways they can minimize exposure.

Goal: Raise awareness of the problems associated with current and past production of PCBs.

Goal: Educate residents to identify and address possible household sources of PCBs.

To reach the goal of raising public awareness for PCBs, Ecology and the Department of Health would work together to help residents, people who fish, schools, local governments and businesses understand the risks associated with PCB exposure and ways to reduce risks, including the availability of safer alternatives.

The public educational campaign will include perspectives on public health risks and information on where exposures to PCB are most likely. It will also include advice on how individuals can minimize their own exposures to PCBs. The campaign will include where to look for potential sources of PCBs in households, such as in old appliances, electrical equipment, and building materials. It will also teach the public how to safely remove and dispose of these materials to prevent PCB releases.

Ecology anticipates that this recommendation would require the addition of 1 FTE Communication Consultant 3 (CC3) to develop and disseminate information to businesses, purchasing agents, vendors, residents, fishers, schools, and local governments describing the hazards associated with exposure to PCBs and resources available to address the problem. This FTE would cost \$92,957 each year. This work includes promotion of BMPs for containment and demolition of buildings containing PCB laden materials.

We employed Washington State employee pay grades at step H (DOP, 2014) and standard overhead cost assumptions used for legislative fiscal notes and related estimation (Ecology, 2013). Wages include the following adjustments for overhead expenses (per FTE):

- Benefits of 33.0 percent of salary
- Goods and services of \$5,709 annually, or \$2.74 per hour
- Travel costs of \$1,394 annually, or \$0.67 per hour
- Equipment costs of \$1,131 annually, or \$0.54 per hour
- Agency administrative overhead of 32.25 percent of salaries and benefits (Agency administrative overhead FTEs are included at 0.15 FTE per direct FTE, and are identified as Fiscal Analyst 2 and IT Specialist 2.)

Ecology anticipates that the community awareness work would continue on an ongoing basis. Estimated costs for this recommendation from FY2016 through FY2021 are \$557,742.

8. Conduct a study on which PCB congeners are present in Washington residents

Goal: Learn more about PCB congeners to which Washington residents are exposed

Goal: Find out more about the distribution of PCBs in Washington to prioritize future actions

Within available resources, the Department of Health should conduct bio-monitoring of Washington residents for PCBs including PCB 11 and other inadvertently produced PCBs associated with dyes, pigments, and printing inks. Researchers would use the data to better understand 1) the extent of total human exposure from multiple potential pathways and 2) the relative contribution of these congeners to human body burden of PCBs. In addition, the data would enable researchers to estimate the statewide distribution of PCBs in Washington residents, which would provide a better baseline than national data given the elevated levels of PCBs in local fish populations and relatively high fish consumption in a number of Washington communities and regions.

Ecology believes that this sort of bio-monitoring falls within criteria already established under existing DOH programs. Accordingly, we do not anticipate new costs with this recommendation.

Summary of Economic Impacts

Table 38 presents estimated costs to Ecology to implement the recommendations above.

Table 38. Estimated costs to Ecology to implement recommendations

Recommendation		FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
1	0.75 FTE (ES3) to survey and assess lamp ballasts in schools.	\$68,198	\$68,198				
2	1 FTE (ES3) to develop and promote BMPs.	\$90,931	\$90,931	\$90,931			
3	1 FTE (ES3) to assess schools for PCB-containing building materials.			\$90,931	\$90,931	\$90,931	\$90,931
4	Conduct an alternatives assessment for pigments and dyes.	\$470,000					
	1 FTE (NRS3)	\$116,641	\$116,641	\$116,641	\$116,641	\$116,641	\$116,641

	to look for sources of PCBs in products.						
	Lab costs for product testing.	\$100,000	\$100,000	\$100,000	\$100,000	\$100,000	\$100,000
5	0.25 FTE (ES3) to survey owners of electrical equipment.	\$22,733	\$22,733				
6	1 FTE (NRS3) to identify environmental hot spots.	\$116,641	\$116,641	\$116,641			
	1 FTE (ES2) to assist with monitoring.	\$79,513	\$79,513				
	Environmental monitoring/ lab analysis.	\$87,192	\$87,192				
	1 FTE (ES3) for air monitoring	\$90,931	\$90,931				
	Sampling/lab analysis for air monitoring stations.	\$37,967	\$37,967				
7	1 FTE (CC3) to conduct an education campaign.	\$92,957	\$92,957	\$92,957	\$92,957	\$92,957	\$92,957
Total		\$1,373,704	\$903,704	\$608,101	\$400,529	\$400,529	\$400,529
All estimates in (2014 \$)							
ES2 = Environmental Specialist 2							
ES3 = Environmental Specialist 3							
NRS3 = Natural Resource Scientist 3							
CC3 = Communications Consultant 3							

Ecology does not anticipate that these initial recommendations would increase compliance costs for affected firms or public entities.

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Appendices

Appendix A. List of 209 PCB Congeners (EPA, 2003)

CASRN	Congener Number	IUPAC Name
1336-36-3		Polychlorinated biphenyl (PCB)
2051-60-7	1	2-Chlorobiphenyl
2051-61-8	2	3-Chlorobiphenyl
2051-62-9	3	4-Chlorobiphenyl
13029-08-8	4	2,2'-Dichlorobiphenyl
16605-91-7	5	2,3-Dichlorobiphenyl
25569-80-6	6	2,3'-Dichlorobiphenyl
33284-50-3	7	2,4-Dichlorobiphenyl
34883-43-7	8	2,4'-Dichlorobiphenyl
34883-39-1	9	2,5-Dichlorobiphenyl
33146-45-1	10	2,6-Dichlorobiphenyl
2050-67-1	11	3,3'-Dichlorobiphenyl
2974-92-7	12	3,4-Dichlorobiphenyl
2974-90-5	13	3,4'-Dichlorobiphenyl
34883-41-5	14	3,5-Dichlorobiphenyl
2050-68-2	15	4,4'-Dichlorobiphenyl
38444-78-9	16	2,2',3-Trichlorobiphenyl
37680-66-3	17	2,2',4-Trichlorobiphenyl
37680-65-2	18	2,2',5-Trichlorobiphenyl
38444-73-4	19	2,2',6-Trichlorobiphenyl
38444-84-7	20	2,3,3'-Trichlorobiphenyl
55702-46-0	21	2,3,4-Trichlorobiphenyl
38444-85-8	22	2,3,4'-Trichlorobiphenyl
55720-44-0	23	2,3,5-Trichlorobiphenyl
55702-45-9	24	2,3,6-Trichlorobiphenyl
55712-37-3	25	2,3',4-Trichlorobiphenyl
38444-81-4	26	2,3',5-Trichlorobiphenyl
38444-76-7	27	2,3',6-Trichlorobiphenyl
7012-37-5	28	2,4,4'-Trichlorobiphenyl
15862-07-4	29	2,4,5-Trichlorobiphenyl
35693-92-6	30	2,4,6-Trichlorobiphenyl
16606-02-3	31	2,4',5-Trichlorobiphenyl

