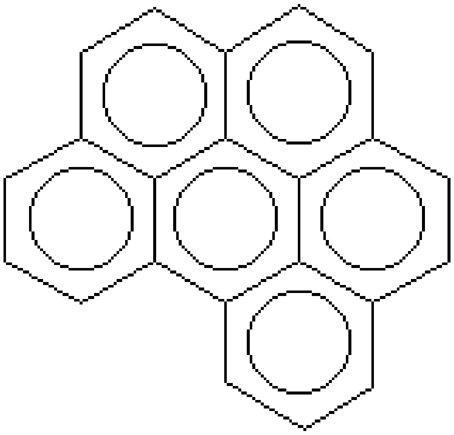

Draft PAH Chemical Action Plan

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PAH Chemical Action Plan

by;

Washington State Department of Ecology

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- Heather Trim, People for Puget Sound

Summary of findings

PBT Rule and Chemical Action Plans

Persistent, bioaccumulative, and toxic substances (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. The focus of our work on PBTs is preparing and implementing Chemical Action Plans. A Chemical Action Plan (CAP) is a plan that identifies, characterizes, and evaluates uses and releases of a specific persistent, bioaccumulative, toxic chemical (PBT) or a group of PBTs and recommends actions to protect human health and the environment (173-333 WAC).

This PAH CAP estimates release of PAHs from various sources to air, land and water. It also describes the physical and chemical properties of PAHs 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.

PAHs almost always occur as complex mixtures that include many PAH compounds; some of which meet the PBT criteria and some do not or have unknown characteristics. The overall toxicity of PAHs is caused by these mixtures and as a result Ecology chose to evaluate available information on the 16 PAH compounds on the Washington State PBT list as well as additional PAHs.

Toxic Effects

Both the EPA and IARC classify several PAH compounds/mixtures as known carcinogens, possible carcinogens, or probable carcinogens for humans. Cancer has also been the key endpoint for many other organisms. Other health effects include mortality, heart defects, reduced growth, immune-suppression, effects on reproduction, and population effects on diversity and abundance in ecosystems.

Major Sources

PAHs form and are released into the environment primarily from incomplete combustion of organic material including wood burning and vehicle emissions. Most PAHs are first released to air and then later deposit directly on water or on land and may runoff in stormwater. Other large sources are unburned petroleum and creosote treated wood railroad ties, utility poles and marine pilings. The largest releases of PAHs to water and land are from creosote treated wood used as marine pilings or railroad ties.

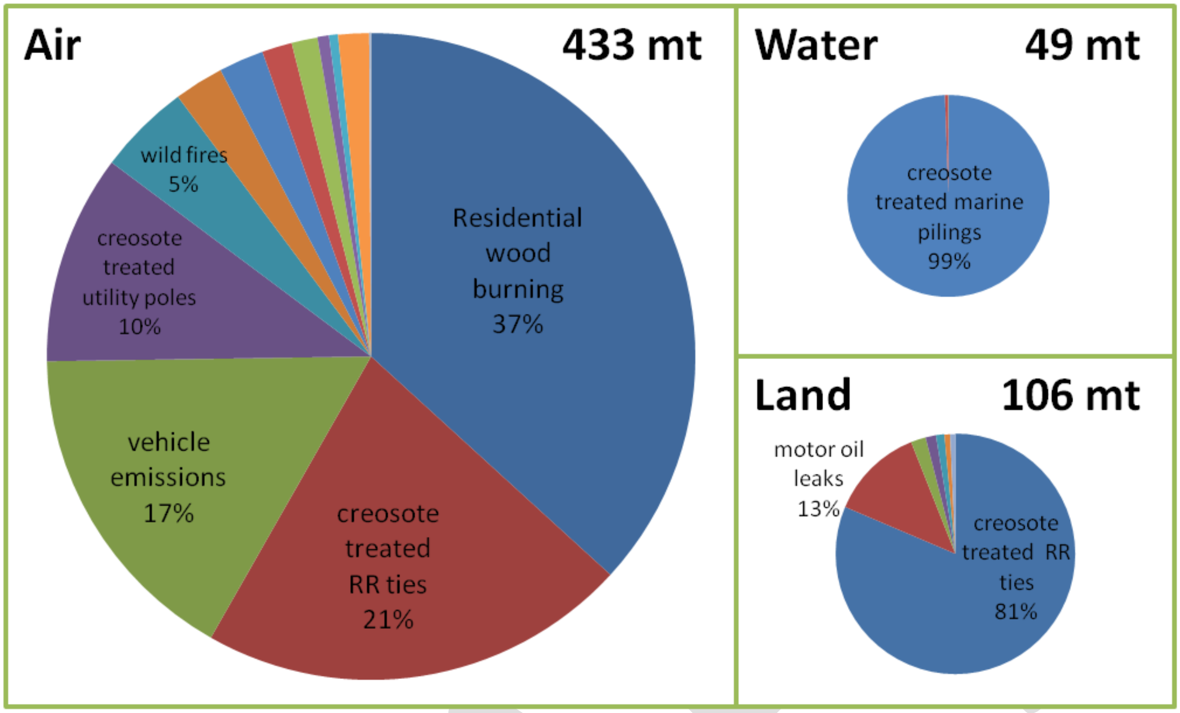
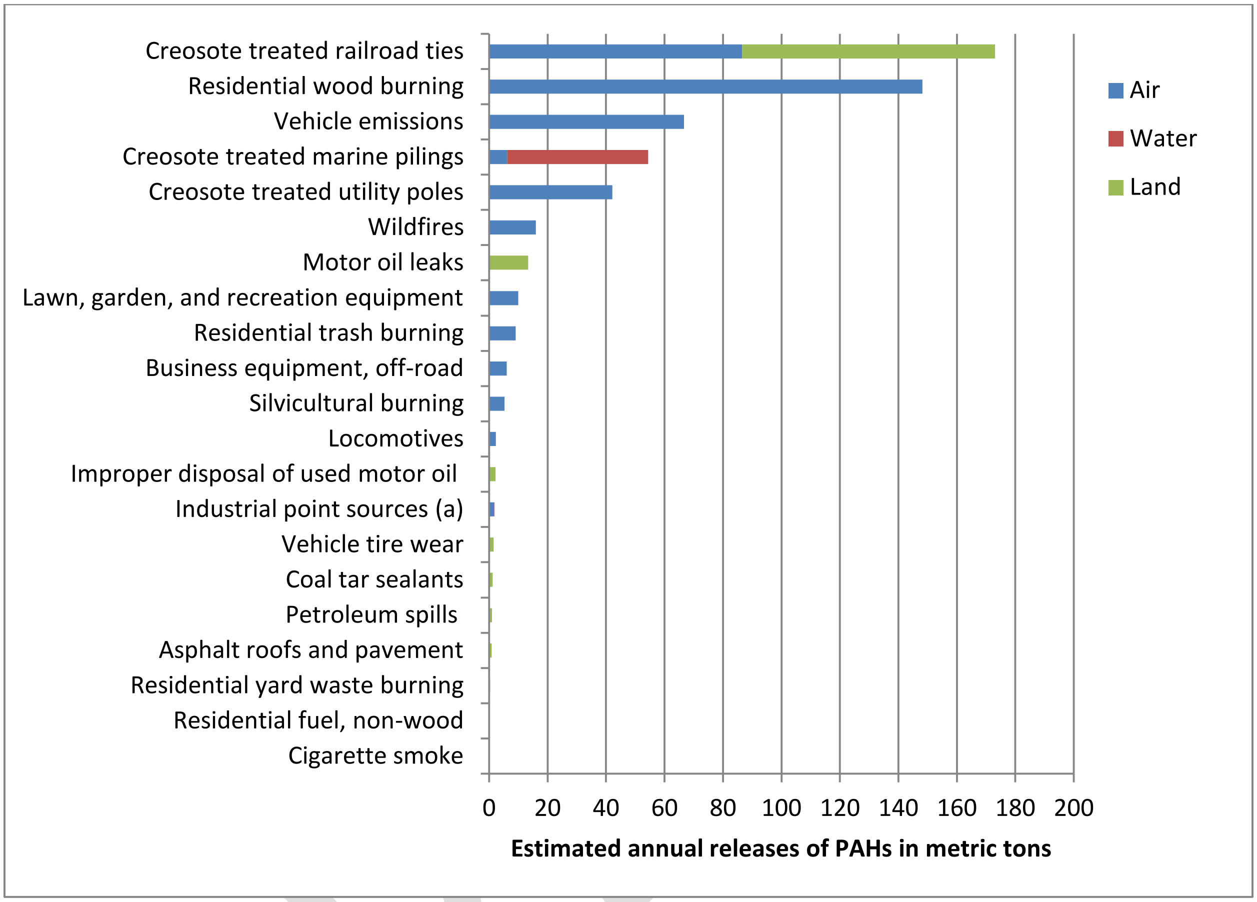


Figure 1 Estimated annual releases in Washington by medium and percentage in metric tons



(a) Industrial point sources do not include releases to landfills.

Figure 2 Summary of annual PAH releases in Washington by media of initial release in metric tons.

Pathways

The estimates of PAH released from various sources only tell part of the story. It is important to consider the different pathways from the sources to receptors. The Puget Sound Toxics Loading Study, recently published by Ecology, the Puget Sound Partnership and other state and federal agencies (http://www.ecy.wa.gov/programs/wq/pstoxics/index.html), evaluated PAHs and other chemicals of concern for releases, pathways to Puget Sound, levels in the environment, and likelihood of harm to people and other organisms. The major pathways for PAHs to Puget Sound are air deposition and surface runoff. One challenge to estimating pathways for PAHs is that they are hydrophobic and adhere tightly to particles, so they are often not detected in water, but are detected in soil or sediment. The Puget Sound Toxics Loading Study did not attempt to quantify how much PAH was loaded into Puget Sound from each individual source. We do not have enough information about the fate and transport of PAHs in Washington to estimate how far PAHs migrate from each source, but we do know that some sources of PAHs have longer range impacts than others.

Summary table

The table that follows summarizes releases, transport to people and the environment, the current feasibility and effectiveness of potential actions, and our priorities.

Transport

Since we don't have numerical estimates of how much PAH is transported from each release to organisms, the table uses a more subjective approach with high, medium and low transport to receptors.

- High transport to receptors

Sources with high transport have more direct pathways to receptors, such as marine pilings in Puget Sound that release PAHs into the water, where they accumulate in the sediment. Releases onto hard surfaces, where they are transported by stormwater into sediment are also considered high. An example of a high transport to the environment is PAHs from motor oil leaks and drips that fall on roads, where a higher percentage of them will be swept by stormwater into sediment.

- Medium transport to receptors

More general air releases that fall on both pervious and impervious surfaces have an indirect pathway to receptors and are considered medium. For example, PAHs from residential wood burning fall on pervious and impervious surfaces, and some fraction of these get into surface water and eventually reach benthic organisms in the sediment. Since there is more direct exposure of wood smoke to people who are inhaling the particles, that release has a high transport to people.

- Low transport to receptors

Sources with low transport are more localized, such as PAHs leaching from railroad ties and utility poles which are most likely to result in contamination of adjacent soils, although railroad ties and utility poles near shorelines may also release PAHs into water.

Current feasibility and effectiveness

The table also includes comments on the current feasibility and effectiveness of potential actions. Over time, with improved technologies and control options, some actions will increase in feasibility. In the absence of numerical estimates of how much each potential action will either reduce PAH releases or the exposure to people and other organisms, there are comments on potential actions. More details are in the section on recommendations and the section on estimated releases. Briefly, known technologies refer to actions that currently exist that we know reduce PAHs, such as reducing idling and switching from uncertified wood stoves to other sources of heat. We also noted that some sources, such as gasoline car engines, have already become much more efficient and, therefore, it is currently challenging to get further reductions, while other sources have more opportunities for PAH reductions. Sources that have had large reductions can be reduced further with additional work, but they are not a high priority at this time. Several sources are being addressed by other ongoing programs, such as programs to reduce diesel emissions, due to negative health effects from that complex mixture that includes PAHs. The need to get people to change their behavior is a common theme for reducing PAHs and one that is likely to take many years.

Major Sources of Concern

For most individuals, the largest exposures to PAHs are from food and smoking, with a lesser contribution from air emissions. For wildlife, the largest concern is sediment, since that is where PAHs collect. Sediment is also where PAHs enter the aquatic food chain, ending up in higher levels in the food chain, which includes people. Sources that are more than 2% of the total PAHs released in Washington are shaded in red in Table 2 The largest anthropogenic sources to the environment come from wood burning stoves, creosote treated wood, and vehicle emissions, including tire wear, motor oil disposal and leaks.

Table 1 Summary of releases, transport, potential actions and priorities

Source	Estimated environmental releases (kg/yr)	Percent of total release	Transport to receptors [a]		Feasibility and effectiveness of potential actions	Priorities
			Human	**Environ.**		
Residential wood burning	150,000	27	high	med	Known technologies, potential new technologies, and behavior change	X
Creosote treated wood (total)	270,000	50	low	mixed		
Railroad ties	*170,000*	*32*	low	low	Localized releases, but there may be ties in sensitive areas, such as nearshore areas	
Marine pilings	*54,000*	*10*	low	high	Most new uses have been phased out, but existing pilings remain	X
Utility poles	*42,000*	*8*	low	low	Most new uses have been phased out. Localized releases, but there may be poles in sensitive areas, such as nearshore areas	
Vehicles, on-road (total)	84,000	16	mixed	mixed		X
Light duty gasoline, air	*47,000*	*9*	med	med	Large reductions in emissions have already taken place in recent years due to federal authority	
Heavy duty gasoline, air	*17,000*	*3*	med	med	Large reductions in emissions have already taken place in recent years due to federal authority	
Heavy duty diesel, air	*2,700*	<1	med	med	Existing technology and other ongoing programs	
Light duty diesel, air	*330*	<1	med	med	Existing technology and other ongoing programs	
motor oil leaks	*13,000*	*2*	low	high	Known technologies and behavior change	
improper disposal of used motor oil	*2,100*	*<1*	low	high	Known technologies and behavior change	
vehicle tire wear	*1,500*	*<1*	low	high	Linked to reductions in miles driven	
Lawn and recreation equipment	10,000	<2	med	med	Known technologies and behavior change	
Residential trash burning	9,100	<2	med	med	Large reductions from regulations and behavior change have already taken place.	
Business equipment, off-road	6,100	<2	med	med	Known technologies and behavior change	
Silvicultural burning	5,200	<1	med	med	Limited technologies	
Locomotives	2,300	<1	med	med	Known technologies and behavior change	

Industrial point sources	1,800	<1	med	med	Larger reductions in emissions have already taken place and highly regulated	
Coal tar sealants	1,200	<1	med	high	State ban going into effect. Some individuals may have a high exposure	
Peroleum spills	1,000	<1	med	med	Existing programs to prevent spills	
Asphalt roofs and pavement	830	<1	low	med	Research is needed in order to determine appropriate actions for this product	
Residential yard waste burning	300	<1	med	med	Large reductions from regulations and behavior change have already taken place	
Residential fuel, non-wood	54	<1	med	med	Limited technologies	
Cigarette smoke	44	<1	high	med	Ongoing programs. Some individuals may have a high exposure	

[a] *High transport includes sources with more direct pathways to people or the environment, especially in sediment.*
Medium transport includes sources with indirect pathways to people or the environment, especially in sediment.
Low transport includes sources that are less likely to be transported to people or other organisms, especially in sediment.