38444-77-8	32	2,4',6-Trichlorobiphenyl
38444-86-9	33	2,3',4'-Trichlorobiphenyl
37680-68-5	34	2,3',5'-Trichlorobiphenyl
37680-69-6	35	3,3',4-Trichlorobiphenyl
38444-87-0	36	3,3',5-Trichlorobiphenyl
38444-90-5	37	3,4,4'-Trichlorobiphenyl
53555-66-1	38	3,4,5-Trichlorobiphenyl
38444-88-1	39	3,4',5-Trichlorobiphenyl
38444-93-8	40	2,2',3,3'-Tetrachlorobiphenyl
52663-59-9	41	2,2',3,4-Tetrachlorobiphenyl
36559-22-5	42	2,2',3,4'-Tetrachlorobiphenyl
70362-46-8	43	2,2',3,5-Tetrachlorobiphenyl
41464-39-5	44	2,2',3,5'-Tetrachlorobiphenyl
70362-45-7	45	2,2',3,6-Tetrachlorobiphenyl
41464-47-5	46	2,2',3,6'-Tetrachlorobiphenyl
2437-79-8	47	2,2',4,4'-Tetrachlorobiphenyl
70362-47-9	48	2,2',4,5-Tetrachlorobiphenyl
41464-40-8	49	2,2',4,5'-Tetrachlorobiphenyl
62796-65-0	50	2,2',4,6-Tetrachlorobiphenyl
68194-04-7	51	2,2',4,6'-Tetrachlorobiphenyl
35693-99-3	52	2,2',5,5'-Tetrachlorobiphenyl
41464-41-9	53	2,2',5,6'-Tetrachlorobiphenyl
15968-05-5	54	2,2',6,6'-Tetrachlorobiphenyl
74338-24-2	55	2,3,3',4-Tetrachlorobiphenyl
41464-43-1	56	2,3,3',4'-Tetrachlorobiphenyl
70424-67-8	57	2,3,3',5-Tetrachlorobiphenyl
41464-49-7	58	2,3,3',5'-Tetrachlorobiphenyl
74472-33-6	59	2,3,3',6-Tetrachlorobiphenyl
33025-41-1	60	2,3,4,4'-Tetrachlorobiphenyl
33284-53-6	61	2,3,4,5-Tetrachlorobiphenyl
54230-22-7	62	2,3,4,6-Tetrachlorobiphenyl
74472-34-7	63	2,3,4',5-Tetrachlorobiphenyl
52663-58-8	64	2,3,4',6-Tetrachlorobiphenyl
32284-54-7	65	2,3,5,6-Tetrachlorobiphenyl
32598-10-0	66	2,3',4,4'-Tetrachlorobiphenyl
73575-53-8	67	2,3',4,5-Tetrachlorobiphenyl
73575-52-7	68	2,3',4,5'-Tetrachlorobiphenyl

60233-24-1	69	2,3',4,6-Tetrachlorobiphenyl
32598-11-1	70	2,3',4',5-Tetrachlorobiphenyl
41464-46-4	71	2,3',4',6-Tetrachlorobiphenyl
41464-42-0	72	2,3',5,5'-Tetrachlorobiphenyl
74338-23-1	73	2,3',5',6-Tetrachlorobiphenyl
32690-93-0	74	2,4,4',5-Tetrachlorobiphenyl
32598-12-2	75	2,4,4',6-Tetrachlorobiphenyl
70362-48-0	76	2,3',4',5'-Tetrachlorobiphenyl
32598-13-3	77	3,3',4,4'-Tetrachlorobiphenyl
70362-49-1	78	3,3',4,5-Tetrachlorobiphenyl
41464-48-6	79	3,3',4,5'-Tetrachlorobiphenyl
33284-52-5	80	3,3',5,5'-Tetrachlorobiphenyl
70362-50-4	81	3,4,4',5-Tetrachlorobiphenyl
52663-62-4	82	2,2',3,3',4-Pentachlorobiphenyl
60145-20-2	83	2,2',3,3',5-Pentachlorobiphenyl
52663-60-2	84	2,2',3,3',6-Pentachlorobiphenyl
65510-45-4	85	2,2',3,4,4'-Pentachlorobiphenyl
55312-69-1	86	2,2',3,4,5-Pentachlorobiphenyl
38380-02-8	87	2,2',3,4,5'-Pentachlorobiphenyl
55215-17-3	88	2,2',3,4,6-Pentachlorobiphenyl
73575-57-2	89	2,2',3,4,6'-Pentachlorobiphenyl
68194-07-0	90	2,2',3,4',5-Pentachlorobiphenyl
68194-05-8	91	2,2',3,4',6-Pentachlorobiphenyl
52663-61-3	92	2,2',3,5,5'-Pentachlorobiphenyl
73575-56-1	93	2,2',3,5,6-Pentachlorobiphenyl
73575-55-0	94	2,2',3,5,6'-Pentachlorobiphenyl
38379-99-6	95	2,2',3,5',6-Pentachlorobiphenyl
73575-54-9	96	2,2',3,6,6'-Pentachlorobiphenyl
41464-51-1	97	2,2',3,4',5'-Pentachlorobiphenyl
60233-25-2	98	2,2',3,4',6'-Pentachlorobiphenyl
38380-01-7	99	2,2',4,4',5-Pentachlorobiphenyl
39485-83-1	100	2,2',4,4',6-Pentachlorobiphenyl
37680-73-2	101	2,2',4,5,5'-Pentachlorobiphenyl
68194-06-9	102	2,2',4,5,6'-Pentachlorobiphenyl
60145-21-3	103	2,2',4,5',6-Pentachlorobiphenyl
56558-16-8	104	2,2',4,6,6'-Pentachlorobiphenyl
32598-14-4	105	2,3,3',4,4'-Pentachlorobiphenyl

70424-69-0	106	2,3,3',4,5-Pentachlorobiphenyl
70424-68-9	107	2,3,3',4',5-Pentachlorobiphenyl
70362-41-3	108	2,3,3',4,5'-Pentachlorobiphenyl
74472-35-8	109	2,3,3',4,6-Pentachlorobiphenyl
38380-03-9	110	2,3,3',4',6-Pentachlorobiphenyl
39635-32-0	111	2,3,3',5,5'-Pentachlorobiphenyl
74472-36-9	112	2,3,3',5,6-Pentachlorobiphenyl
68194-10-5	113	2,3,3',5',6-Pentachlorobiphenyl
74472-37-0	114	2,3,4,4',5-Pentachlorobiphenyl
74472-38-1	115	2,3,4,4',6-Pentachlorobiphenyl
18259-05-7	116	2,3,4,5,6-Pentachlorobiphenyl
68194-11-6	117	2,3,4',5,6-Pentachlorobiphenyl
31508-00-6	118	2,3',4,4',5-Pentachlorobiphenyl
56558-17-9	119	2,3',4,4',6-Pentachlorobiphenyl
68194-12-7	120	2,3',4,5,5'-Pentachlorobiphenyl
56558-18-0	121	2,3',4,5',6-Pentachlorobiphenyl
76842-07-4	122	2,3,3',4',5'-Pentachlorobiphenyl
65510-44-3	123	2,3',4,4',5'-Pentachlorobiphenyl
70424-70-3	124	2,3',4',5,5'-Pentachlorobiphenyl
74472-39-2	125	2,3',4',5',6-Pentachlorobiphenyl
57465-28-8	126	3,3',4,4',5-Pentachlorobiphenyl
39635-33-1	127	3,3',4,5,5'-Pentachlorobiphenyl
38380-07-3	128	2,2',3,3',4,4'-Hexachlorobiphenyl
55215-18-4	129	2,2',3,3',4,5-Hexachlorobiphenyl
52663-66-8	130	2,2',3,3',4,5'-Hexachlorobiphenyl
61798-70-7	131	2,2',3,3',4,6-Hexachlorobiphenyl
38380-05-1	132	2,2',3,3',4,6'-Hexachlorobiphenyl
35694-04-3	133	2,2',3,3',5,5'-Hexachlorobiphenyl
52704-70-8	134	2,2',3,3',5,6-Hexachlorobiphenyl
52744-13-5	135	2,2',3,3',5,6'-Hexachlorobiphenyl
38411-22-2	136	2,2',3,3',6,6'-Hexachlorobiphenyl
35694-06-5	137	2,2',3,4,4',5-Hexachlorobiphenyl
35065-28-2	138	2,2',3,4,4',5'-Hexachlorobiphenyl
56030-56-9	139	2,2',3,4,4',6-Hexachlorobiphenyl
59291-64-4	140	2,2',3,4,4',6'-Hexachlorobiphenyl
52712-04-6	141	2,2',3,4,5,5'-Hexachlorobiphenyl
41411-61-4	142	2,2',3,4,5,6-Hexachlorobiphenyl