Recommendations

There are current programs in place in Washington to address the major anthropogenic sources of concern. These programs can be enhanced to improve or speed up results, but we did not find that major new programs are needed.

The Departments of Ecology and Health have existing programs to reduce PAH releases from complex mixtures, such as wood smoke, diesel, and creosote. Many other individuals and groups are also working to reduce emissions from combustion including businesses, other state and federal agencies, local air agencies, counties, ports, cities, and not-for-profit organizations. Creosote treated wood, the largest non-combustion source of PAHs, also differs from other sources, because it is regulated as a pesticide at the federal and state levels.

Recommendations for Environmental Priorities

Below are recommendations for the sources predicted to have the most impact on the environment. We considered opportunities for reduction for each anthropogenic source of PAHs (detailed in the section on Production, Uses and Releases). Options were evaluated in consideration of: the effectiveness of the option in reducing releases and exposures to PAHs, feasibility, cost, public support, and agency authority.

Wood Smoke Recommendations

1. Increase education and outreach

Ecology and other partners should continue work to motivate people to reduce all wood smoke emissions, including PAHs. As the Puget Sound Clean Air Agency (PSCAA) found in their outreach to the Tacoma non-attainment area, a sizeable percentage of residents do not see how their individual actions contribute to poor air quality. Tools like community based social marketing can be used to change people's behavior.

(a) Cleaner burning. Changing how people burn wood can reduce PAHs, because how a wood stove is operated has a significant effect on how much smoke is produced. Ways to burn cleaner include

Local Clean Air Agencies

Most areas in Washington State are protected by local clean air agencies (listed below) or tribes. The remaining areas are protected by Ecology's regional offices.

Benton Clean Air Agency - Benton County
Northwest Clean Air Agency - Whatcom, Island, & Skagit counties
Olympic Region Clean Air Agency - Thurston, Mason, Pacific, Grays Harbor, Jefferson, & Clallam counties
Puget Sound Clean Air Agency - King, Snohomish, Pierce, & Kitsap counties
Southwest Clean Air Agency - Lewis, Skamania, Clark, Cowlitz, & Wahkiakum counties
Spokane Regional Clean Air Agency - Spokane County

using seasoned wood, keeping the fire hotter, and following the manufacturer’s instructions.

(b) Switching to alternative heating sources. Switching to certified wood stoves or pellet stoves can reduce emissions by 50% to 90%. Switching to non-wood heating alternatives such as natural gas and electric heat pump will reduce emissions by >90%. Fireplaces are highly inefficient and should not be used to heat a house. Weatherization can also reduce fuel use by reducing heating need.

(c) Efforts toward the education and enforcement of restrictions on trash burning and non-cooking outdoor burning should be expanded.

2. Increase voluntary incentive programs

Voluntary incentives are linked to education and outreach. Getting people to burn cleaner requires them to change their behavior and incentives are an important part of that. Ecology and local air agencies should continue to provide incentives for cleaner devices. Public and political support to require removal of uncertified wood stoves in most parts of the state is unlikely, so more funding for voluntary actions and education is needed.

(a) Ecology and local air agencies should investigate additional incentives to speed up results, such as making the purchase of cleaner burning devices exempt from state sales tax.

(b) Ecology should work with industry to use a technology challenge for businesses, schools, and other organizations to encourage the development of the next generation of cleaner burning wood stoves. An example of this is InnoCentive, a company that finds solutions using crowdsourcing and prizes. This challenge could also be linked to a state eco-endorsement for the highest performing stoves, similar to the federal Energy Star program for appliances. An easily identifiable way for consumers within Washington and in other states to find the most efficient stoves would help both consumers and our local stove manufacturers.

(c) Education and funding for voluntary replacements should be extended to include fireplaces. Fireplaces emit more pollution than other wood burning devices and are not efficient at providing heat.

One challenge is helping low income residents transition to a cleaner source of heat. The existing regulations allow people to burn wood, even during a burn ban, if it is their only adequate source of heat. This is a short term solution that addresses the inability of many people to afford the monthly utility bills and to instead use free or cheap wood fuel. Renters, especially lower income renters, are subject to their landlords’ choice of heating methods. In the longer term, we need to address the use of wood stoves for heat, especially in rental properties and how to encourage landlords to put in a certified device or another source of heat.

3. Prohibit the use of uncertified wood stoves in specified areas

PSCAA should use their authority to prohibit the use of older, more polluting uncertified wood stoves when there is an area in nonattainment with the federal air quality standards.[1] This may include disclosure or removal of devices, or making devices inoperable, but does not currently include requiring removal at the time of sale of a residence.

After actions have been taken in the Tacoma non-attainment area to lower levels of fine particulates, other local clean air agencies and Ecology should look at the recommendations of the Tacoma non-attainment Task Force[2], the actions taken in that non-attainment area, and the resulting levels of particulate, and consider those recommendations and actions for other areas that become out of attainment with a Federal standard. The agencies should also consider the Task Force recommendations to reduce wood smoke to keep particulate levels under the federal limits (i.e., prevent other areas from becoming non-attainment areas) and lower particulate levels to improve residents' health. The agencies and the state legislature should consider the possibility of new legislation for other areas with high levels of fine particulates from wood smoke.

Other recommendations from the Tacoma Piece County Clean Air Task Force are not appropriate for reducing overall PAH levels. For example, increased enforcement of burn bans is expected to reduce levels of fine particulate below the federal limits on those specific days, but will not reduce fine particulate or PAHs on the majority of days that do not have a burn ban.

4. Support new federal standards

Ecology and the local air agencies should continue to support the EPA in their work to update the federal standards for wood burning devices to make them consistent with the best performing stoves now available. There are devices now available with much lower emission rates than either our 1991 standard for non-catalytic wood burning devices of 4.5 g/hr as well as the current federal standard of 7.4 g/hr. Ecology should consider lowering the standard for stoves sold and installed in the state of Washington.

Vehicles Recommendations

5. Expand outreach on reducing fuel consumption and eliminating drips and leaks

Ecology and other agencies should continue to educate people on ways to use less fuel, which both reduces PAH emissions and saves money. This includes proper car maintence for both fuel efficiency and to reduce drips and leaks of used motor oil. Used motor oil contains PAHs both from the original oil and from the combustion in the engine. For example, Seattle Public Utilities, Ecology, and South Seattle Community College have free workshops for residents to

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[1] SHB 2326 passed by Washington State Legislature (2012).

[2] Tacoma Pierce County Clean Air Task Force Final Report (2011)

learn how to prevent, find, and correct leaks.[3] Public and political support to start a statewide inspection program to find and fix automotive drips and leaks is unlikely, so more funding for voluntary projects is needed.

6. Continue incentives to lower fuel consumption

Another way of reducing fuel use is to encourage different ways to reduce car trips and miles, such as the use of public transit. Washington has a commute trip reduction law[4] that works with local government, state agencies, and large employers to encourage employees to commute without driving alone each day. The Washington State Department of Transportation currently oversees the state program.[5] Washington should also continue to encourage purchase of zero emission vehicles using financial incentives.

7. Continue anti-idling education programs and write an anti-idling rule

   (a) Ecology and other agencies should continue the existing education and outreach programs on anti-idling. For example, the Spokane Regional Clean Air Agency and Puget Sound Clean Air Agency provides support to school districts to implement no idle zones. Idling, in addition to its contribution to air pollution, is a waste of fuel and money.

   (b) In addition to outreach to reduce idling, Ecology should promulgate a statewide anti-idling rule using our existing authority under the Clean Air Act. This would address all engines in both passenger cars and commercial equipment. According to the American Transportation Research Institute, 14 states and 17 cities or counties have anti-idling regulations.

8. Continue the current diesel reduction strategy

Ecology has identified diesel exhaust as the air pollutant most harmful to public health in Washington State and has developed a strategy to reduce diesel exhaust[6]. Reducing these sources of diesel emissions will also reduce PAH emissions, since PAHs are part of this complex mixture. Ecology should continue to work on its diesel reduction strategy to address the most significant sources: heavy duty highway vehicles, non-road construction equipment, marine vessels and port related equipment, and locomotive engines. The strategy identifies reducing idling, installing pollution reducing technologies on engine exhausts, installing technologies that increase fuel efficiency, and replacing older engines and vehicles as the most effective to reduce diesel emissions. It is important to address existing diesel engines because they typically have a

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[3] http://www.ecy.wa.gov/washington_waters/cars.html

[4] RCW 70.94.521-555

[5] http://www.wsdot.wa.gov/transit/ctr

[6] Ecology publication 06-02-022. Diesel Particulate Emission Reduction Strategy for Washington State (2006).

long life and replacement is expensive. Sharing our successes will influence private investment on diesel engines in the private sector. An estimated 90% of the 134,000 existing diesel engines that are suitable for reductions are privately owned and operated.

Emissions from many of the public sector fleets, such as school buses, have been addressed by existing programs. The Washington Clean Diesel Program has put 9,100 emission control devices on 6,400 school bus engines, plus helped pay for the replacement of 80 school buses with new buses equipped with the latest pollution reduction technology. The grant program has also funded 2,200 retrofits on 1,900 engines on public vehicles and equipment (garbage, port, city maintenance, etc.). The Clean Diesel Grant Program has begun putting anti-idling technology on emergency vehicles. For example, in Thurston County, a one-time investment of $390,000 for 40 vehicles is projected to save $1 million a year in fuel costs. These programs save money and reduce diesel emissions and should be expanded, but additional funding is needed to reach all publically owned diesel engines.

Another anti-idling project is expanding the multi-agency program for electrified parking for commercial trucks. Currently 76 truck parking spaces in two Washington truck stops have been electrified to help drivers operate on-board electronics and systems during rest periods. This program is being done with Oregon in a joint effort to reduce idling along the West Coast. This is only a small percentage of the available truck parking spaces in Washington and additional funding is needed to electrify a significant portion of the truck parking spaces.

9. Support new federal actions

(a) Ecology should encourage the EPA to continue to update regulations to require more efficient cars and cleaner burning fuel. This will continue to reduce air emissions, including PAHs, from vehicles, while maintaining or increasing the performance of vehicles. Under existing authorities, Washington can either adopt California or federal regulations on car emissions, and we have adopted the more strict California emissions in the Washington Clean Car Law. Gasoline engines have become much more efficient and large reductions in emissions have already taken place. There are fewer opportunities for Washington State to make further reductions in emissions in the absence of federal action.

(b) Ecology should encourage the federal government to improve performance standards by requiring lower emissions for all diesel engines, stationary and mobile, including locomotives. Locomotives emit fewer pollutants per ton of cargo per mile compared to trucks but opportunities for further reductions in emissions are possible. For example, many switching engines used at local cargo yards date from the 1960s and 1970s. The EPA should also continue other programs, such as its voluntary and collaborative "SmartWay" program to improve the fuel efficiency of shipping materials.

Creosote Treated Wood and Other Products Recommendations

10. Continue creosote piling removal

The Washington State Department of Natural Resources (DNR) has been leading efforts to remove creosote treated wood throughout Puget Sound. New creosote pilings are generally not installed in marine waters and are not allowed in lakes. These actions remove a source of PAHs to sediment and are part of restoring Puget Sound. DNR has removed over 13,000 pilings and is continuing to remove more pilings and other creosote-treated wood. The DNR Creosote Removal Program webpage has a map of projects in Puget Sound and summaries of materials removed.[7] Other groups, such as the Port of Seattle, have also been removing creosote treated wood pilings and replacing the structures with concrete. During creosote piling removal care must be taken to minimize localized increases in PAHs.

11. Map railroad tie locations

Ecology should use GIS mapping to locate creosote treated wood railroad ties near sensitive habitat such as salmon spawning streams and marine nearshore habitat. Creosote treated wood is still used for the majority of railroad ties and PAHs from creosote treated wood near aquatic environments may impact aquatic organisms. PAHs from uses of creosote-treated wood in other areas have less direct transport pathways to sediments and aquatic organisms and, therefore, we are not recommending additional actions to remove or replace them at this time. In the future, Ecology should investigate the advantages and disadvantages of other wood treatment options and non-wood options, especially for aquatic areas. Because the purpose of treating wood with creosote is to preserve the wood and protect it from pests, many chemical alternatives will also be toxic and need to be reviewed carefully for impacts to the aquatic environment.

12. Monitor uses and environmental fate of PAHs from other products

(a) Ecology should continue to monitor how creosote-treated wood and other PAH containing products, such as asphalt shingles, are reused such that the beneficial re-uses do not present a threat to human health or the environment.

(b) Ecology should investigate PAH releases from roofing. The Puget Sound Toxics Loading Analysis identified roofing materials as one of the largest potential sources of several toxic chemicals to Puget Sound and recommended that we evaluate roofing materials.[8] PAHs were not included in the recommendation from the Puget Sound Toxics Loading Analysis, but they should be added to that study. A first step is to study chemicals in

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[7] http://www.dnr.wa.gov/ResearchScience/Topics/AquaticClean-UpRestoration/Pages/aqr_creosote_removal_program.aspx

[8] Ecology publication 11-03-055. Control of Toxic Chemicals in Puget Sound: Assessment of Selected Toxic Chemicals in the Puget Sound Basin, 2007-2011.

runoff from various roofing materials commonly used in Washington to refine the estimates made in the Puget Sound Toxics Loading studies. If there are significant contributions of PAHs from roofing materials, then future actions may continue to look for roofing materials that do not release PAHs or other chemicals of concern.

Recommendations for Human Health Priorities

All of the recommendations to reduce PAH releases to the environment will reduce people's exposure to PAHs. However, the largest sources of PAH exposure for most people are the foods they eat and, for smokers, their use of tobacco products.

Limiting People's PAH Exposure from Tobacco Products and Food Recommendations

13. Smoking – Continue anti-smoking programs and work to enhance them in the future

Smoking harms people, and public health agencies around the world have programs to help people quit and to encourage people not to start in the first place. The Washington State Department of Health monitors tobacco use in the state and provides information on ways to quit smoking. From 2002 to 2008, Washington ranked in the top 10 states in per capita spending on tobacco prevention and control, and the decline in the state's rates of youth and adult smoking outpaced national rates. More recently, state funding for the program has been significantly reduced, with a concomitant decrease in activities to reduce smoking. The Department of Health should continue to discourage tobacco use and to help people quit smoking. Further, the department should pursue additional funds to make up for recent cuts and ensure that future efforts will continue the pattern of success experienced in the past.

14. Food – Develop outreach on food preparation methods that reduce exposure to PAHs

Certain preparation methods promote the formation and collection of PAHs in food. In addition, some cooking methods release PAHs into the air where they can be inhaled. The Department of Health should develop educational materials that discuss how different food preparation methods contribute to the production of PAHs and how exposure to PAHs can be reduced by choosing appropriate cooking methods.

Summary of Recommendations

Priority Recommendations for the Environment

Wood Smoke

1. Increase education and outreach
    a. Cleaner burning
    b. Switching to alternative heat sources
    c. Include trash and other outdoor burning.
2. Increase voluntary incentive programs
    a. Additional incentives
    b. Technology challenge
    c. Include fireplaces
3. Prohibit the use of uncertified stoves in specified areas
4. Support new federal standards

Vehicles

5. Expand outreach on reducing fuel consumption and eliminating drips and leaks
6. Continue incentives to lower fuel consumption
7. Continue anti-idling education and create an anti-idling rule
    a. Anti-idling education
    b. Anti-idling rule
8. Continue the current diesel reduction strategy
9. Support new federal actions
    a. Gasoline engines
    b. Diesel engines

Creosote treated wood and other products

10. Continue creosote piling removal
11. Map railroad tie locations
12. Monitor uses and environmental fate of PAHs from other products
    a. Monitory reuse of products like shingles
    b. Further research on roofing

Priority Recommendations for Human Health

13. Continue anti-smoking programs
14. Develop outreach materials

Implementation Steps

The PBT Rule requires that Ecology outline steps it will take to implement the CAP recommendations.