68194-15-0	143	2,2',3,4,5,6'-Hexachlorobiphenyl
68194-14-9	144	2,2',3,4,5',6-Hexachlorobiphenyl
74472-40-5	145	2,2',3,4,6,6'-Hexachlorobiphenyl
51908-16-8	146	2,2',3,4',5,5'-Hexachlorobiphenyl
68194-13-8	147	2,2',3,4',5,6-Hexachlorobiphenyl
74472-41-6	148	2,2',3,4',5,6'-Hexachlorobiphenyl
38380-04-0	149	2,2',3,4',5',6-Hexachlorobiphenyl
68194-08-1	150	2,2',3,4',6,6'-Hexachlorobiphenyl
52663-63-5	151	2,2',3,5,5',6-Hexachlorobiphenyl
68194-09-2	152	2,2',3,5,6,6'-Hexachlorobiphenyl
35065-27-1	153	2,2',4,4',5,5'-Hexachlorobiphenyl
60145-22-4	154	2,2',4,4',5,6'-Hexachlorobiphenyl
33979-03-2	155	2,2',4,4',6,6'-Hexachlorobiphenyl
38380-08-4	156	2,3,3',4,4',5-Hexachlorobiphenyl
69782-90-7	157	2,3,3',4,4',5'-Hexachlorobiphenyl
74472-42-7	158	2,3,3',4,4',6-Hexachlorobiphenyl
39635-35-3	159	2,3,3',4,5,5'-Hexachlorobiphenyl
41411-62-5	160	2,3,3',4,5,6-Hexachlorobiphenyl
74472-43-8	161	2,3,3',4,5',6-Hexachlorobiphenyl
39635-34-2	162	2,3,3',4',5,5'-Hexachlorobiphenyl
74472-44-9	163	2,3,3',4',5,6-Hexachlorobiphenyl
74472-45-0	164	2,3,3',4',5',6-Hexachlorobiphenyl
74472-46-1	165	2,3,3',5,5',6-Hexachlorobiphenyl
41411-63-6	166	2,3,4,4',5,6-Hexachlorobiphenyl
52663-72-6	167	2,3',4,4',5,5'-Hexachlorobiphenyl
59291-65-5	168	2,3',4,4',5',6-Hexachlorobiphenyl
32774-16-6	169	3,3',4,4',5,5'-Hexachlorobiphenyl
35065-30-6	170	2,2',3,3',4,4',5-Heptachlorobiphenyl
52663-71-5	171	2,2',3,3',4,4',6-Heptachlorobiphenyl
52663-74-8	172	2,2',3,3',4,5,5'-Heptachlorobiphenyl
68194-16-1	173	2,2',3,3',4,5,6-Heptachlorobiphenyl
38411-25-5	174	2,2',3,3',4,5,6'-Heptachlorobiphenyl
40186-70-7	175	2,2',3,3',4,5',6-Heptachlorobiphenyl
52663-65-7	176	2,2',3,3',4,6,6'-Heptachlorobiphenyl
52663-70-4	177	2,2',3,3',4,5',6'-Heptachlorobiphenyl
52663-67-9	178	2,2',3,3',5,5',6-Heptachlorobiphenyl
52663-64-6	179	2,2',3,3',5,6,6'-Heptachlorobiphenyl

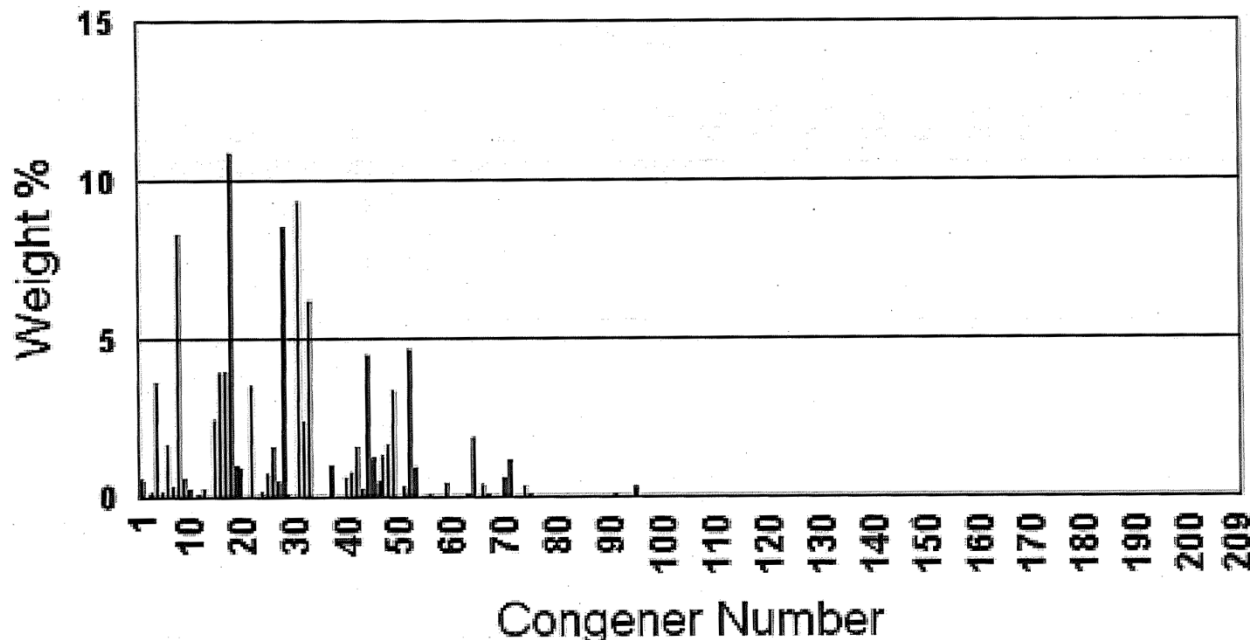
35065-29-3	180	2,2',3,4,4',5,5'-Heptachlorobiphenyl
74472-47-2	181	2,2',3,4,4',5,6-Heptachlorobiphenyl
60145-23-5	182	2,2',3,4,4',5,6'-Heptachlorobiphenyl
52663-69-1	183	2,2',3,4,4',5',6-Heptachlorobiphenyl
74472-48-3	184	2,2',3,4,4',6,6'-Heptachlorobiphenyl
52712-05-7	185	2,2',3,4,5,5',6-Heptachlorobiphenyl
74472-49-4	186	2,2',3,4,5,6,6'-Heptachlorobiphenyl
52663-68-0	187	2,2',3,4',5,5',6-Heptachlorobiphenyl
74487-85-7	188	2,2',3,4',5,6,6'-Heptachlorobiphenyl
39635-31-9	189	2,3,3',4,4',5,5'-Heptachlorobiphenyl
41411-64-7	190	2,3,3',4,4',5,6-Heptachlorobiphenyl
74472-50-7	191	2,3,3',4,4',5',6-Heptachlorobiphenyl
74472-51-8	192	2,3,3',4,5,5',6-Heptachlorobiphenyl
69782-91-8	193	2,3,3',4',5,5',6-Heptachlorobiphenyl
35694-08-7	194	2,2',3,3',4,4',5,5'-Octachlorobiphenyl
52663-78-2	195	2,2',3,3',4,4',5,6-Octachlorobiphenyl
42740-50-1	196	2,2',3,3',4,4',5,6'-Octachlorobiphenyl
33091-17-7	197	2,2',3,3',4,4',6,6'-Octachlorobiphenyl
68194-17-2	198	2,2',3,3',4,5,5',6-Octachlorobiphenyl
52663-75-9	199	2,2',3,3',4,5,5',6'-Octachlorobiphenyl
52663-73-7	200	2,2',3,3',4,5,6,6'-Octachlorobiphenyl
40186-71-8	201	2,2',3,3',4,5',6,6'-Octachlorobiphenyl
2136-99-4	202	2,2',3,3',5,5',6,6'-Octachlorobiphenyl
52663-76-0	203	2,2',3,4,4',5,5',6-Octachlorobiphenyl
74472-52-9	204	2,2',3,4,4',5,6,6'-Octachlorobiphenyl
74472-53-0	205	2,3,3',4,4',5,5',6-Octachlorobiphenyl
40186-72-9	206	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl
52663-79-3	207	2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl
52663-77-1	208	2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl
2051-24-3	209	Decachlorobiphenyl