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

We will focus 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 PAHs may arise and it makes sense to reduce all sources of PAHs where possible.

Ecology will continue our existing programs to reduce the largest sources of PAHs to the environment, namely wood smoke, diesel, and creosote. Expanding or increasing programs will require additional funds. Ecology will work on acquiring additional funds, but cannot predict when we will be able to obtain them.

There are three recommendations with specific plans for new work by Ecology.

Recommendation 7(b) Promulgate a statewide anti-idling rule using our existing authority under the Clean Air Act. Ecology expects to begin this rulemaking in FY14.

Recommendation 11 Map railroad tie locations using GIS to locate creosote treated wood near sensitive habitat such as salmon spawning streams and marine nearshore areas. Ecology will do this in FY13.

Recommendation 12(b) Investigate PAH releases from roofing. Ecology has begun a project to evaluate chemicals in runoff from roofing, based on the recommendations in the Puget Sound Toxics Loading Analysis.[9] The project is expected to be completed in fall of 2013.

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[9] http://www.ecy.wa.gov/programs/wq/pstoxics/index.html

What are PBTs and why are PAHs on our list?

What are PBTs?

Persistent, bioaccumulative, and toxic substances (PBTs) are considered the "worst of the worst," chemical contaminants because they remain in the environment for a long time, and accumulate within organisms and/or within the food chain, in addition to having harmful effects. PBTs can travel long distances and generally move easily between air, water, sediment, and land, spanning boundaries of geography and generations. Some PBTs have been banned for decades, but they remain in the environment and within people. Examples include DDT and PCBs.

Ecology published our *Strategy to Reduce PBTs* in December 2000 (Ecology 2000a). After working with an advisory committee and getting input from the public, the PBT Rule (WAC 173-333) was adopted in January 2006. The goal of the PBT Rule is to reduce and phase out the uses, releases, and exposures to PBTs in Washington to protect human health and the environment. The PBT rule includes PBT criteria and a list of chemicals (PBTs) that meet these criteria, as well as procedures to periodically update the list. The focus of our work on PBTs is preparing and implementing Chemical Action Plans (CAPs). The PBT rule describes the parts of a CAP, how CAPs are developed, and how PBTs are chosen for a CAP.

What are PAHs?

Polycyclic aromatic hydrocarbons (PAHs) were selected for the next CAP in the 2007 Multiyear schedule (http://www.ecy.wa.gov/biblio/0707016.html). PAHs rated high in most of the criteria ranking which determines the order of the development of CAPs in Washington State. They are toxic to organisms and are widespread in Washington's environment. PAHs are also toxic to humans and are found in people. PAHs are released during commonplace activities, such as burning wood and driving cars, and from commonplace objects, like railroad ties. While some of these are regulated, opportunities for further intervention are still substantial.

PAHs are a group of chemicals on the PBT list, rather than being an individual chemical. PAHs are sometimes called polycyclic organic matter (POM), or polynuclear aromatics (PNAs). They are a class of organic compounds characterized by two or more fused aromatic rings composed of carbon and hydrogen. Rings containing nitrogen, sulfur and oxygen are included in the more general definition of a PAH and are typically referred to as heterocyclic PAHs. There are hundreds of such compounds and they usually occur as mixtures. They are found in some natural sources like petroleum oil and coal and are formed during the incomplete burning of organic matter such as coal, oil, gas, wood, garbage, and other materials, such as tobacco and meat.

PAHs are non-essential for the growth of plants, animals or humans. While considerable work has been done on the carcinogenicity of individual PAHs, PAHs also affect the survival, growth and reproduction of many species. PAH toxicity in the environment is caused by a complex mixture of PAH compounds rather than exposure to individual PAHs. The effects of PAH exposure was first noted by English physician and surgeon Percivall Pott in 1775, when he observed that exposure to soot might explain the high incidence of scrotal cancer in chimney sweeps.

Why are PAHs on our PBT list?

About 30 PAHs were evaluated for inclusion on the PBT list and not all of those met the inclusion criteria. Even though only16 PAHs are on the PBT list, Ecology evaluated information available on additional PAHs for this CAP, since PAHs occur as complex mixtures that include many PAHs. This CAP addresses PAHs as complex mixtures rather than as individual compounds.

The following secion is a brief overview of how PAHs met the criteria for inclusion on the PBT list during development of the PBT Rule. More details on persistence, bioaccumulation, toxicity, and chemical properties are also found in other sections.

Persistence

The criterion for persistence in the PBT Rule is that 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. Ecology found a variety of half-lives for individual PAH compounds and the ones that had half-lives greater than 60 days were further considered for the PBT List. Both the parent chemical and its degradation products are considered for this and the other criteria.

Bioaccumulation

The criterion for bioaccumulation in the PBT rule is:

1. The bioconcentration factor (BCF) or bioaccumulation factor (BAF) in aquatic species for the chemical is greater than 1,000, or
2. In the absence of such data, the log-octanol water partition coefficient (log K_{ow}) is greater than five.

The information gathered for the PBT Rule found BCF values, ranging from 602 - 25,703 and log K_{ow} values of 3.92 to 6.75 for various PAH compounds.

Toxicity

In order for a chemical to be considered toxic as defined in the PBT rule, it must meet at least one of the following criteria:

1. Be a carcinogen, a developmental or reproductive toxicant, or a neurotoxicant.
2. Have a reference dose or equivalent toxicity measure that is less than 0.003 mg/kg/day.
3. Have a chronic no-observed-effect concentration (NOEC) or equivalent toxicity measure that is less than 0.1 mg/L or an acute NOEC or equivalent toxicity measure than is less than 1.0 mg/L.

Ecology found a wide range of health effects for PAHs. The EPA established reference doses for some PAH compounds. Both the EPA and IARC classify several PAH compounds as known carcinogens, possible carcinogens, or probable carcinogens for humans. Cancer has also been the key endpoint for many other organisms. Other health effects include mortality, heart defects, ,reduced growth, immunosuppression, effects on reproduction, and population effects on diversity and abundance in ecosystems.

PAHs in PBT Rule

Not all PAHs examined met all the criteria to be included in the PBT Rule. For example, benzo(a)pyrene is a well known carcinogenic PAH, but it was not considered bioaccumulative under Washington's PBT rule because the BCF of 912 that was identified at that time is less than 1000. There are differences among different PBT lists, for example, the EPA did include benzo(a)pyrene in their list of twelve priority PBTs. Other PAHs, such as fluorene, were not considered persistent under our PBT Rule criteria.

PAHs occur as complex mixtures, rather than as individual compounds, however, and therefore it made sense to address mixtures in the CAP. As part of the CAP, we consider mixtures such as creosote and wood smoke which contain other PAHs as well. The three key lists of PAHs to consider in this document are Washington's PBT List (WAC733-333), the Toxics Release Inventory (TRI), and in the Clean Water Act. See Appendix A for a comparison of different lists of PAHs. Table 2 lists the most commonly referenced individual PAHs and shows which PAHs are considered carcinogenic, possibly carcinogenic, or probably carcinogenic by the EPA Integrated Risk Information System (IRIS) and the World Health Organization (WHO) International Agency for Research on Cancer (IARC).

Table 2 PAHs in the PBT Rule and other key lists of PAHs

CAS	Name	Washington PBT list	TRI	1977 Clean Water Act Priority Pollutants
56-49-5	3-methyl chlolanthrene	x	x	
194-59-2	7H-dibenzo(c,g)carazole +	x	x	
218-01-9	benzo(a)phenanthrene (chrysene)*+	x	x	x
205-99-2	benzo(b)fluoranthene*+	x	x	x
191-24-2	benzo(g,h,i)perylene	x	x	x
205-82-3	benzo(j)fluoranthene+	x	x	
207-08-9	benzo(k)fluoranthene* +	x	x	x
189-55-9	benzo(r,s,t)pentaphene +	x	x	
192-65-4	dibenzo(a,e)pyrene	x	x	
189-64-0	dibenzo(a,h)pyrene +	x	x	
226-36-8	dibenzo(a,h)acridine +	x	x	
53-70-3	dibenzo(a,h)anthracene* +	x	x	x
224-42-0	dibenzo(a,j)acridine +	x	x	
206-44-0	Fluoranthene	x	x	x
193-39-5	indeno(1,2,3-cd)pyrene* +	x	x	x
198-55-0	Perylene	x		
83-32-9	Acenaphthene			x
208-96-8	Acenaphthylene			x
56-55-3	Benzo(a)anthracene*+		x	x
91-20-3	Naphthalene +			x
86-73-7	Fluorene			x
120-12-7	Anthracene			x
85-01-8	Phenanthrene			x
129-00-0	Pyrene			x
50-32-8	benzo(a)pyrene* ++		x	x
5522-43-0	1- nitropyrene+		x	
3697-24-3	5-methyl chrysene+		x	
57-97-6	7,12-dimethylbenz(a)anthracene		x	
5385-75-1	dibenzo(a,e)fluoranthene		x	
191-30-0	dibenzo(a,l)pyrene +		x	

* listed as a probable human carcinogen by the EPA IRIS

\+ listed as probably or possibly carcinogenic to humans by IARC

++ listed as carcinogenic to humans by IARC

General Chemical Information

The information in this section is compiled from four main references: US Dept. Of Health & Human Services Agency for Toxic Substances and Disease Registry (ATSDR 1995); National Park Services (1997); the US National Institute of Health Hazardous Substances Database; and PAHs: An Ecotoxicological Perspective (Douben 2003). Any additional references are called out specifically in the document.

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemicals consisting primarily of numerous fused rings of carbon and hydrogen. They are found in some natural substances like oil and coal and are formed during the incomplete burning of organic matter such as coal, oil, gas, wood, garbage, or other organic substances, such as tobacco and meat. More information on the three major sources of PAHs is found later in this chapter.

The definition of a PAH can vary significantly. The most commonly used definition requires the fused rings to be based upon benzene. In this instance, six carbon atoms are bonded together in a ring and each carbon atom contains a double bond to a carbon atom on one side and a single bond to one hydrogen atom. The aromatic character of the molecule is based on the benzene ring-shaped structure which makes its carbon-carbon skeleton more stable when compared with other hydrocarbons. For ease of drawing the molecular structure of benzene, carbons and hydrogens are not typically shown; it is assumed carbons are found at the intersection of any two lines and hydrogens are bound to any unsubstituted portion of the carbon atoms. The double bonds between carbon atoms are shared equally throughout and denoted by a circle within the ring struction. Therefore, the most commonly used symbol for benzene (C_6H_6) appears below:

Benzene

CAS 71-43-2

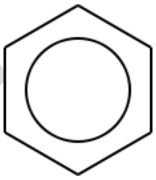


Figure 3 Structure of Benzene

Multiple benzene rings can be fused together to form a PAH. This structure repeats throughout the compound. Naphthalene, a simple PAH, consists of two fused benzene rings and meets this definition:

Naphthalene ($C_{10}H_8$)

CAS 91-20-3

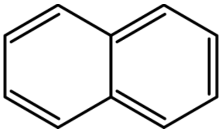
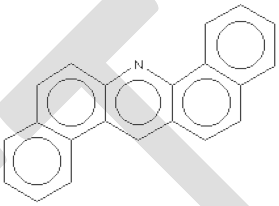


Figure 4 Structure of the simple PAH Naphthalene

Other definitions of PAH include more exotic features such as rings with fewer than 6 carbons, other elements in place of carbon or rings that do not contain any double bonds. Rings containing nitrogen, sulfur and oxygen can be included in the more general definition of a PAH and are typically referred to as heterocyclic PAHs. Some PAHs can be found containing rings of 5 or fewer carbons. Examples of heterocyclic PAHs, which meet this broader definition, are shown below:

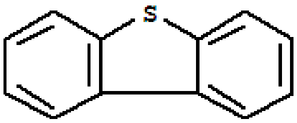
Dibenzo(a,h)acridine
($C_{21}H_{13}N$)

CAS 226-36-8



Dibenzothiophene ($C_{12}H_8S$)

CAS 132-65-0



Dibenzofuran ($C_{12}H_8O$)

CAS 132-64-9

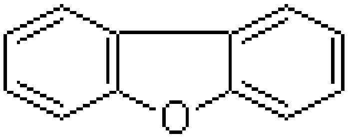
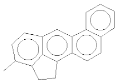
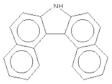
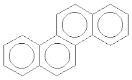
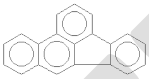
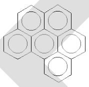
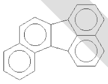
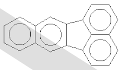
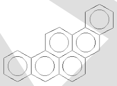
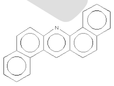
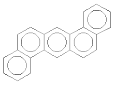
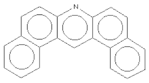
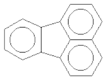
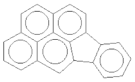
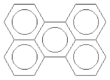


Figure 5 Examples of heterocyclic PAHs

More than 100 different PAH compounds exist and theoretically the potential compounds, which meet the broader definition of PAH, could be in the thousands. Except in specialized applications or for research purposes, PAHs rarely exist alone but are found in mixtures. As it is impractical to consider all of the known or potential PAH compounds, several PAH compounds have been identified for study due to their toxicity and/or their prevalence. Once certain compounds are identified for study, additional studies tend to be done on the same compounds, instead of on different ones. Table 2 compares the 16 PAHs in the Washington PBT Rule to the 22 PAHs reported in the Toxics Release Inventory (TRI) and the 16 PAHs that are priority pollutants in the Clean Water Act. Appendix A compares PAHs on additional lists.

There are 16 PAHs on the Washington State PBT list. Table 3 below lists the 16 PAHs on the Washington State PBT list with their chemical structures. These 16 PAHs meet the criteria in the PBT rule for persistence, bioaccumulation and toxicity.

Table 3 PAHs on the PBT list with chemical structures

CAS	Name	Chemical structure
56-49-5	3-methyl chlolanthrene	
194-59-2	7H-dibenzo(c,g)carazole	
218-01-9	chrysene	
205-99-2	benzo(b)fluoranthene	
191-24-2	benzo(g,h,i)perylene	
205-82-3	benzo(j)fluoranthene	
207-08-9	benzo(k)fluoranthene	
189-55-9	benzo(r,s,t)pentaphene	
192-65-4	dibenzo(a,e)pyrene	
189-64-0	dibenzo(a,h)pyrene	
226-36-8	dibenzo(a,h)acridine	
53-70-3	dibenzo(a,h)anthracene	
224-42-0	dibenzo(a,j)acridine	
206-44-0	Fluoranthene	
193-39-5	indeno(1,2,3-cd)pyrene	
198-55-0	Perylene	

The Agency for Toxic Substances and Disease Registry (ATSDR, 2005) used 17 PAHs to provide a good approximation of the harmful effects that are representative of the group. One reason these 17 PAHs were chosen by the ASTDR is because there is more scientific and technical information available on these compounds, including potential health impacts. More information on the chemical identity of these 17 PAHs can be found in the ASTDR report (ASTDR, 1995). Additional information on specific PAHs is also available from the International Agency for Research on Cancer (IARC, 1998; IARC, 2010) and the National Library of Medicine's Hazardous substances Database (HSDB, 2011).