Appendix B. PCB Mixtures and Trade Names (EPA 2013d)

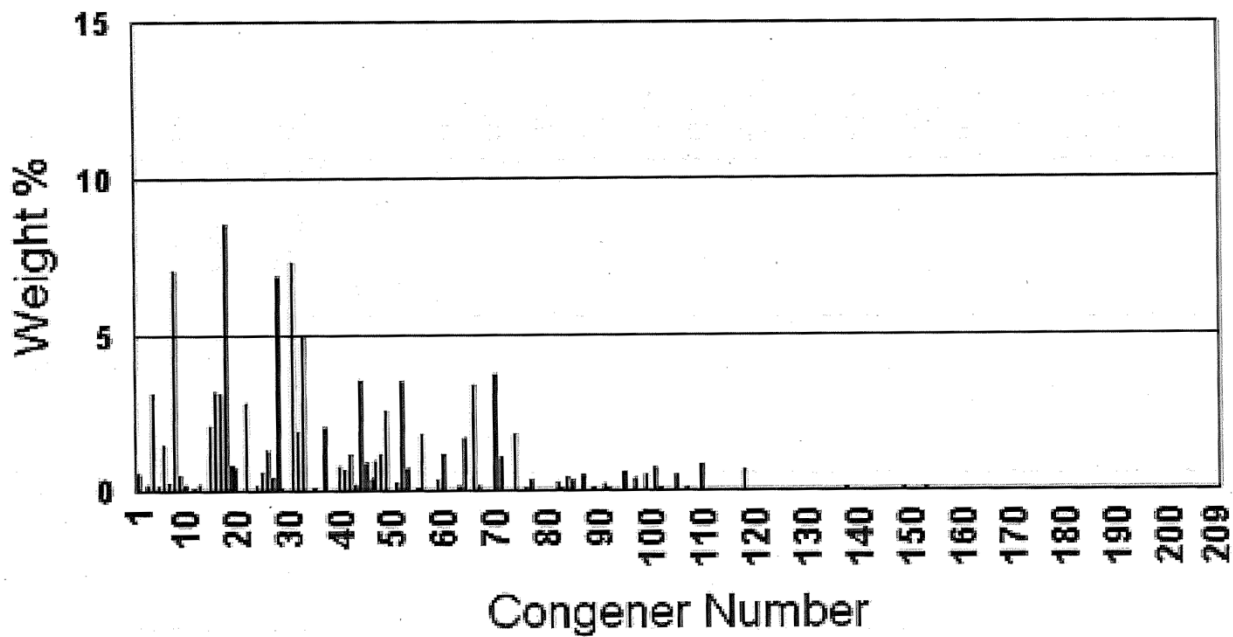
Aceptor	Dicolor	PCB
Adkarel	Diconal	PCB's
ALC	Diphenyl, chlorinated	PCBs
Apirolio	DK	Pheaoclor
Apirorlio	Duconal	Phenochlor
Arochlor	Dykanol	Phenoclor
Arochlors	Educarel	Plastivar
Aroclor	EEC-18	Polychlorinated biphenyl
Aroclors	Elaol	Polychlorinated biphenyls
Arubren	Electrophenyl	Polychlorinated diphenyl
Asbestol	Elemex	Polychlorinated diphenyls
ASK	Elinol	Polychlorobiphenyl
Askael	Eucarel	Polychlorodiphenyl
Askarel	Fenchlor	Prodelec
Auxol	Fenclor	Pydraul
Bakola	Fenocloro	Pyraclor
Biphenyl, chlorinated	Gilotherm	Pyralene
Chlophen	Hydol	Pyranol
Chloretol	Hyrol	Pyroclor
Chlorentol	Hyvol	Pyronol
Chlorinated biphenyl	Inclor	Saf-T-Kuhl
Chlorinated diphenyl	Inerteen	Saf-T-Kohl
Chlorinol	Inertenn	Santosol
Chlorobiphenyl	Kanechlor	Santotherm
Chlorodiphenyl	Kaneclor	Santothern
Chlorphen	Kennechlor	Santovac
Chorextol	Kenneclor	Solvol
Chorinol	Leromoll	Sorol
Clophen	Magvar	Soval
Clophenharz	MCS 1489	Sovol
Cloresil	Montar	Soltol
Clorinal	Nepolin	Terphenychlore
Clorphen	No-Flamol	Therminol
Decachlorodiphenyl	NoFlamol	Therminol
Delor	Non-Flamol	Turbinol
Delorene	Olex-sf-d	
Diachlor	Orophene	

Appendix C. Distribution of Aroclor mixtures (EPA, 2013d)