In 2008, ATSDR announced in the Federal Register it was seeking input on a list of priority substances that will be evaluated for toxicological profile development (ASTDR, 2008). This list included the 17 PAHs mentioned above, added an additional 8, and included a separate entry for the whole class of PAH compounds (see Appendix A for a comparative list of PAHs)..

The US Environmental Protection Agency (EPA) included sixteen common PAHs in their list of 129 priority pollutants (EPA, 1979). Fifteen of these are the same as the ASTDR list except for the omission of benzo[e]pyrene and benzo[j]fluoranthene while naphthalene was added (see Appendix A for a comparative list of PAHs)..

The US National Institute of Health's Hazardous Substances Databank (HSDB, 2010) lists 43 PAHs of concern (see Appendix A for a comparative list of PAHs). The HSDB list includes coal tar which contains PAHs and a separate Chemical Abstract Services (CAS) number for the PAH class of compounds. For a more detailed description of coal tar and related compounds, see below in the section on Formation of PAHs in Industrial Point Sources. As indicated previously, PAHs most often appear in mixtures and the use of a unique CAS number for all PAHs is often warranted.

The US Department of Health and Human Services National Toxicology Program indicated in its 11th Report on Carcinogens (NTP, 2005) that 15 PAHs are "reasonably anticipated to be a human carcinogen." All but one of these 15 (7H-dibenzo[c,g]carbazole) appear among the 44 on the HSDB list. Interestingly, only 7 of these compounds are found on the ATSDR expanded list (see Appendix A for a comparative list of PAHs).

Manufacturing

Purified, individual PAHs are not currently produced in the US for commercial use (NTP, 2005). Historically, most PAHs were primarily manufactured either from oil or as a byproduct of the generation of coke and coal gas. In both instances, PAHs are present in a complex mix of chemicals and must be distilled from the source if individual PAHs are required. In many instances, PAHs are used as a complex mixture and no further process is necessary. Some of the major sources of PAHs are from combustion byproducts, which are not included as intentional manufacture.

Physical and Chemical Properties of PAHs

As pure chemicals, PAHs appear in a wide range of forms. They can be colorless, white, or pale yellow-green solids, which often have a faint, pleasant odor. As a rule, they are heavier than water. Most PAHs are solid at room temperature although some of the lighter molecular weight PAHs can release vapors at room temperature that have made them useful as pesticides as in the case with naphthalene historically used in moth balls. In general, PAHs are highly lipophilic and have very low solubility in aqueous solutions. Their solubility in organic solvents varies considerably depending upon the size of the PAH molecule. The lower molecular weight PAHs range from slightly soluble to insoluble in ethanol. Higher molecular weight PAHs are soluble in toluene, xylene and some are soluble in natural oils such as olive oil and mineral oil. Solubility should not be assumed however and each unique mixture must be evaluated separately. Some of the lower molecular weight PAHs have higher vapor pressures that contribute to the odor found with most PAH mixtures. The higher molecular weight compounds generally have low vapor pressures and do not readily volatilize.

Because of their structure, PAHs can be effectively targeted for specific reactions and can function as the precursor for numerous other chemicals. Pyrene, for example, is used as a starting material in the manufacture of optical brighteners and dyes. Anthracene is used to manufacture anthraquinone, an important intermediary in the production of dyes and is also used in the production of synthetic fibers and plastics (HSDB). Many other PAHs serve similar functions.

Some PAHs have alkyl and chlorine groups attached which changes the chemical characteristics, often in ways that can increase the opportunity for harm to the environment. For example, alkyl naphthalenes[10] are often found in the same petroleum fraction as naphthalene. The alkyl naphthalenes, due to their mobility and toxicity, are particularly damaging if released into the aquatic environment (NPS, 1997).

More specific details on the physical and chemical properties of the 17 individual PAHs identified by ATSDR can be found in the ASTDR report (ASTDR 1997). Additional information on specific PAHs is also available from the International Agency for Research on Cancer (IARC, 1998; IARC, 2010), PAHs: An Ecotoxicological Perspective (Douben, 2003) and the National Library of Medicine’s Hazardous Substances Database (HSDB, 2011).

As mentioned previously, however, except in laboratory research or in a few limited applications, PAHs rarely exist alone but are most commonly found in mixtures. The chemical characteristics of the mixtures can vary widely depending upon the source and what PAHs are included. Most mixtures range from a light brown liquid to a dark black viscous material with the consistency of molasses.

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[10] Alkyl naphthalenes are naphthalenes in which one or more of the hydrogen atoms have been replaced by another organic compound. For example, methyl naphthalene is naphthalene to which one of the hydrogen atoms has been replaced by a methyl (-CH_3) group.

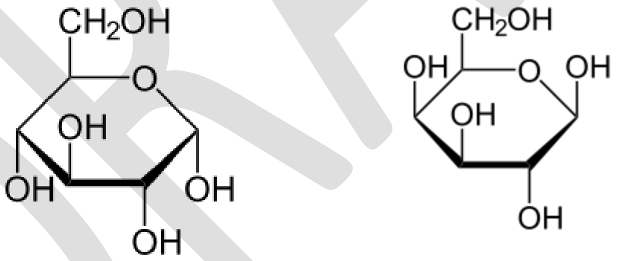
Fate and transport

PAHs are sensitive to light and undergo extensive photochemical reactions. Although most PAHs have a low vapor pressure, they readily absorb to particulate matter, which can be easily transported throughout the atmosphere. Volatile PAHs in the atmosphere have been found to exist for less than a day. Particles with PAHs absorbed, however, have been shown to remain in the atmosphere for 1-2 weeks. Suspended PAHs interact with radicals formed in the atmosphere, particularly hydroxy (OH-), ozone (O_3-) and nitro (NO_x). PAHs undergo degradation through formation of a wide range of photochemical reactions. Degradation products include highly mutagenic nitro-PAHs and nitro-PAH lactones as well as other chemicals for which no toxicity information exists. (Douben, 2003).

Due to their hydrophobic nature, PAHs exhibit a high affinity for particulates in air and water. PAHs tend to sorb to particles and eventually settle out into sediments, so the highest levels in the environment are often found in sediments.

Ring Structures Impact on Biological Systems

Ring compounds are common in organic chemistry and many play an important role in biology. For example, common sugars such as glucose and galactose (see structures below) contain six member rings of carbon and oxygen.



Fructose ($C_6H_{12}0_6$) Galactose ($C_6H_{12}0_6$)

Figure 6 Examples of common sugars

Many other biological compounds contain rings including important compounds such as:

- Hemoglobin used to transfer oxygen throughout the body.
- Thyroid hormones such as levothyroxine used to regulate metabolism.
- Neurotransmitters such as serotonin.

Due to their basic chemistry and stability, ring structures are important to life. Conversely, many toxic compounds also contain rings such as:

- Pesticides including DDT, the pyrethrins, parathion, etc.

- Flame retardants like the polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA).
- Benzene, itself, which has been identified as a carcinogen and can cause acute myeloid leukemia after longer-term exposure.

One of the reasons for the widespread appearance of ring compounds is the stability of the ring structure itself. Ring stability is tied to the ability of carbon to share its four electrons with other atoms.

Stability of Ring Structure

The simplest hydrocarbon (compounds containing hydrogen and carbon) is methane with four hydrogen atoms attached to the carbon atom:

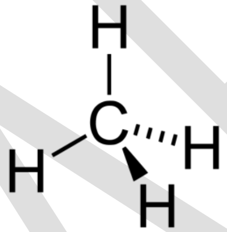


Figure 7 3-Dimensional structure of Methane

In this structure, methane forms a tetrahedron where each hydrogen atom is equally distant from each other and from the central carbon atom. The angle between any two hydrogen atoms is 109.5 degrees. This structure is maintained as the hydrocarbon complexity increases and more carbon atoms are joined together or the hydrogen atom is replaced with other elements. As long as this basic structure is maintained, the bond angles remain around the optimal angle of 109.5 degrees. The molecule is not stressed and the compound remains relatively stable.

When multiple chemical bonds are formed as is the case with aromatic compounds such as benzene, the bond angles decrease and the stress upon the molecule increases. The greater the stress, the more reactive the compound becomes. The bond angle for hydrogen and a carbon-to-carbon double bond increases to 121 degrees. The bond angle between hydrogen and a carbon-to-carbon triple bond increases to 180 degrees. The greater the deviation from the stable 109.5 degree angle, the greater the reactivity as the compound attempts to restore optimal conditions.

Ring structures, however, have some unique characteristics, which increases their stability. Cyclohexane is the most basic 6-carbon ring structure and the bonds between all of its carbon atoms are at 109.5 degrees, equivalent to the optimal angle described earlier for methane. In order to maintain this stability, cyclohexane does not maintain a flat structure but is arranged in what has become known as the ‘chair’ configuration:

Figure 8 Chair configuration of cyclohexane

By maintaining this structure, cyclohexane is able to increase its stability by maintaining optimal bond angles.

As some of the hydrogen atoms are removed from cyclohexane, however, and single carbon-to-carbon bonds are replaced by double bonds, the structure loses its optimal structure and stability. For example, cyclohexene (cyclohexane with two fewer hydrogen atoms and one carbon-to-carbon double bond) is explosive and unstable. Instability increases, however, until three double bonds are formed within the structure and the compound benzene is formed.

Benzene is the basic building block of PAH compounds (Fig. 3). Benzene (cyclohexa-1,3,5-triene) [11] is cyclohexane with three double bonds equally spaced throughout the molecule. Unlike previous 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. 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 as shown in Figure 3.

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 based upon similar structures like PAHs. 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 PAHs can be attributed to the unique ringed structure and sharing of electrons throughout the molecule.

PAH Grouping

PAHs are often broken down into two main groups based upon the number of fused carbon rings. Breaking PAHs into two groups is somewhat arbitrary, since there is a continuum of characteristics, and different researchers put them in slightly different groupings. One way of grouping them is to define low molecular weight PAHs as containing three or fewer fused rings while high molecular weight PAHs consist of four or more fused rings. Examples of low and high molecular weight PAHs appear in Table 4. There are no low molecular weight PAHs on the

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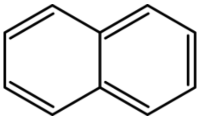
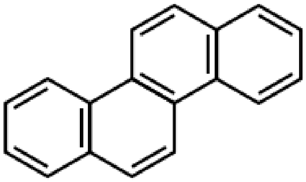
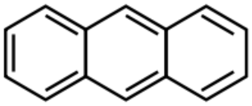
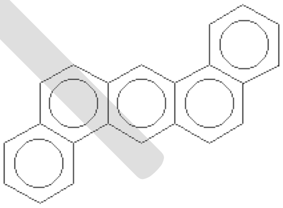
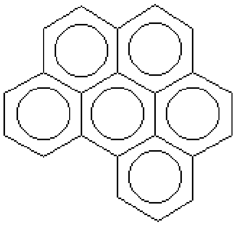
[11] The formal name for benzene describes a cyclical compound (cyclo) with six carbons (hexa) and three (tri) double bonds (ene). The '1,3,5' indicates which carbon atoms contain the double bond. Given the structure, the double bonds are between the carbons 1 & 2, 3 & 4 and 5 & 6.

Washington State PBT list, but the high molecular weight examples in Table 4 are on the PBT list.

Table 4: Low and High Molecular Weight PAHs

Low Molecular weight PAHs		High Molecular Weight PAHs	
Naphthalene ($C_{10}H_8$)		Chrysene ($C_{18}H_{12}$)	
Anthracene ($C_{14}H_{10}$)		Dibenzo(a,h)anthracene ($C_{22}H_{14}$)	
		Benzo(g,h,i)perylene ($C_{22}H_{12}$)	

There are two additional types of PAHs, parent and alkylated, both related to the general structure of PAHs. Parent PAHs are primarily unsubstituted PAHs that consist of benzene rings fused together. Alkylated PAHs are parent PAHs to which an alkyl[12] group has been added in place of one of the hydrogen atoms on a specific ring. It is often difficult to identify the source of both parent and alkylated PAHs as both petrogenic and pyrogenic sources can generate both classes (Burgess, 2009). Alkyl substituted PAHs persist in the environment for longer periods of time and often are more toxic than other PAHs (Irwin, 1997).

---

[12] Alkyl group – a functional group consisting solely of hydrogen and single-bonded carbon of indeterminate length and structure. The simplest alkyl group is the methyl group (CH_3-) and complexity can increase depending upon the number of carbons and amount of branching involved.

PAH Categories

PAHs can be primarily attributed to three categories based upon the way they are generated, i. e. biogenic (also called diagenic in some references), petrogenic, or pyrogenic.

Biogenic: Generated within living organisms.

Petrogenic: Generated from organic matter in ancient sediments/rocks by geologic conditions (temperature and pressure) over geologic time.

Pyrogenic: Generated from incomplete combustion (pyrolysis) of organic matter (e.g., wood, coal, petroleum, wastes).

Biogenic

Biogenic PAHS, also referred to as diagenic PAHs by some researchers (Crane et al, 2010, Roush & Maruo, 2009; Environment Canada, 1994) are the result of biological processes which generate PAH-like compounds. Examples include compounds like plant terpenes including retene, perylene and derivatives of phenanthrene and chrysene (Crane et al, 2010). Diagenic sources constitute a very small fraction of the PAHs generated or released into the environment (Environment Canada, 1994) and, therefore, are often omitted from consideration and, for that reason, we are not going to consider biogenic PAHs further.

Petrogenic

Petrogenic PAHs are formed in organic matter in ancient sediments/rocks by geologic conditions (temperature and pressure) over geologic times and thus are found today in crude oil, coal, organic shales and crude oil derivatives such as gasoline, diesel fuel, heating oil and asphalt (Burgess, 2009; Roush & Maruo, 2009). Petrogenic sources contain high levels of aromatic compound such as benzene, toluene, ethylbenzene and the three common xylenes (meta-, ortho-, and para-xylene) and typically also contain the PAH naphthalene.

The single largest use of crude oil is gasoline. Some of the fractions contain PAHs and can be a major route of PAH release to the environment. The following is the breakdown of products from a barrel of oil with the approximate percentage of the total (Refining Process Services Inc, 2001):

Table 5: Oil products

Product	Per cent (%)
Motor Gasoline	44
Distillate	17.5
Jet Fuel	8.4
Residual	4.2
Other Products	25.9

Copied from Refining System Resources, Inc, 2001

Petrogenic sources of PAHs characteristically have a higher amount of alkyl substituted PAHs than pyrogenic sources. Sources of petrogenic PAHs released to the environment include:

- Oil spills, leaks, drips, etc.
- Tire particles
- Asphalt or asphalt sealant

Pyrogenic

Pyrogenic primarily refers to PAHs generated from the combustion of organic material including petroleum, coal, wood, forest fires, etc. Pyrogenic PAHs are typically released directly into the atmosphere, forming soot and carbon black in the process (Burgess, 2009). The production of coke or gas from coal or oil also is also a petrogenic source of PAHs (Roush & Maruo, 2009). More information on the generation of coke and coal gas is provided in the section on the formation of PAHs in industrial facilities. Typically, pyrogenic PAHs are formed under high temperatures and low oxygen conditions (Irwin, 1997). Other factors affect which PAHs are created including type and amount of fuel, temperature and combustion length and availability of oxygen (Environment Canada, 1994). Sources of pyrogenic PAHs released to the environment include:

- Wood burning stoves
- Gasoline and diesel combustion from vehicles and equipment
- Coal tar and its products including some consumer products such as shampoos, coal tar sealant and other products for waterproofing and sealing
- Roofing
- Forest and grass fires

Burning petrogenic PAHs, such as petroleum oil, creates pyrogenic PAHs. For this reason, used motor oil has pyrogenic PAHs, even though the original motor oil contained a lower concentration of petrogenic PAHs.

Pyrolysis and PAH Generation

Pyrolysis is a chemical process in which a chemical compound is transformed into a wide range of products through the use of heat during industrial manufacture and processing. Pyrolysis is extensively used to alter organic molecules although inorganic compounds can also be changed through heat. For the purposes of the following discussion, only the impacts of pyrolysis upon organic molecules will be discussed with the subsequent generation of complicated molecules including PAHs.

During pyrolysis, organic molecules undergo three primary reactions (Parker, 1993):

1. Dissociation into free radicals.
2. Elimination of a small molecule.
3. Carbon-carbon bond fission.

All three reactions play an important role in the formation of PAHs during pyrolysis.

Dissociation into free radicals

At temperatures ranging from 1,100 - 1,500 degrees Fahrenheit, chemical compounds are provided with sufficient energy during pyrolysis to break bonds and form free radicals. Free radicals are primarily charge neutral compounds although free radicals have been identified in charged species as well. Free radicals are formed when compounds become unstable due to unfilled electron shells. Most elements have a set number of electrons that can be accepted, released or shared in order to create a stable structure. In the case of free radicals, specific atoms or ions within a compound can have electrons that fall into one of these three categories, i.e. they can be 1) shared, 2) released or 3) added to in order to complete their outermost shell. All three alternatives will ultimately increase the stability of the compound although some compounds will undergo further reactions. Radicals, therefore, are very reactive compounds and, in standard chemical shorthand, are denoted with a simple dot for every electron that is available for reaction. Radicals exist only for short periods of times and can be used to synthesize a wide range of compounds depending upon the conditions at the point in which they are generated.

During pyrolysis, radicals form constantly, react and reform until the conditions that led to their generation no longer exist or they have been reduced to stable compounds. Researchers are not able to identify all of the free radicals created during pyrolysis due to the complexity of the reactions involved and technology limitations. Below are several examples to illustrate the most common processes.

In the case of simple alkanes (chemicals with single bonds consisting of only carbon and hydrogen), free radical formation occurs through the loss of hydrogen or cleavage of the molecule into smaller fractions. For example, the simple alkane, butane (C_4H_{10}), can undergo various reactions during pyrolysis. Two examples, loss of a hydrogen atom and cleavage into smaller radicals, are shown below:

Loss of a hydrogen radical from butane:

$$CH_3CH_2CH_2CH_3 \Rightarrow CH_3CH_2CH_2CH_2\bullet + H\bullet$$

Butane

Butane Radical

Hydrogen Radical

Cleaving of butane into smaller radicals:

$$CH_3CH_2CH_2CH_3 \Rightarrow 2CH_3CH_2\bullet$$

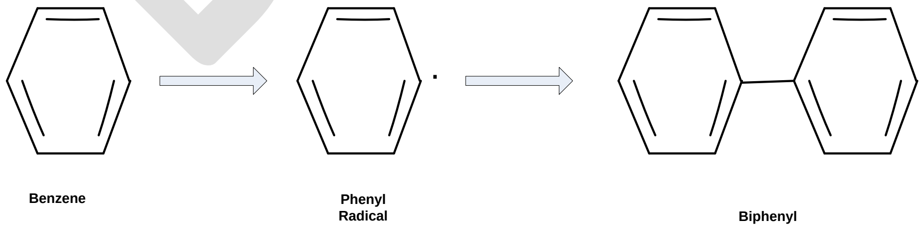
Butane

Ethane Radicals

Radicalization of longer chains can also lead to the formation of cyclical compounds that may ultimately lead to complicated compounds such as PAHs. As described previously, radicals with 6 carbon atoms can easily form cyclical compounds like cyclohexane due to the stability of the boat structure of such compounds. In addition, small radicals can undergo multiple reactions that result in ringed compounds.

Pyrolysis of simple aromatic compounds (chemicals comprised primarily of carbon and hydrogen that contain at least one carbon-to-carbon double bond) also produces radicals that give rise to other, more complicated compounds. For example, simple aromatic compounds such as benzene and naphthalene found commonly in fuels can undergo radicalization forming simple biphenyls as shown below (Parker, 1993):

Formation of biphenyl through pyrolysis of benzene:

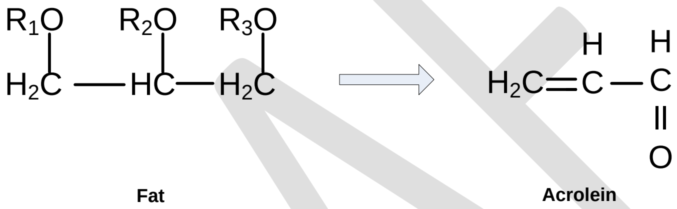


These reactions are only shown to provide an example of the types of reactions possible. Numerous compounds are formed during any pyrolysis action through radical formation and the exact compounds formed are dependent upon a number of criteria including compounds in the fuel, access to oxygen, temperatures at which the pyrolysis occurs, presence of catalysts, etc.

Elimination of a small molecule

Another mechanism that leads to larger molecules is the release of a portion of the compound as a separate compound. In this process, a larger molecule can undergo several steps in which one or more radicals form to ultimatly create a carbon-to-carbon double bond and the release of other compounds. These other compounds are then available for continued radicalization and reaction. An example of this process is the generation of acrolein, a complicated alkene (organic compound with at least one carbon-to-carbon double bond) responsible for the smell associated with cooked meat (Parker, 1993). This process cleaves fat at the oxygen bonds and forms the alkene acrolein:

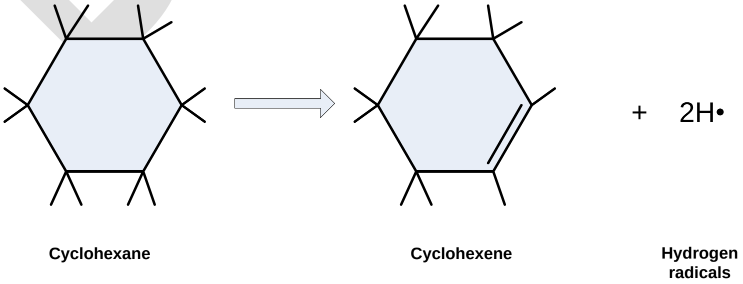
Creation of the alkene Acrolein from fat



A wide range of compounds based upon the previously attached ‘R’ groups are also formed and are available for other reactions during pyrolysis.

This process has been shown to be important in the generation of PAHs. Cyclohexane (CAS 110-82-7) is a common component in diesel fuel. During pyrolysis, cyclohexane releases hydrogen, leading to the formation of the aromatic compound cyclohexene. Cyclohexene has been shown to be the starting molecule in a series of chain reactions that lead to the formation of PAHs and are responsible for increased soot generation during diesel combustion (Slavinskaya, 2009).

Formation of cyclohexene from cyclohexane:



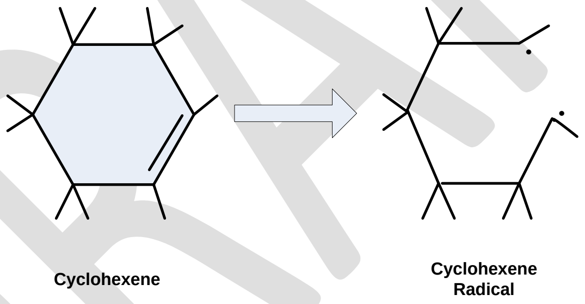
The number and types of the compounds created by the elimination of smaller molecules from larger organic compounds are numerous and the above example was only meant to describe the general process. More complicated and detailed reactions are possible including the formation of PAH compounds.

Carbon-to-carbon bond fission

Lastly, carbon-to-carbon bonds can be broken during pyrolysis including alkanes, alkenes and cyclical compounds. Carbon-to-carbon bonds are very stable but during pyrolysis, carbon bonds can be broken and a wide range of chemicals generated. It is outside the scope of this document to list or discuass all of the possible reactions that occur during pyrolysis. Some common reactions do occur and will be used to describe potential reactions that occur and lead to the formation of PAHs.

During pyrolysis, the carbon backbone of organic acids, for example, can lead to the release of carbon dioxide and the formation of alkenes. Cleavage of ring structures leads to the formation of complicated compounds, many of which are the precursors of PAHs. Cyclohexene formed during other pyrolysis steps can be cleaved as shown in the following reaction and used as the formation for a wide range of PAHs:

Cleaving of cyclohexene



Through numerous pathways and intermediates, more complicated compounds including a wide range of PAHs are formed. However, it is important to understand that the pathways that give rise to PAHs are still being investigated. The possible reactions during pyrolysis are varied and are dependent upon the fuel source and pyrolysis conditions.

Further information on these and other potential reactions which give rise to PAHs can be found in the scientific literature (Richter, 2000a & 200b; Kidder, 2001; Wang, 2002; Britt, 2004; Westbrook, 2007; Lindstedt, 2009) and numerous publications (Parker, 1993; Douben, 2003; Atkinson, 2006). These sources are not exhaustive though extensive work has been done in this area; however, they are included to show the depth and breadth of work being conducted in the issue of PAH formation.

Formation of PAHs in industrial point sources

Incomplete Combustion

Point sources of PAHs found in WA state include petroleum refineries, power plants (coal and oil), coal-tar production plants, coking plants, bitumen and asphalt production plants, paper mills, wood products manufacturers, aluminum production plants and industrial machinery manufacturers. These emissions are usually to air and, other than from petroleum related industries and aluminum smelters, are typically a result of the combustion of petroleum-based fuels.

Aluminum smelters

Aluminum smelting uses the Hall- Heroult process to extract aluminum from alumina ore. In this process, aluminum oxide is combined with sodium hexafluoroaluminate and heated until the mixture melts. An electrical current is passed through the mixture causing pure aluminum metal to be deposited at the cathode. The oxygen is combined with carbon from the anode and released as carbon dioxide. This electrolytic process requires a major source of electrical energy and consumes anodes in the reaction. The anodes are made from coal tar pitch and carbon and PAHs are released during forming and baking of the anodes. Both the forming and baking emissions are controlled using EPA required Maximum Achievable Control Technoligy (MACT). Unbaked anode, scrap that is not remade into new anodes, is disposed of as a state-only hazardous waste as required by Washington State’s Dangerous Waste Regulations (WAC 173-303; see regulatory section for more details) due to PAHs. Until recently, there were 7 major aluminum smelters in Washington. Currently, only 2 smelters are still operating.

Coal Tar

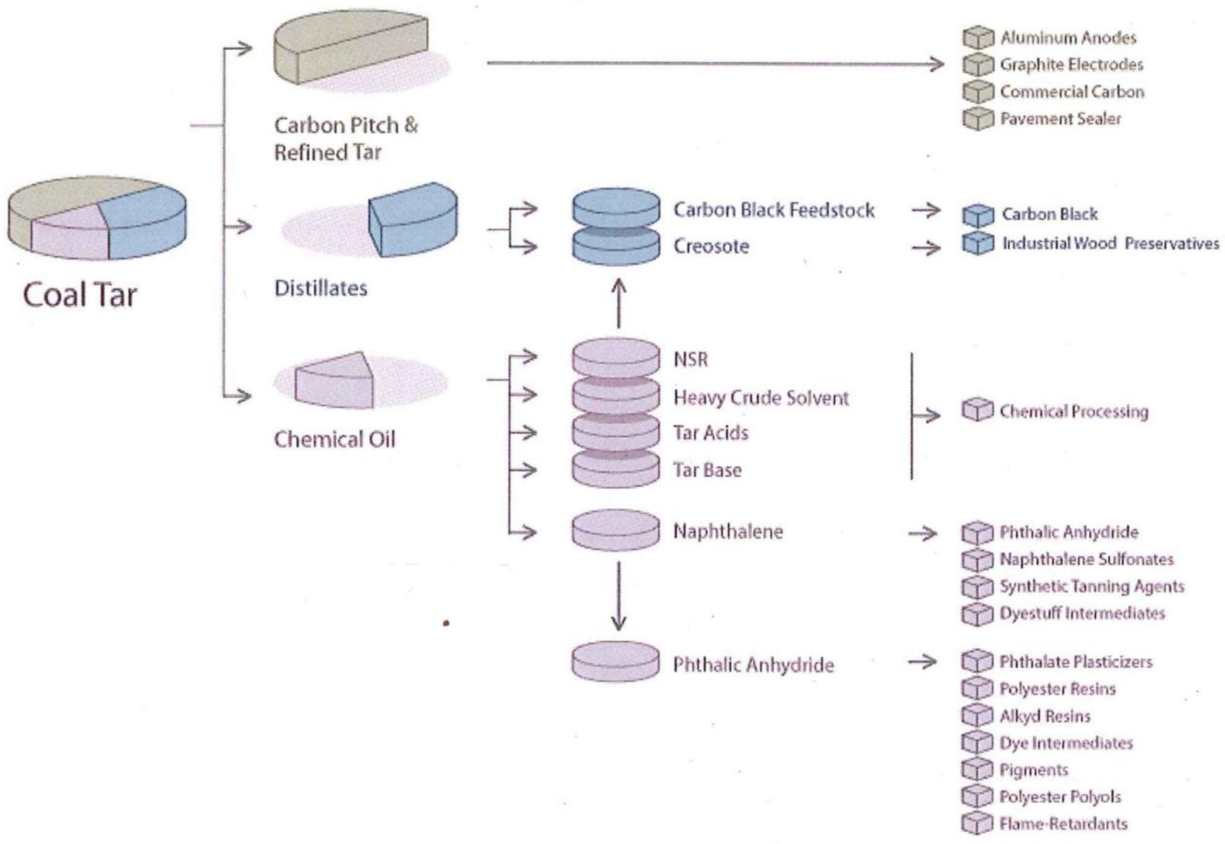
The production of coal tar is another source of PAHs. Coal tar is the liquid material leftover after coal has been processed to form coke or coal gas. Coke is created when volatile components are driven from coal either in an oxygen-free furnace or at high temperatures in the vicinity of 2,000 degrees Celsius. Coke is primarily used either as a fuel or as an ingredient in the smelting of iron ore to produce steel and other iron alloys.

Coal gas is produced by distilling coal to generate a gaseous mixture of hydrogen, methane, carbon monoxide and other flammable gases. Coal gas was used extensively in the late 19th century as a fuel source for lighting prior to the introduction of electricity and several coal gasification plants were built throughout the US. A major coal gas facility was build on the North shore of Lake Union in Seattle and operated for many years to provide gas to the developing community. The plant closed down in 1956 after the demand for coal gas decreased due to the development of natural gas supplies. The site was eventually purchased by the City of Seattle and converted into Gas Works Park. To this day, however, the land around Gas Works Park remains heavily contaminated with PAHs from these processes (Ecology, 2003).

Typically coal tar is a highly viscous black or brown sludge-like material that has a strong organic smell. It can be used as a fuel source and historically was used in the manufacture of ‘tarmac’ roads. This use has decreased recently and coal tar is no longer widely used on roads in the United States.