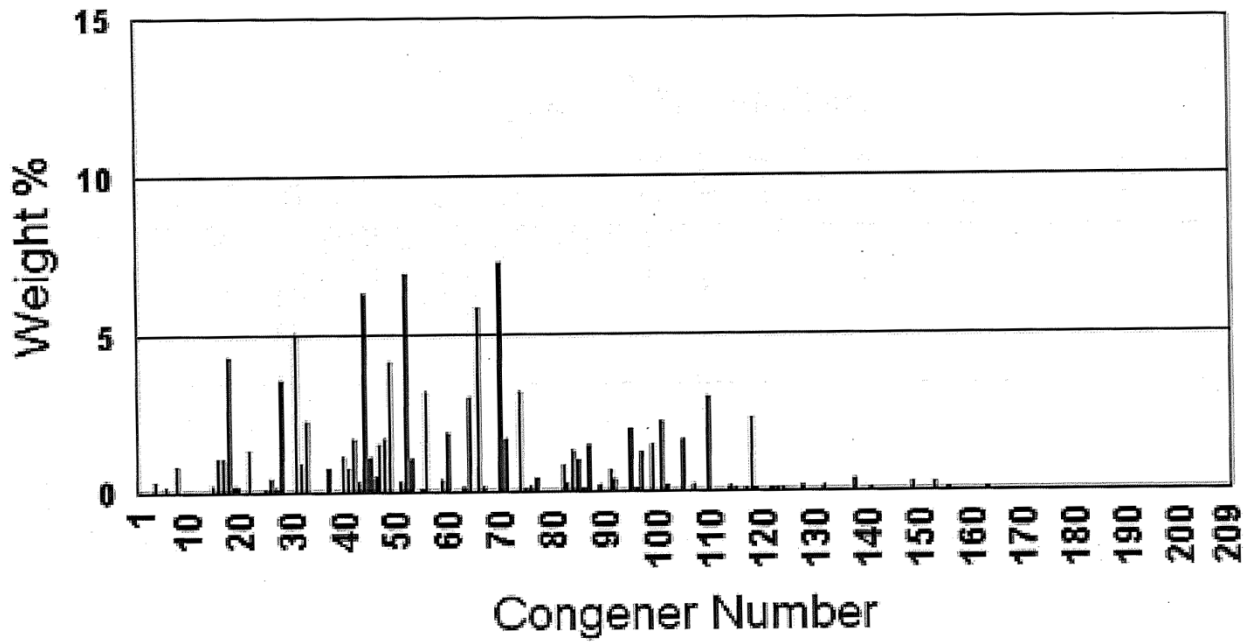
Aroclor 1016



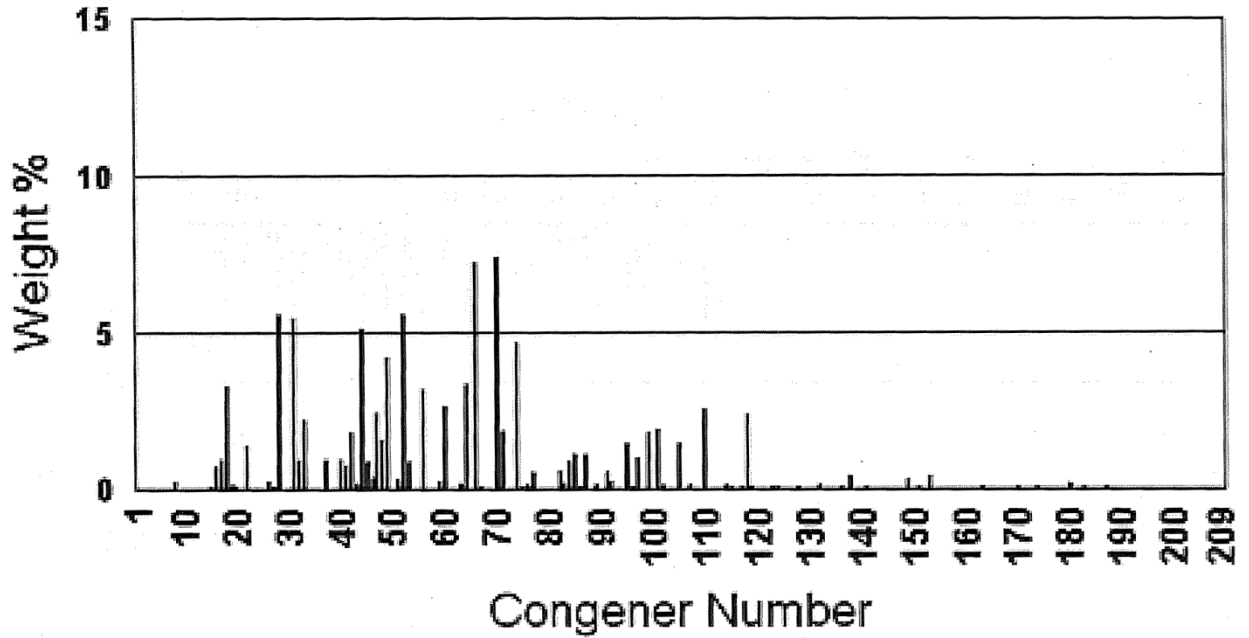
Aroclor 1242



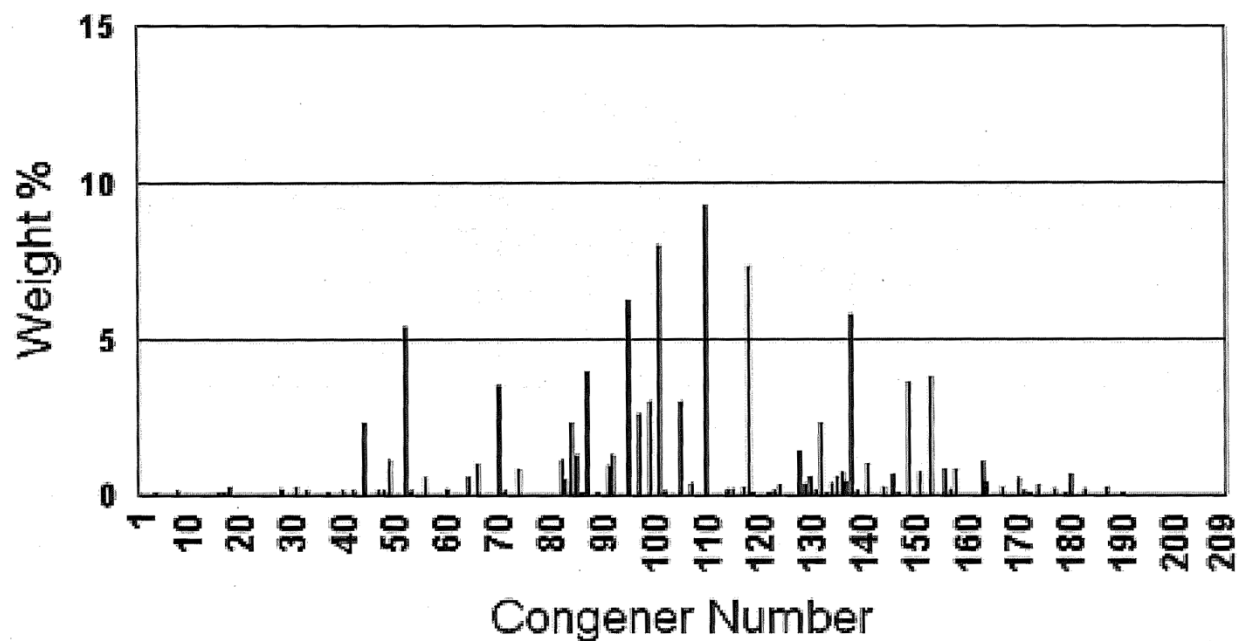
Aroclor 1248a



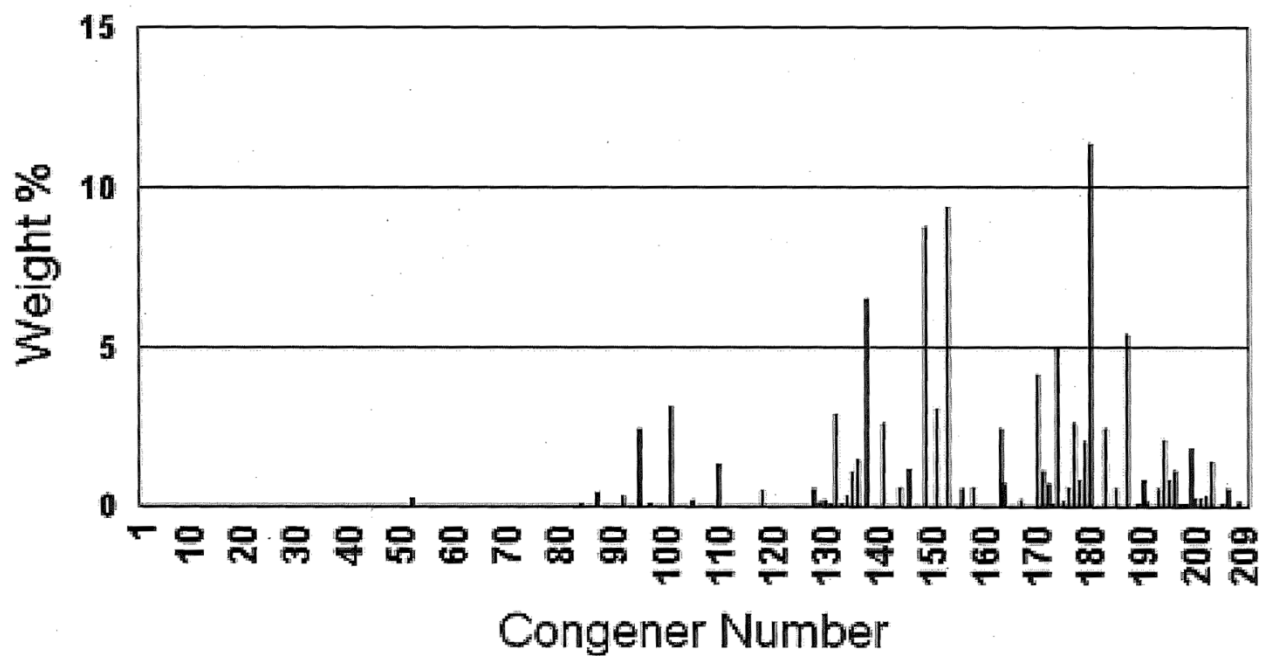
Aroclor 1248g



Aroclor 1254g



Aroclor 1260



Appendix D. Chemical Processes that have the Potential to Generate PCBs

The following was transcribed from EPA rulemaking records from “Polychlorinated Biphenyls (PCBs); Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions: Exclusions, Exemptions and Use Authorizations” Doc No. OPTS-62032. This was transcribed for Panero *et al.* (2005).

Chlorinated Compounds Produced Using Direct Chlorination	Chlorinated Compounds Produced Using Chlorinated Feedstocks	Non-chlorinated Compounds Produced Using Chlorinated Feedstocks	IPPPE U No.
Petroleum Feedstock: BENZENE			
Chlorinated benzenes	Chloronitrobenzenes	Phenol	8
Chlorinated phenols	Dichloronitrobenzenes	Aniline	9
Hexachlorocyclohexane	Dichloroanilines	o-Phenylenediamine	28
Chloranilines	Chlorinated methyl phenols	o-,p-Nitroanilines	29
Trichloroanilines	Chlorophenyl phenylethers	Diphenylamine	34
	Chlorinated benzidines	Acetanilide	17
Petroleum Feedstock: ETHYLENE			
Mono, di-chloroacetic acid	Ethyl chloroacetate	Glycine	108
Sodium chloroacetate	Vinyl chloride	Cyanoacetic acid	111
Chlorinated ethanes	Vinylidene chloride	Sodium, carboxymethyl cellulose	112
Chlorinated ethylenes	Bis (2-chloroethyl) ether	Ethyl cellulose	118
Ethylene chlorohydrin	Chlorinated acetophenones	Ethylene diamine	134
Chlorinated, fluorinated ethanes	Choline chloride	Aminoethylethanolamine	135
Chlorinated, brominated ethylenes	Hexachlorobutadiene	Mono-, di-, and triethylene glycol ethers	150
Chlorinated, fluorinated ethylenes		Tetramethylethylene diamine	(3341)
Chlorinated acetaldehyde			
Chlorinated acetyl chloride			
Hexachlorobenzene			
Petroleum Feedstock: METHANE			
Chlorinated methanes	Chlorinated, fluorinated methanes	Carbon tetrabromide	162