Coal tar has also been used in some medical applications, particularly shampoos, soaps or salves. Coal tar has been used to treat skin diseases such as psoriasis and dandruff. It has also proven to be useful in the treatment of head lice. Concerns have surfaced, however, over the increased carcinogenicity risks and adverse dermal and respiratory effects of coal tar and its use is decreasing for these applications.

Coal tar undergoes fractionation through distillation and has numerous uses. The separation of coal tar into three primary fractions (Carbon Pitch and Refined Tar, Coal Tar Distillates and Coal Tar Chemical Oil) and the use of each fraction are shown in the following figure:



Copied from Koppers’, a leading distiller of coal tar, website (http://www.koppers.com/htm/PandS_Proc_Main.html), accessed 2/28/2011

Figure 9 Coal Tar Fractions

Coal tar is used directly in the manufacture of products such as anodes used in aluminum smelting process and as a feedstock for a wide range of plastic resins.

Creosote

Creosote is a distillate of coal tar used as a wood preservative (Figure 9). It’s chemical composition varies depending on the source, distillation, and fraction removed. Stratus Consulting summarized several studies of coal tar composition for NOAA Fisheries (Stratus 2006), focusing on the EPA priority pollutants. The World Health Organization includes more individual PAHs in its report (WHO 2004). Creosote is a mixture of hundreds of chemicals, but PAHs are the major class of compounds present. Creosote can be up to 90% non-heterocyclic PAHs by weight (WHO 2004) and are at least 75% PAHs (ATSDR 2002). Other classes of compounds in creosote include alkyl-PAHs, phenolics, heterocyclic PAHs, and aromatic amines (Stratus 2006).

PAHs and Human Health

Exposure

Everyone is exposed to chemical mixtures that contain PAHs

The combustion or pyrolysis of organic material results in the formation of mixtures that contain many different chemicals including polycyclic aromatic hydrocarbons (PAHs). These mixtures often contain numerous distinct PAHs, PAH derivatives, other chemicals, and materials such as particulates.[1-3] Many of these individual components may contribute to the toxicity of the mixture. Examples of common activities that produce PAHs are the use of gasoline and diesel engines, wood burning, and smoking cigarettes.[4] People are exposed to PAH-containing mixtures such as vehicle exhaust or coal tar, and not to individual PAHs.[4]

Everyone is exposed to PAHs, which are present in food and found throughout the environment in air, water, soil, and dust.[4] PAHs are lipid soluble and readily absorbed through the skin, respiratory tract, and gastrointestinal tract.[4] Exposure to four PAHs (fluorine, naphthalene, phenanthrene, and pyrene) was evaluated in a representative sample of the U.S. population, and metabolites indicative of exposure were found in 99 - 100% of those tested.[5] Although none of these is on the Ecology's list of persistent, bioaccumulative, and toxic chemicals (PBTs), they are found in PAH-containing mixtures such as wood smoke, diesel exhaust, and power plant emissions that also contain many of the PAHs on the list. People who smoke and workers in certain occupations tend to have greater than normal exposure to PAHs.[4]

Many common human activities release PAHs into the environment

Many human activities cause PAHs to be released into the air where people can breathe them in. The main sources of exposure can be different for different people. Some of the more significant environmental airborne exposures[4] may come from:

- Gasoline and diesel motor vehicle emissions.
- Emissions from oil- and coal-fired power plants.
- Emissions from certain industrial facilities.
- Burning of organic material for disposal.
- Burning of wood for home heating and other purposes.
- Residential cooking and heating.
- Tobacco smoke.

People who live or work near PAH-emitting power plants or industrial facilities, or heavily used transportation corridors are likely to have greater exposure to airborne PAHs than people who don't.[4] People who burn wood for home heating (and their neighbors), are likely to have more exposure to airborne PAHs than those who don't.[4] People who smoke tobacco products, and people who live or work with smokers, are likely to have more exposure to PAHs than those who don’t.[4]

Natural events such as volcano eruptions and forest fires also release PAHs into the atmosphere.

Some PAHs that become airborne can later fall to earth, contaminating the ground, water bodies, and food. People can be exposed to these PAHs by ingesting the contaminated soil, dust, water, or food.

A discussion of major sources responsible for the release of PAHs to the environment in Washington can be found in Chapter X of this document.

Some consumer and industrial products contain PAHs

PAHs are present in many consumer and industrial products, usually as contaminants that serve no useful function. They are formed during manufacturing when organic materials are heated.

People can be exposed directly to the PAHs when they use certain products. For example, many foods contain PAHs that are ingested when the food is consumed;[4,6] coal tar medications contain PAHs that are absorbed through the skin;[3] new and used motor oil contain PAHs that can be absorbed when oil gets on the skin;[7] coal tar pavement sealers contain PAHs that can be inhaled or absorbed through the skin.[3]

For other products, exposure to the PAHs is not from the use of the product by the consumer. Instead, PAHs from the product first enter the environment where they contribute to the overall contaminant load to which people are exposed. For example, coked coal that is burned for power generation releases PAHs into the air where they are inhaled; motor oil that leaks from vehicles can contaminate soil and water with PAHs that can be ingested or absorbed through the skin; PAHs in dust generated from motor vehicle tires can be ingested or inhaled.

Some workers are at risk of greater-than-normal exposure to PAHs

People in some occupations have greater than normal exposure to PAHs because their work involves greater than normal exposure to vehicle exhaust, to certain industrial processes, or to certain products or byproducts that contain significant amounts of PAHs.[3,4,8] Those workers include, but are not limited to:

- aluminum workers,
- asphalt workers,
- carbon black workers,
- chimney sweeps,
- coal-gas workers,
- coke oven workers,
- graphite electrode workers,
- machinists,
- mechanics (auto and diesel engine),

- printers,
- road (pavement) workers,
- roofers,
- steel foundry workers,
- tire and rubber manufacturing workers, and
- workers exposed to creosote, such as
    - carpenters,
    - farmers,
    - railroad workers,
    - tunnel construction workers, and
    - utility workers.

The toxicity to people of several PAH-containing mixtures has been established by studying workers in some of these occupations.

Comparing the amount of PAH exposure from major sources

The importance of various sources of exposure to PAHs is expected to differ from person to person due to factors such as diet, personal habits like smoking, occupation, and location relative to industrial emissions. Estimates of typical exposures from various sources and media have been published.[6,9-11]

Food accounts for 80 to 95% of PAH exposure for people who do not smoke and who do not have significant exposure on the job.[6] Many foods are heated during processing or preparation, resulting in the formation of PAHs.[6] Some foods may acquire PAHs when they are smoked or are exposed to environmental contamination.[6] For the average consumer, the three food groups that contribute most to dietary exposure appear to be cereals, vegetables/nuts, and meat.[6] For people who regularly eat shellfish, PAH exposure from seafood may contribute 25% or more of dietary exposure.[6] PAHs are commonly detected in breast milk, which may be a source of exposure for newborns and infants.[4]

Inhalation of PAHs in air is estimated account for about 10% of exposure.[6] Two major contributors of airborne PAHs in the Puget Sound region of Washington are exhaust from combustion engines and wood smoke from home heating.[12] Industrial emissions, outdoor burning, small engine use, and creosote-treated wood may also contribute to the atmospheric load.[4]

PAHs in water and soil are estimated to make only a minor contribution to most people's exposure.[4,6] However, soil, sediment, and water can become contaminated from spills and industrial releases, resulting in increased exposure for some people who live, fish, or work nearby.

Ointments and shampoos that contain coal tar are sometimes recommended for the treatment of certain skin conditions. The medicinal use of these products increases exposure to PAHs.[3]

For smokers, PAH exposure from tobacco smoke can equal or exceed that from food. People who live or work with smokers can have greater than normal exposure to PAHs.[6,10] In 2009, 14.8% of adults (about 750,000 people) in Washington were cigarette smokers.[13] A 2010 survey found that 1.7% of 6th graders and 19.6% of 12th graders in Washington had smoked in the previous 30 days.[13]

As noted in the previous section, some occupations can be associated with greater than normal PAH exposure. If appropriate worker protection is not employed, exposures can be significantly greater than those from food.

Toxicity

Some individual PAHs are toxic

There are hundreds of different PAHs, but only some of these individual compounds have been evaluated for toxic effects. Although few studies of the toxicity of individual PAHs have been conducted in humans, many such have been performed in laboratory animals and *in vitro* test systems.

Several PAHs have been found to cause cancer in animals. All 16 individual chemicals that are included in of this CAP have been assessed for carcinogenicity by one or more independent scientific bodies. Their conclusions are presented in Table 6.

Table 6: Carcinogenicity of selected PAHs

	NTP[14] *	IARC[8,15,16] #	IRIS[17-23] +	Prop 65[24] &
3-Methyl chlolanthrene	-	-	-	carcinogen
7H-Dibenzo(c,g)carbazole	Anticipated **	2B	-	carcinogen
Chrysene	-	2B	B2	carcinogen
Benzo(b)fluoranthene	Anticipated	2B	B2	carcinogen
Benzo(g,h,i)perylene	-	3	D	-
Benzo(j)fluoranthene	Anticipated	2B	-	carcinogen
Benzo(k)fluoranthene	Anticipated	2B	B2	carcinogen
Benzo(r,s,t)pentaphene	Anticipated	2B	-	carcinogen
Dibenzo(a,e)pyrene	Anticipated	3	-	carcinogen
Dibenzo(a,h)pyrene	Anticipated	2B	-	carcinogen
Dibenz(a,h)acridine	Anticipated	2B	-	carcinogen
Dibenz(a,h)anthracene	Anticipated	2A	B2	carcinogen
Dibenz(a,j)acridine	Anticipated	2B	-	carcinogen
Fluoranthene	-	3	D	-
Indeno(1,2,3-cd)pyrene	Anticipated	2B	B2	carcinogen
Perylene	-	3	-	-

Classification by scientific organizations of the likelihood that the chemicals on the PBT list could cause cancer in humans. (*) NTP = National Toxicology Program. (**) = Reasonably anticipated to be a human carcinogen. (#) IARC = International Agency for Research on Cancer. (+) IRIS = United States Environmental Protection Agency Integrated Risk Information System. (&) Prop 65 = California Environmental Protection Agency Proposition 65 List of Chemicals Known to the State to Cause Cancer or Reproductive Toxicity.

All but three of the chemicals on the PBT list (benzo(g,h,i)perylene, fluoranthene, and perylene) have been classified as carcinogens by at least one of these bodies. Much of the evidence for carcinogenicity for the remaining 13 chemicals on the list comes from studies where the chemical was introduced topically by spreading on the skin, direct application to the trachea, or injection into tissues.[4] However, there is evidence that some of these compounds can cause tumors when ingested.[4] Also, while there are few studies that examined the effects from inhalation of these chemicals, intratracheal application of dibenz(a,h)anthracene or 7H-dibenzo(c,g)carbazole induced respiratory tumors, suggesting that these compounds may be carcinogenic when inhaled.[4]

Compared to the data on cancer, information about other toxic effects of the 16 chemicals on the PBT list is limited and the implications for human health are less clear. In one study, several of the listed chemicals appeared to have immunosuppressive properties.[25] In other studies, relatively large oral doses of few of the compounds affected the livers of laboratory animals.[4] When injected into laboratory animals, 3-methylcholanthrene affected reproductive parameters,[26] and dibenz[a,h]anthracene caused increased fetal death and reduced growth rate.[16]

One of the best studied PAHs, benzo(a)pyrene, is not on the PBT list because Ecology determined that it does not meet the criterion for bioaccumulation. However, it is usually present in PAH mixtures and is often used as the index PAH to which the carcinogenicity of other PAHs is compared.[27] Benzo(a)pyrene has been found to induce tumors when inhaled, ingested, or applied topically.[4] Compared to benzo(a)pyrene, one of the PAH PBTs appears to have greater cancer potency while ten others have less.[27]

There are many unanswered questions and data gaps in our knowledge of PAH toxicity because most of the compounds have not undergone extensive toxicity testing and many potential noncancer effects have not been adequately evaluated. However, the carcinogenicity of the several of the chemicals on the PBT list has been well documented.

Some mixtures that contain PAHs are toxic to humans

Many activities and processes result in the formation of complex mixtures that contain PAHs and other toxic chemicals and materials. Health problems have been documented in people and laboratory mammals exposed to some of these mixtures.

The types and concentrations of the individual chemicals (including PAHs) that are formed depend on factors such as the composition of the starting materials, the temperature at which the process occurs, and the amount of oxygen available, which can be different for each mixture. For substances such as coal tar or creosote, the chemical composition can vary significantly from batch to batch.[3]

Several PAH-containing mixtures have been assessed for carcinogenicity by one or more independent scientific bodies. Their conclusions, based mostly on studies in workers and laboratory animals, are presented in Table 7.

Table 7 Carcinogenicity of selected PAH mixtures

	NTP[14] *	IARC[28,29] #	IRIS[30-32] +	Prop 65[24] &
Coal tar	Known	1	-	carcinogen
Coal tar pitches	Known	1	-	-
Coke oven emissions	Known	1?	A	carcinogen
Creosote	-	2A	B1	carcinogen
Diesel exhaust	Anticipated **	2A	Likely to be carcinogenic to humans	carcinogen
Gasoline engine exhaust	-	2B	-	carcinogen
Mineral oils (untreated and mildly treated)	Known	1	-	carcinogen
Smokeless tobacco	Known	1	-	carcinogen
Tobacco smoke	Known	1	-	carcinogen

Classification by scientific organizations of the likelihood that the PAH-containing mixtures could cause cancer in humans. (*) NTP = National Toxicology Program. (**) = Reasonably anticipated to be a human carcinogen. (#) IARC = International Agency for Research on Cancer. (+) IRIS = United States Environmental Protection Agency Integrated Risk Information System. (&) Prop 65 = California Environmental Protection Agency Proposition 65 List of Chemicals Known to the State to Cause Cancer or Reproductive Toxicity.

There are thousands of variations on these mixtures and only a few have been evaluated for toxicity. Since many of the individual PAHs in these mixtures have been shown to cause cancer, it is assumed that they contribute to the carcinogenicity of the mixtures as a whole. But while PAHs are expected to play a role in tumor development, their exact contribution to the carcinogenicity of any particular mixture is usually not known since the mixtures also contain many other cancer-causing chemicals. This applies both to PAHs in general and to the 16 specific PAHs and PAH derivatives on the PBT list.

Noncancer effects have been documented for some of these mixtures, but there is little or no overlap between these effects and the health outcomes that have been documented for the 16 compounds on the PBT list. For example, inhalation of particulate matter from common sources such as diesel exhaust and wood smoke can reduce lung function and contribute to cardiovascular disease.[33,34] However, the role of PAHs in these effects, if any, is not known.

IARC has evaluated certain occupations where workers are exposed to PAH-containing mixtures and concluded:

- There is *sufficient evidence* in humans for the carcinogenicity of occupational exposures during coal gasification. (lung cancer)[8]
- There is *sufficient evidence* in humans for the carcinogenicity of occupational exposures during coke production. (lung cancer)[8]
- There is *sufficient evidence* in humans for the carcinogenicity of occupational exposures during coal-tar distillation. (skin cancer)[8]

- There is *sufficient evidence* in humans for the carcinogenicity of occupational exposure as a chimney sweep. (cancer of the lung, esophagus, bladder, skin, scrotum, and hematolymphatic system)[8]
- There is *sufficient evidence* in humans for the carcinogenicity of occupational exposures during paving and roofing with coal-tar pitch. (cancer at several sites)[8]
- There is *sufficient evidence* in humans for the carcinogenicity of occupational exposures during aluminium production. (lung and bladder cancer)[28]
- There is *limited evidence* in humans for the carcinogenicity of occupational exposures during carbon electrode manufacture.[8]

Summary – Would controlling PAH releases benefit human health?

All people in Washington are exposed to PAHs from a variety of sources, and there is concern that they contribute to cancer and, potentially, other health problems. When the 16 PBT chemicals addressed in this document are formed by combustion or pyrolysis, they represent an inseparable component of a complex mixture. In practical terms, controlling the human and environmental health hazards of the16 PBTs can be accomplished only by reducing exposure to the mixture as a whole. Many common mixtures that contain these 16 chemicals have been shown to cause a variety of health problems. Food is the largest exposure source for most people, but food-related health effects from PAHs have not been adequately investigated and the true health hazard, if any, is notunderstood. On the other hand, particulate matter from common sources such as diesel exhaust and wood smoke is known to be harmful, reducing lung function and increasing the risk of cardiovascular disease and lung cancer. While the carcinogenicity of PAHs suggests that they play a role in the development of lung cancer from exposure to particulate matter, the contribution to other health effects is not clear. However, controlling exposure to mixtures such as diesel exhaust and wood smoke would reduce the occurrence of many different health problems and therefore have public health benefits that go beyond addressing only the PAHs.

Human Health References

1. United States Environmental Protection Agency. 2002. Health Assessment Document for Diesel Engine Exhaust. EPA/600/8-90/057F. http://www.epa.gov/airtoxics/dieselfinal.pdf Accessed August 1, 2011.
2. Fowles, J and Bates, M. 2000. The chemical Constituents in Cigarettes and Cigarette Smoke: Priorities for Harm Reduction. A Report to the New Zealand Ministry of Health. Epidemiology and Toxicology Group, ESR: Kenepuru Science Centre, PO Box 50-348, Porirua, New Zealand. http://www.moh.govt.nz/moh.nsf/pagescm/1003/$File/chemicalconstituentscigarettespriorities.pdf Accessed August 1, 2011.
3. Agency for Toxic Substances and Disease Registry. 2002. Toxicological Profile for Wood Creosote, Coal Tar Creosote, Coal Tar, Coal Tar Pitch, and Coal Tar Pitch Votaliles. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.
4. Agency for Toxic Substances and Disease Registry. 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs) (Update). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.
5. Department of Health and Human Services, Centers for Disease Control and Prevention. 2009. Fourth National Report on Human Exposure to Environmental Chemicals. http://www.cdc.gov/exposurereport/pdf/FourthReport.pdf Accessed August 1, 2011.
6. European Food Safety Authority. 2008. The EFSA Journal 724: 1-114. Polycyclic Aromatic Hydrocarbons in Food. Scientific Opinion of the Panel on Contaminants in the Food Chain. (Question No. EFSA-Q-2007-136). Adopted on 9 June 2008. http://www.efsa.europa.eu/en/efsajournal/doc/724.pdf Accessed August 1, 2011
7. Agency for Toxic Substances and Disease Registry. 1997. ToxFAQ – Used Mineral-Based Crankcase Oil. http://www.atsdr.cdc.gov/toxfaqs/tfacts102.pdf Accessed August 1, 2011.
8. International Agency for Research on Cancer. 2010. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 92. Some Non-heterocyclic Polycyclic Aromatic Hydrocarbons and Some Related Exposures. http://monographs.iarc.fr/ENG/Monographs/vol92/mono92.pdf Accessed August 1, 2011.
9. Menzie, CA, Potocki, BB, and Santodonato, J. 1992. Exposure to carcinogenic PAHs in the environment. Enviro. Sci. Technol. 26(7): 1278-1284.
10. Phillips, DH. 1999. Polycyclic aromatic hydrocarbons in the diet. Mutation Research 443: 139-147.
11. Lioy, PL, Waldman, JM, Greenberg, A, Harkov, R., Pietarinen, C. 1988. The total human environmental exposure study (THEES) to benzo(a)pyrene: comparison of the inhalation and food pathways. Arch. Env. Health 43(4): 304-312.
12. Washington State Department of Ecology. 2010. Control of Toxic Chemicals in Puget Sound, Phase 3: Study of Atmospheric Deposition of Air Toxucs to the Surfact of Puget Sound. Publication No. 10-02-012. http://www.ecy.wa.gov/pubs/1002012.pdf Accessed August 1, 2011.

13. Washington State Department of Health. Tobacco Prevention and Control Program. Washington Tobacco Facts 2010. http://www.doh.wa.gov/tobacco/other/TobFacts-Public.pdf Accessed August 1, 2011.
14. U.S. Department of Health and Human Services, National Toxicology Program. Report on Carcinogens. Twelfth Edition. 2011. http://ntp.niehs.nih.gov/ntp/roc/twelfth/roc12.pdf Accessed August 1, 2011.
15. International Agency for Research on Cancer. 1973. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 3. Certain Polycyclic Aromatic Hydrocarbons and Heterocyclic Compounds. http://monographs.iarc.fr/ENG/Monographs/vol3/volume3.pdf Accessed August 1, 2011.
16. International Agency for Research on Cancer. 1983. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 32. Polynuclear Aromatic Compounds, Part 1, Chemical, Environmental, and Experimental Data. http://monographs.iarc.fr/ENG/Monographs/vol32/volume32.pdf Accessed August 1, 2011.
17. United States Environmental Protection Agency. Integrated Risk Information System entry for: Chrysene. <http://www.epa.gov/iris/subst/0455.htm> accessed 8/1/2011
18. United States Environmental Protection Agency. Integrated Risk Information System entry for: Benzo[b]fluoranthene. <http://www.epa.gov/iris/subst/0453.htm> Accessed August 1, 2011.
19. United States Environmental Protection Agency. Integrated Risk Information System entry for: Benzo[g,h,i]perylene. <http://www.epa.gov/iris/subst/0461.htm> Accessed August 1, 2011.
20. United States Environmental Protection Agency. Integrated Risk Information System entry for: Benzo[k]fluoranthene. <http://www.epa.gov/iris/subst/0452.htm> Accessed August 1, 2011.
21. United States Environmental Protection Agency. Integrated Risk Information System entry for: Dibenz[a,h]anthracene. <http://www.epa.gov/iris/subst/0456.htm> Accessed August 1, 2011.
22. United States Environmental Protection Agency. Integrated Risk Information System entry for: Fluoranthene. <http://www.epa.gov/iris/subst/0444.htm> Accessed August 1, 2011.
23. United States Environmental Protection Agency. Integrated Risk Information System entry for: Indeno[1,2,3-cd]pyrene. <http://www.epa.gov/iris/subst/0457.htm> Accessed August 1, 2011.
24. California Environmental Protection Agency. Chemicals Known to the State to Cause Cancer or Reproductive Toxicity, July 29, 2011. http://www.oehha.ca.gov/prop65/prop65_list/files/P65single072911.pdf Accessed August 1, 2011.
25. Silkworth, JB, Lipinskas, T, Stoner, CR. 1995. Immunosuppressive potential of several polycyclic aromatic hydrocarbons (PAHs) found at a Superfund site: a new model used to evaluate additive interactions between benzo[a]pyrene and TCDD. Toxicology 105(2-3): 375-386.
26. Konstandi, M, Pappas, P, Johnson, E, Lecklin, A, Karageorgou, M, and Marselos, M. 1997. Modification of reproductive function in the rat by 3-methylcholanthrene. Pharmacol. Res. 35(2): 107-111.

27. United States Environmental Protection Agency. 2010. Draft document: Development of a relative potency factor (RPF) approach for polycyclic aromatic hydrocarbon)PAH) mixtures. http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=494851 Accessed August 1, 2011.
28. International Agency for Research on Cancer. 1987. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Supplement 7. Overall Evaluations of Carcinogenicity: An Updating of IARC Monographs Volumes 1 to 42. http://monographs.iarc.fr/ENG/Monographs/suppl7/index.php Accessed August 1, 2011.
29. International Agency for Research on Cancer. 1989. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 46. Diesel and Gasoline Exhausts and Some Nitroarenes. http://monographs.iarc.fr/ENG/Monographs/vol46/volume46.pdf Accessed August 1, 2011.
30. United States Environmental Protection Agency. Integrated Risk Information System entry for: Coke Oven Emissions. http://www.epa.gov/iris/subst/0395.htm Accessed August 1, 2011.
31. United States Environmental Protection Agency. Integrated Risk Information System entry for: Creosote. http://www.epa.gov/iris/subst/0360.htm Accessed August 1, 2011.
32. United States Environmental Protection Agency. Integrated Risk Information System entry for: Diesel Engine Exhaust. http://www.epa.gov/iris/subst/0642.htm Accessed August 1, 2011.
33. Ling, SH and van Eeden, SF. 2009. Particulate matter air pollution exposure: role in the development and exacerbation of chronic obstructive pulmonary disease. Int J COPD 4: 233-243.
34. Sun, Q, Hong, X, and Wold, LE. 2010. Cardiovascular effects of ambient particulate air pollution exposure. Circulation 121: 2755-2765.

PAHs and Environmental Health

Introduction

PAH toxicity in the environment is caused by a complex mixture of PAH compounds rather than exposure to individual PAHs in isolation (Mount *et al.* 2003). While considerable work has been done on the carcinogenicity of individual PAHs, PAH mixtures have also been shown to affect the survival, growth and reproduction of many species. For example, PAH contamination is known to adversely affect the viability of benthic species and the diversity of aquatic, estuarine, and marine ecosystems (Valle *et al.* 2007).

This brief review will focus on mechanisms of toxicity, exposure (including bioaccumulation, trophic transfer, and bioavailability), and ecotoxicity to several taxa.

Mechanisms of Toxicity

PAHs have four mechanisms of toxicity (van Brummelen *et al.* 1998):

(1) Nonpolar narcosis (non-specific toxicity) from the physical disturbance of the structure of biological membranes by accumulation of non-reactive, non-electrolyte organics in the membrane.
(2) Phototoxicity from exposure to UV light which increases the toxicity of certain PAHs via free radical formation.
(3) Macromolecule adduct formation (e.g., DNA, protein) which may generate mutations and ultimately lead to carcinogenesis and teratogenesis.
(4) Disturbance of hormonal regulation directly through PAH metabolites that mimic hormones, and indirectly through induction of the Mixed Function Oxidase (MFO) system.

The MFO system consists of enzymes that catalyze reactions between specific chemicals and oxygen which lead to an oxygen atom being incorporated into the structure of the chemical. These chemical reactions play an important part in the metabolism of natural and foreign compounds and can lead to metabolites with decreased or increased toxicity compared with the parent compound.

The MFO system and its cytochrome P450 enzymes are important for PAH toxicity. Elevated levels of PAHs and other toxic chemicals (e.g., PCBs) cause an increase in the activity of the MFO system. Cytochrome P450 mediated biotransformation of PAHs is well established in mammals, birds, and many fish species. Most invertebrates have a less well developed MFO-system, with higher activity in terrestrial invertebrates than in aquatic invertebrates (van Brummelen *et al.* 1998). Organisms that effectively metabolize PAHs generally have lower levels in their tissues and are less likely to suffer from narcosis and phototoxicity. However, induction of MFO system is more likely to cause DNA adduct formation or disturbance of hormone regulation.

Phototoxicity

There have been a number of studies documenting the fact that UV light can greatly increase the toxicity (generally by one to two orders of magnitude) of PAHs in a broad range of aquatic species in different taxa (reviewed in Ankley *et al.* 2003). Aquatic organisms in deep and turbid waters and shaded areas may not be affected by this phototoxicity. However, juveniles of most fish are found in the shallow areas of the littoral zone and are subject to photo-induced toxicity of PAHs. Phototoxicity has also been seen in invertebrates that live in sediment.

Summary of Cellular Interactions

Figure 10, which is Figure 16.1 in Altenburger *et al.* (2003) summarizes the known cellular interactions of PAHs. The figure summarizes uptake, distribution, photoactivation, DNA adduct formation, ROS formation, Ah receptor binding, cytochrome p450 induction and reactions, and excretion from the cell.

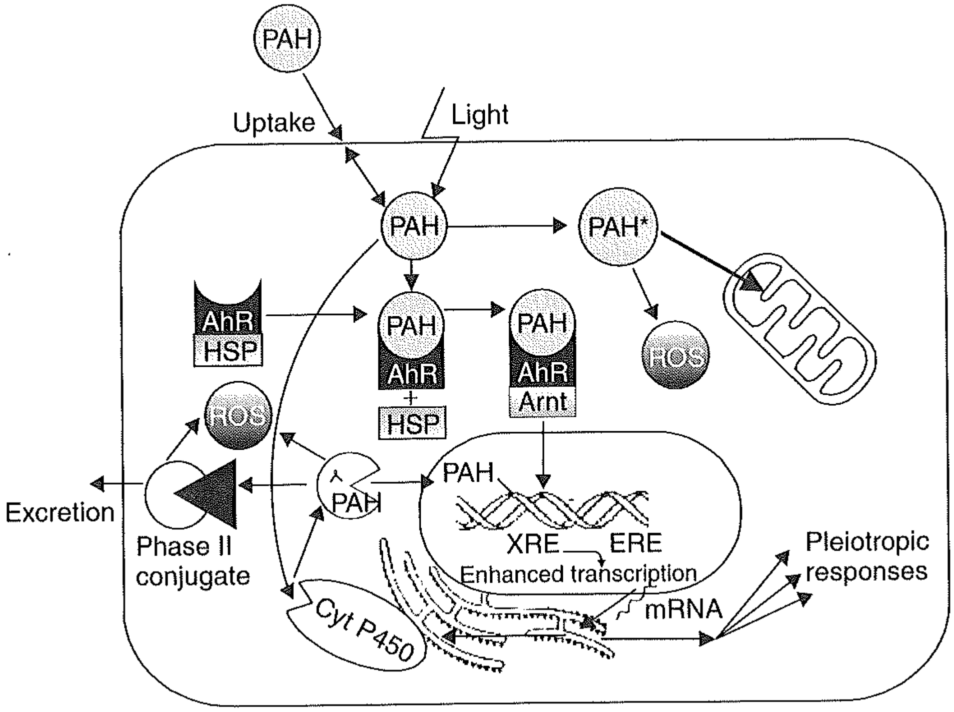


Figure 16.1 Schematic illustration of different modes of cellular interaction of PAHs (according to Ma 2001; Nie *et al.* 2001; Safe 2001; Klinge *et al.* 1999; Van Brummelen *et al.* 1998; Stegeman and Hahn 1994; Winston and Di Giulio 1991). AhR, aryl hydrocarbon receptor; Arnt, arylhydrocarbon nuclear translocator; HSP, heat shock protein; ROS, reactive oxygen species

Figure 10 Cellular interactions of PAHs

Exposure

PAHs are most prevalent in sediment, and therefore benthic organisms (biota living on or in the bottom of water bodies) have the greatest exposure to PAHs. Species that live in sediments are exposed to PAHs by direct contact and ingestion of PAH-contaminated sediment and pore waters, and by ingestion of PAH-contaminated biota. For these reasons, bottom fish (which have more contact with sediment) display the higher levels of PAH contamination compared to other fish. Species that live in the water column are exposed to PAHs by direct exposure to PAH-contaminated water, as well as via trophic transfer. Terrestrial species are primarily exposed through diet. Direct contact exposure is important in some instances, such as oil spills.