Phosgene	Chlorinated, brominated methanes	Carbon tetrafluoride	(812)
Tetrachloroethane	Bis (chloromethyl) ether		
Chlorodifluoroethane (?)	Cyanuric chloride		
Perchloromethyl mercaptan (?)	Trichloroethylene		
Cyanogen chloride			

Chlorinated Compounds Produced Using Direct Chlorination	Chlorinated Compounds Produced Using Chlorinated Feedstocks	Non-chlorinated Compounds Produced Using Chlorinated Feedstocks	IPPEU No.
Petroleum Feedstock: NAPHTHALENE			
Chloronaphthalenes			
Tetrachlorophthalic anhydride			
Petroleum Feedstock: PARAFFINS			
n-Propyl chloride		n-Propylamine	231
Carbon tetrachloride		Butyronitrile	232
Perchloroethylene		Amyl amines	243
Hexachloroethane		Amyl alcohols	244
Amyl chlorides		Amyl Mercaptans	245
Chloroprene		Benzophenone	249
Hexachlorocyclopentadiene		Linear alkylbenzenes	(2417)
Methallyl Chloride			
Petroleum Feedstock: PROPYLENE			
Dichlorohydrin	Epichlorohydrin	Isopropylphenols	272
Chloranil	Bis (2-chloroisopropyl) ether	Propylene oxide	280
Propylene chlorohydrin		Anisols	302
Chlorinated propanes		Allyl alcohol	317
Chlorinated propylenes		Glycerol	318/319
		Propyl amines	(1446)
Petroleum Feedstock: TOLUENE			
Benzyl chloride	Benzoyl chloride	Benzyl alcohol	334
Benzyl dichloride		Benzyl amine	335
Benzyl trichloride		Benzamide	337
Chlorotoluenes		Toluenesulfonamide	358
Chlorobenzaldehyde		Benzoyl peroxide	(495)
Chlorobenzoic acids & esters			
Chlorobenzoyl chlorides			
Toluenesulfonyl chloride			
Chlorobenzotrichlorides			

*The IPPEU No. refers to the process description in the 1977 EPA summary (EPA, 1977). Those numbers bracketed by parentheses refer to the OCPDB numbers in the 1980 EPA summary (EPA, 1980)

Appendix E. Reported Products with Inadvertently Generated PCBs

Manufacturers are required to report inadvertent generation of PCBs to EPA. Below is a summary table of the 77 reports received from 1994 to present. See the Regulations section for explanation of the requirement and “discounted.”

Date	Reporter	Product	Concentration or amount	Category
4/13/1995	Sun Chem. Corp	2-Naphthalenecarboxylic acid, 4-[(2,5-dichlorophenyl) azo]-3-hydroxy, a dye precursor		pigments and dyes
2/11/2004	Clariant	imported dyes		pigments and dyes
6/13/2005	Clariant	imported dyes		pigments and dyes
5/19/2011	Clariant	imported dyes		pigments and dyes
7/29/1994	Ciba-Geigy Pigments Division	CBI		pigments and dyes
12/28/1994	Ciba-Geigy Pigments Division	CBI		pigments and dyes
12/29/1994	DIC Trading	3 pigments		pigments and dyes
6/22/1995	Ciba-Geigy Pigments Division	CBI		pigments and dyes
7/25/1995	Cappelle	4 pigments		pigments and dyes
7/2/1996	Uhlich Color Co	CI Pigment Orange 24		pigments and dyes
7/15/1996	Ciba-Geigy Pigments Division	CBI		pigments and dyes
8/16/1996	Engelhard	CI Pigment Violet 23	19.6 ppm	pigments and dyes
8/23/1996	Cappelle	CI Pigment Yellow 170		pigments and dyes
9/27/1996	UMC (United Mineral and Chem)	CI Pigment Green 7		pigments and dyes
1/13/1997	Zeneca	7 pigments		pigments and dyes
7/29/1996	CDR Pigments and Dispersions	6 pigments		pigments and dyes
6/18/1997	Fabricolor	12 pigments		pigments and dyes
7/1/1997	BASF	13 pigments		pigments and dyes
8/18/1997	Ciba Pigments Division	CBI for several pages		pigments and dyes
10/21/1997	Mil International	5 pigments		pigments and dyes
1/6/1998	Sun Chem. Corp	4 pigments		pigments and dyes
10/26/1997	Mil International	4 pigments		pigments and dyes
5/15/1998	Mil International	5 pigments		pigments and dyes
7/20/1998	Ciba Pigments Division	CBI		pigments and dyes
10/23/1998	Ciba Pigments Division	CBI		pigments and dyes
2/2/1999	Lansco Colors	7 pigments		pigments and dyes
7/15/1999	Ciba Colors	CBI		pigments and dyes

	Division			
7/31/1999	Sun Chem. Corp	CBI		pigments and dyes
2/2/2000	Ciba Colors Division	CBI		pigments and dyes
5/23/2000	Ciba Colors Division	CBI		pigments and dyes
8/31/2000	Ciba Colors Divison	CBI		pigments and dyes
9/8/2000	Avecia	7 pigments		pigments and dyes
11/22/2000	Mil International	7 pigments		pigments and dyes
12/13/2000	Ciba Colors Division	CBI		pigments and dyes
3/30/2001	Ciba Colors Division	CBI		pigments and dyes
5/4/2001	Magruder Color Co	3 pigments		pigments and dyes
6/1/2001	Sun Chem. Corp	9 pigments		pigments and dyes
7/18/2001	Ciba Colors Division	CBI		pigments and dyes
4/8/1994	PCL Group	Copper Phthalocyanine Blue		pigments and dyes
10/17/2001	Ciba Colors Division	CBI		pigments and dyes
1/25/2002	Ciba Colors Division	CBI		pigments and dyes
3/27/2002	Mil International	8 pigments		pigments and dyes
4/29/2002	Ciba Coating Effects	CBI		pigments and dyes
8/6/2002	Ciba Coating Effects	CBI		pigments and dyes
8/28/2002	Sun Chem. Corp	CBI		pigments and dyes
11/5/2002	Ciba Coating Effects	CBI		pigments and dyes
6/13/2003	Ciba Coating Effects	CBI		pigments and dyes
10/16/2003	Ciba Coating Effects	CBI		pigments and dyes
4/2/2004	Ciba Coating Effects	CBI		pigments and dyes
7/6/2004	Ciba Coating Effects	CBI		pigments and dyes
7/6/2004	Ciba Coating Effects	CBI		pigments and dyes
8/8/2005	Sun Chemical	CBI		pigments and dyes
5/25/2006	Cappelle	CI Pigment Yellow 17		pigments and dyes
1/30/1995	GE Silicones	CBI	<2.5 ppm discounted, total discounted quantity <1.1 lbs	silicones
1/30/1996	GE Silicones	CBI	<1.1 ppm discounted, total discounted quantity <0.9 lbs	silicones

1/24/1997	GE Silicones	CBI	<1.5 ppm discounted, total discounted quantity <0.6 lbs	silicones
1/24/1997	GE Silicones	CBI	<1.3 ppm discounted, total discounted quantity <0.53 lbs	silicones
2/25/1999	GE Silicones	CBI	<1.5 ppm discounted, total discounted quantity <0.8 lbs	silicones
2/7/2000	GE Silicones	CBI	<1.7 ppm discounted, total discounted quantity <0.5 lbs	silicones
3/13/2001	GE	CBI	<1.9 ppm discounted, total discounted quantity <0.7 lbs	silicones
5/28/2002	GE	CBI, adding hydrolyzed phenylchlorosilanes and phenylchlorosilanes	total discounted quantity < 0.83 lbs	silicones
4/30/1997	ABB	electrical capacitors	3.9 ppm, 134 liters	Unique
6/24/1994	Nagase America	2,4,6-TCPH (2,4,6-Trichlorophenylhydrazine)	9-12 ppm	Unique
11/30/1995	PHT International	2,6-Dichloro-4-Nitro Aniline		Unique
3/17/1998	ISK Biosciences	CBI, Chlorothalonil production		Unique
5/15/2001	PPG Industries	trichlorobenzene (TCB)		Unique
8/17/2012	Future Fuel	pesticide intermediate		Unique
4/7/1997	Elf Atochem		4 and 5 ppm	Unknown
2/18/2000	CBI	CBI		Unknown
6/13/2001	CBI	CBI		Unknown
2/4/2003	CBI	CBI		Unknown
CBI	CBI	CBI		Unknown
5/31/2011	CBI	CBI		Unknown
9/11/2012	CBI	CBI, 220 kg shipment		Unknown
8/23/2004	Formosa Plastics		up to 215-255 ppm, 143 lbs	vinyl chloride
6/24/1996	Geon		740 lbs PCB/ 62,676,000 lbs chemical feedstocks	vinyl chloride
11/13/1997	Dow			vinyl chloride

Appendix F. Washington PCB transformers in EPA database

We attempted to contact the registrants to find out about the current whereabouts of the registered transformers. While owners of PCB transformers (> 500 ppm PCBs) were required to register with the EPA, the EPA is not required to update the database.

Company	City	Contact	Transformer street address	Trans. City	Trans. Zip code	No. of Trans.	Weight (kg)	Current whereabouts
Puget Sound Energy	Bellevue	John Rork	Talcott Avenue & Columbia Street	Olympia	98501	3	7	In use
Puget Sound Energy	Bellevue	John Rork	14401 278th Avenue NE	Duval	98019	2	5	In use
Puget Sound Energy	Bellevue	Lea Boyle	14401 188th Avenue NE	Redmond	98052	2	4.52	In use
Puget Sound Energy	Bellevue	John Rork	S 173rd & 43rd Avenue S	Renton	98055	0	0	
Puget Sound Energy	Bellevue	John Rork	2211 Nevada Street	Bellingham	98225	0	0	
Puget Sound Energy	Bellevue	John Rork	24810 156th Avenue SE	Kent	98025	0	0	
Puget Sound Energy	Bellevue	John Rork	Hodgedon & Garfield Streets	Tenino	98589	0	0	
Puget Sound Energy	Bellevue	John Rork	70th Street E & Myers Road	Bonney Lk	98390	0	0	
Puget Sound Energy	Bellevue	John Rork	Dolarway Road	Ellensburg	98922	0	0	
Puget Sound Energy	Bellevue	John Rork	Jackson & Main Streets	Cle Elum	98922	0	0	
Puget Sound Energy	Bellevue	John Rork	19319 Electron Road	Orting	98360	0	0	
Puget Sound Energy	Bellevue	John Rork	W. side of Stottlemeyer Road	Poulsbo	98370	0	0	
Puget Sound Energy	Bellevue	John Rork	40801 268th Avenue SE	Enumclaw	98022	0	0	
Puget Sound Energy	Bellevue	John Rork	N. Tapps Highway & Vandermark Road	Auburn	98002	0	0	
Puget Sound Energy	Bellevue	John Rork	SE 80th Street & 246 Avenue SE	Issaquah	98027	0	0	
Puget Sound Energy	Bellevue	John Rork	13635 SE 26th	Bellevue	98004	0	0	
Puget Sound Energy	Bellevue	John Rork	3975 E. Highway 525	Langley	98260	0	0	
Puget Sound Energy	Bellevue	John Rork	1274 Thompson Road	Anacortes	98221	0	0	
Puget Sound Energy	Bellevue	John Rork	2857 S. 221st	Des Moines	98148	0	0	
Puget Sound Energy	Bellevue	John Rork	12251 Mt Baker Highway	Glacier	98244	0	0	

Puget Sound Energy	Bellevue	John Rork	7537 Portal Way	Ferndale	98248	0	0	
Puget Sound Energy	Bellevue	John Rork	13635 NE 80th	Redmond	98052	0	0	
Puget Sound Energy	Bellevue	John Rork	9512 Pacific Highway SE	Lacey	98503	0	0	
Puget Sound Energy	Bellevue	John Rork	9221 Wilows Road NE	Redmond	98502	0	0	
Puget Sound Energy	Bellevue	John Rork	34717 21st Avenue SW	Federal Way	98003	0	0	
Puget Sound Energy	Bellevue	John Rork	1035 Stevenson Avenue	Enumclaw	98022	0	0	
Puget Sound Energy	Bellevue	John Rork	Hanford Road & Centralia Steam Pt	Centralia	98531	0	0	
Puget Sound Energy	Bellevue	John Rork	South of I-90 between Exits 37 & 38	Snoqualmie	98065	0	0	
Puget Sound Energy	Bellevue	John Rork	Corner of Central Valley Road & Bucklin	Bremerton	98310	0	0	
Puget Sound Energy	Bellevue	John Rork	20th Street E & 169th Avenue E (2111)	Sumner	98340	0	0	
Western Washington University	Bellingham	Gayle Shipley	Commissary 781 25th St.	Bellingham	98225	0	0	
SDS Lumber Co	Bingen	Ronald Schultz	South Side BNSF RR	Bingen	98605	2	2138	Unknown
Kimberly-Clark Worldwide	Everett	Jim Ketchum	2600 Federal Ave.	Everett	98201	0	0	
Grays Harbor Paper L.P.	Hoquiam	Richard Johnston	801 23rd St.	Hoquiam	98550	5	50932	In use
Reynolds Metals Company	Longview	H.S. Hays	4029 Industrial Way	Longview	98632	0	0	
Washington Veneer	Omak	Joe Atwood	1100 Eighth Ave.E.	Omak	98841	7	12412	Unknown
PUD. No. 1 of Clallam Co	Port Angeles	Quimby Moon	1936 West 18th Street	Port Angeles	98362	4	505	Disposed of
City of Port Angeles	Port Angeles	Mark Shamp	321 E. Fifth Street	Port Angeles	98362	1		Disposed of
PUD. No. 1 of Clallam Co	Port Angeles	Quimby Moon	1936 West 18th Street	Port Angeles	98363	1	100	Disposed of
PUD No. 1 of Clallam Co	Port Angeles	Quimby Moon	1936 West 18th Street	Port Angeles	98363	1	68	Disposed of
Port Townsend Paper Corporation	Port Townsend	John M. Recht	100 Mill Hill Rd	Port Townsend	98368	0	0	
City of Richland	Richland	Wayne Collop	806 Thayer Drive	Richland	99352	2	45	Disposed of
US Dept of Energy Richland Oper. Office	Richland	B.J. Dixon	200 East Area	Richland	99352	1	137	Unknown
Energy Northwest	Richland	J.P. Chasse	HPCS Diesel Generator Rm, Nuclear Plant #2, N. Power Plant Loop	Blank	Blank	0	0	
Entercom Communications	Seattle	Martin Hadfield	910 Lone Oak Road	Longview	Blank	0	0	

Corp								
Total Reclaim, Inc	Seattle	Craig Lorch	2200 Sixth Avenue South	Seattle	98134	1	215	Disposed of
Seattle City Light	Seattle	Karen Dinehart	Laurelhurst Lane and 51st	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	4502 NE 41st Street	Seattle	98124	3	182	Disposed of
Seattle City Light	Seattle	Karen Dinehart	Bellevue Ave E & E. John	Seattle	98124	3	160	Disposed of
Seattle City Light	Seattle	Karen Dinehart	2826 NW Market Street	Seattle	98124	2	114	Disposed of
Seattle City Light	Seattle	Karen Dinehart	7710 35th Avenue, SW	Seattle	98124	1	68	Disposed of
Seattle City Light	Seattle	Karen Dinehart	6730 24th Avenue, NW	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen. Dinehart	1414 NW Leary Way	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	7750 28th Ave NW	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	1405 NW 65th Street	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	8032 15th Avenue NW	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	3209 NW 65th Street	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	2333 W Boston Street	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	2100 SW Andover Street	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	35th Ave SE & SW Genessee	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	5601 23rd Avenue SW	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	1605 SW Holden Street	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	3405 SW Graham Street	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	4118 SW Morgan Street	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	9370 52nd Avenue S	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	1stE/Of Earl Ave NW, S/SI NW 90th	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	1stN/Of S Holden,E/SI Rainier AveS	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	1stS/Of W Bertona,E/SI 21st Ave W	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	48th NE & 47th NE	Seattle	98124	0	0	
Seattle City Light	Seattle	Karen Dinehart	51st Ave NE & NE 41st Street	Seattle	98124	0	0	
Inland Power and Light	Spokane	Todd Hoffman	10110 W. Hallett Road	Spokane	99014		1,249.0 0	
Avista Utilities	Spokane	Clarice	various locations	Blank	Blank	157	16,434.	Disposed of

		Robertson					00	
Avista Corporation	Spokane	Clarice Robertson	Onion Creek Road	Colville	Blank	0	0	
Avista Corporation	Spokane	Clarice Robertson	SE corner of Rockwell and Monroe Streets	Spokane	Blank	0	0	
Tacoma Power	Tacoma	Russell Post	418 Gershick Rd	Silver Creek	98585	10	830	Disposed of
Tacoma School District #10	Tacoma	Margaret Ohlson	111 North E Street	Tacoma	98403	1	358	In use
Tacoma School District #10	Tacoma	Margaret Ohlson	2502 North Orchard	Tacoma	98406	1	358	In use
Pioneer Americas, Inc./Chlor Alkali Co. Inc.	Tacoma	Karl Iams	605 Alexander Ave.	Tacoma	98421	0	0	
TransAlta of Calgary	Alberta	Roger Carter	913 Big Hanaford Rd	Centralia	98531	42	34731	Disposed of