Bioaccumulation, trophic transfer, and bioavailability are important aspects of exposure. These dynamic processes are reviewed below.

Bioaccumulation and Trophic Transfer

As with other hydrophobic organic compounds, PAHs can become concentrated in the fat tissues of animals and accumulate along the food chain (Valle *et al.* 2007). However, many animals have the ability to metabolize and eliminate PAHs, leading to biodilution in some instances. Following uptake, PAHs are subject to internal distribution to tissues and organs, to biotransformation, and to elimination (Altenburger *et al.* 2003). The balance between these toxicokinetic processes determines the net bioaccumulation. Many different species of bacteria, fungi, yeasts, and algae are known to degrade PAHs (Volkering *et al.* 2003). Among different groups of invertebrates, the ability to metabolize PAHs is highly variable (Meador 2003), but tends to be lower than in vertebrates. The uptake of PAHs is highly species-specific, being higher in algae, mollusks, and other species which are incapable of metabolizing PAHs, while PAHs are rapidly metabolized in most vertebrates (Eisler 1987). Seasonal changes in physiology, behavior, and environmental inputs may also affect accumulation (Meador 2003).

Bioaccumulation is defined in the PBT Rule as the process by which substances increase in concentration in living organisms as they take in contaminated air, water, soil, sediment or food. The bioaccumulation factor (**BAF**) is defined in the PBT Rule as the ratio of the concentration of a chemical in an organism to the concentration in the surrounding environment.

Bioconcentration is the uptake and accumulation of a substance within an aquatic organism from water. The bioconcentration factor (**BCF**) is defined in the PBT Rule as the ratio of the concentration of a chemical in an aquatic organism to the concentration of a chemical in water.

Biomagnification is the increase in the concentration of a substance with an increase in trophic level.

Biodilution is the decrease in the concentration of a substance with an increase in trophic level.

While bioaccumulation varies among PAH compounds and species, PAHs are considered bioaccumulative under the PBT Rule. Only individual PAHs that met all the criteria in the PBT Rule were put on the PBT List, although PAHs occur in mixtures and it is typically difficult to attribute the hazards associated with a mixture to one specific PAH compound.

The PBT Rule (WAC 173-333) considers a chemical to have a high potential to bioaccumulate if:

1. Based on credible scientific information, the bioconcentration factor (BCF) or bioaccumulation factor (BAF) in aquatic species for the chemical is greater than 1,000.
2. In the absence of such data, the log-octanol water partition coefficient (log K_{ow}) is greater than five.

The information gathered for the PBT Rule found BAF/BCF values, ranging from 602 - 25,703 and log K_{ow} values of 3.92 to 6.75 for various PAH compounds.

Although PAHs are lipophilic (i.e. more soluble in fat than in water), these compounds do not tend to accumulate at high concentrations in vertebrates, as PAHs are rapidly metabolized. Therefore, biomagnification is not expected for food webs involving fish. However, species from lower trophic levels that do not effectively metabolize these compounds may exhibit food web transfer. For example, predatory mollusks and polychaetes (segmented bristle worms) that prey on other polychaetes and mollusks would likely have higher PAH tissue residues than other similar species that only ingest sediment(Meador 2003).

Bioavailability

The toxicity of PAHs is dependent on their bioavailability in different organisms and different environments (van Brummelen *et al.* 1998). The uptake of PAHs in aquatic organisms is influenced greatly by differences in the bioavailability of PAHs in sediment (Besten *et al.* 2003). In general, bioavailability is related to the physiochemical characteristics of the substance, the physiochemical characteristics of the environmental medium, the type and physiological state of the organism, along with other factors such as temperature (Volkering and Breure 2003). The aging or weathering of PAHs also affects bioavailability. Aging may render PAHs less bioavailable, but not less toxic, due to the formation of toxic degradation products (Achazzi and Van Gestel 2003).

Organism physiology is also an important variable for the resulting levels of PAHs in tissues. Factors, including lipid levels and the rates of uptake and elimination, are key determinants of total tissue accumulation (Meador 2003). As mentioned earlier, there is a wide variation in metabolism of PAHs between and within different species, likely due to the variable amount or activity of the cytochrome P450 dependent mixed-function oxidase system (Eisler 1987).

Ecotoxicity

The ecotoxicity of PAH compounds is reviewed for several ecological receptor groups, including aquatic invertebrates, terrestrial invertebrates, fish, mammals, birds, and plants.

Phytoplankton and Zooplankton

Phytoplankton and zooplankton ingest PAHs from contaminated water and through their diet.

Studies have looked at the effects of creosote on communities of phytoplankton and zooplankton. One series of studies looked at the effects of marine-grade creosote either applied once at concentrations of 0.06 to 109 ng/L or from treated pilings (Stratus 2006). These studies included about 200 species of phytoplankton and 80 species of zooplankton. Creosote initially caused a concentration-dependent reduction in zooplankton abundance, with most taxa later recovering. The authors calculated a NOEC for total PAHs for zooplankton community effects at 3.7ug/L in one study and 11.1 ug/L in another. No effects on the phytoplankton community were observed.

Aquatic Invertebrates

Aquatic invertebrates ingest PAHs from contaminated sediments and water and through their diet. Many aquatic invertebrates in diverse locations can accumulate PAHs, often to high concentrations. For example, bivalves can accumulate high levels of PAHs due to their high rate of filtration and low metabolic capacity for these compounds (Meador 2003).

Wide ranges of tissue concentrations have been reported due to variations in environmental concentrations (spatial and temporal), physical and chemical properties of the sediment, time of exposure, and species ability to metabolize these compounds. Tissue concentrations appear to follow seasonal cycles, which may be related to variations in lipid content, spawning cycles, or changing environmental properties. Organisms can also alter their exposure through behavior, e.g., a bivalve can close its shell when contaminants are detected.

Effects of PAHs on aquatic invertebrates include inhibited reproduction, delayed emergence, and mortality (Mahler *et al.* 2005). There are several studies on contaminated sites in Canada and toxic effects on aquatic invertebrates (reviewed Environment Canada 1994). PAH contaminated sediment from Hamilton Harbour (Canadian Great Lakes region) induced nearly 100% mortality in nymphs of the may fly *Hexagenia limbata*.

Surveys of benthic fauna in a Canadian harbor in Nova Scotia known to be contaminated with PAHs showed more diversity and abundance farther from the source of contamination (Environment Canada 1994). The more contaminated part of the harbor had 13-2800 ug/g (d.w.) PAHs compared to 2.5-8.2 ug/g in the less contaminated part. Species such as hermit crabs, limpets and amphipods were not present in the more contaminated arm.

Changes in populations of benthic invertebrates have also been found to be correlated with concentrations of PAHs in sediments in Ontario (Environment Canada 1994). Areas with with more than 80 ug/g (d.w.) had fewer benthic fauna compared to areas with 12-40 or less than 9 ug/g (d.w.).

Fish

PAHs can have biochemical, histopathological, genetic, immunological, reproductive, developmental, and behavior effects on fish (Payne *et al.* 2003). Cancer has been the key endpoint looked at for PAH exposure in fish.

Fish embryos exposed to complex mixtures of PAHs from petrogenic sources (such as oil) show characteristic abnormalities, including cardiac dysfunction, edema, spinal curvature, and reduction in the size of the jaw and other craniofacial structures (Incardona *et al.* 2004). Later work (Carls *et al.* 2008) showed that zebrafish embryos exposed to Alaska North Slope crude oil are affected by PAHs. This study agreed with previous studies showing sublethal effects at low concentrations (1-20 ug/L) of total PAHs. Physical contact with oil droplets was not necessary for embryotoxicity. This study looked at several endpoints and found the heart was the most sensitive indicator of toxicity. Hicken *et al.* (2011) exposed zebrafish embryos to low levels of weathered Alaska crude oil (24-36 ug/L total PAHs) and found changes in adulthood in heart shape and a significant reduction in swimming speed.

Vines *et al.* (2000) studied the effects of diffusible chemical compounds from weathered creosote-treated pilings on embryonic development in Pacific herring. These researchers observed complete lethality for all embryos adhering directly to creosote-treated wood. In addition, approximately 40–50% of embryos not adhering to the creosote-treated wood failed to develop beyond the first few days of incubation. For surviving embryos, significant effects on cardiac function were noted, along with lower hatching rates and higher rates of incomplete hatching. The authors calculated an LC50 for hatching success to be 0.05 mg/L and found a sublethal exposure of 0.003 mg/L significantly reduced hatching success and increased abnormalities in morphology and cardiac function.

Considerable research has been done on the relationship between PAHs and liver lesions in English sole in Puget Sound. There is a strong and consistent statistical association across separate studies. The researchers complimented this epidemiological evidence with long-term laboratory exposure studies to confirm the causal link. Results from a summary of a series of eight studies on sediment and liver lesions in English sole from 45 sites within Puget Sound from 1979-1986 showed a consistent association between prevalence of liver lesions in English sole and levels of PAHs in sediments, which ranged from 0.005 ppm dry weight at an uncontaminated site to 540 ppm dry weight at Eagle Harbor (Landahl *et al.* 1990). The first study in the series looked at a wide range of chemicals, and the strongest correlation was observed between PAHs and occurrence of liver lesions. This led subsequent studies to focus on PAHs. Up to 86% of English sole had liver lesions, with the highest prevalence consistently found at the Eagle Harbor site (Landahl *et al.* 1990). Liver lesions have been found in other bottom fish within Puget Sound, but with lower prevalence (Myers *et al.* 1991).

The liver lesions seen in Puget Sound English sole are similar to those induced experimentally by carcinogens in mammals and fish and are known to be essential early steps in hepatic carcinogenesis (Myers *et al.* 1991). In a laboratory study, sole were injected with a PAH-enriched sediment fraction from Eagle Harbor which induced the same types of liver lesions seen in wild fish.

Eagle Harbor was contaminated by creosote from a wood treatment facility. The EPA began investigating the site in 1971 and it was listed as a Superfund site in 1987 (USEPA 2007). The Eagle Harbor Superfund site has undergone extensive remediation since 1991, including removal of creosote sludges and other contaminated materials and capping contaminated sediments (USEPA 2007). Since these actions, the incidences of liver lesions in English sole from that site have been drastically reduced (Myers *et al.* 2008).

Several laboratory studies have been performed on the effects of PAHs on salmon. Meador *et al.* (2006) fed PAHs to juvenile Chinook salmon at levels that mimicked exposure from Puget Sound urban estuaries during their transition from freshwater to seawater. These investigators observed differences in growth, plasma chemistry, and lipids (termed "toxicant-induced starvation" by the study authors) which have the potential to affect mortality during the salmon's first winter.

Mammals

There are numerous studies on PAH toxicity to laboratory mammals, while fewer studies exist on PAH effects on wild mammals. Field mice exposed to PAHs have reduced food consumption, and there are also DNA-adducts seen in wild species (Malcolm and Shore 2003). One of the most well studied wild marine mammals is the beluga whale of the St. Lawrence estuary in Canada. As with other chemicals and locations, it is difficult to draw a direct link between PAHs and their effects on beluga whales, because of co-contaminants like PCBs and metals (Malcolm and Shore 2003). Low levels of PAHs have been measured in other marine mammals, such as seals, whales, dolphins, and porpoises (HSDB 1994).

While some of the data on human health effects are based on epidemiology, much of the data are from studies on other laboratory mammals. By 1918, it was shown that topical applications of coal tar produced skin tumors in mice and rabbits (Eisler 1987). The ATSDR toxicological profile on PAHs summarizes studies on laboratory animals (ATSDR 1997). Several PAHs have caused tumors in laboratory mammals through different routes of exposures (dermal, inhalation, and oral). Studies in mice have also shown reproductive effects, birth defects, and decreased body weight. Other effects on skin, body fluids, and the immune system have been reported for laboratory mammals. For example, laboratory studies on mice have shown that many carcinogenic PAHs adversely affect the immune system (Eisler 1987, ATSDR 1997). In general, the tissue affected is determined both by the route of exposure and species (ATSDR 1997).

Birds

Birds are primarily exposed to PAHs through their diet, but direct contact is important with an oil spill. PAHs are rapidly metabolized in birds, so they are often not detectable. PAHs and fuel oils applied to chicken and mallard eggs can cause adverse effects, including liver necrosis, renal lesions, extensive edema, growth retardation, and other birth defects (Malcolm and Shore 2003). Herring gull nestlings have also been reported to have reduced growth after being exposed to

Prudoe Bay crude oil (Malcolm and Shore 2003). There are interspecific differences in sensitivity, while the amount, timing, and mixture of PAHs influence toxicity.

Terrestrial Invertebrates

PAHs in soil and litter (i.e. layer of decayed organic matter) may be transferred to soil invertebrates by soil and litter ingestion, as well as porewater contact and ingestion. In species that live on top of the soil, such as springtails and isopods (small crustaceans), uptake occurs mainly with contaminated food and transfer via the gaseous phase (Achazzi and Van Gestel 2003).

There are negative effects on survival, growth and reproduction. Sensitivity varies across species, compounds, and different soil matrices. PAHs may also affect other physiological traits, making organisms more susceptible to additional stresses, such as reduced tolerance to drought stress (Achazzi and Van Gestel 2003).

Plants

Plant roots have a high capacity for hydrophobic compounds and can assimilate PAHs from soil, water, or air. Uptake rates are governed in part, by PAH concentration, water solubility, vapor or particulate form, as well as soil type (Eisler 1987). Because of airborne deposition, the aboveground parts of plants tend to contain more PAHs than belowground parts and plants with broad leaves tend to contain more PAHs than those with narrow leaves (Environment Canada 1994).

Most plant species are sensitive to PAHs to some degree, but they appear to be less sensitive than aquatic organisms (Stratus 2006). PAH impairment of plant growth and/or development limits primary productivity, constraining total biological activity in an ecosystem. Accumulation of PAHs in plants represents a portal into the food web (Greenberg 2003).

PAHs in Washington's environment

Ecology monitors for PAHs as part of its work on PBTs and our state Toxics Monitoring Program has included PAHs in some studies. Ecology also tests for PAHs to determine impairment levels of state water bodies (303d list), identify the extent of contamination at cleanup sites and conduct other toxics studies. Ecology's main database for environmental monitoring is the Environmental Information Management (EIM) system. EIM contains data on PAHs in soil, water, sediment, and animal tissue. Some sites have elevated levels of PAHs and there are about 375 confirmed PAH cleanup sites in groundwater, surface water, drinking water, air, soil, and sediment, with some sites having contamination in multiple media.

Ecology studies have focused on 16 PAH compounds that were designated as priority pollutants in the Clean Water Act. There is some overlap between these 16 PAHs and the 16 PAHs on the Washington PBT list (see Table 2). Because PAHs are found as mixtures in the environment,this CAP uses the data available, which is mostly on the 16 priority pollutants, to provide insight on PAHs in Washington's environment.

Puget Sound Toxics Loading Studies

PAHs were included in the list of chemicals of concern in the Puget Sound Toxic Loading Studies. This multi-year, three phase project was done in collaboration with the Puget Sound Partnership and other agencies. The project focused on sources, loads and pathways, rather than presence in environmental media. http://www.ecy.wa.gov/programs/wq/pstoxics/phase3.html As part of this project, environmental concentrations were evaluated using EIM as the largest source of data (Ecology 2011b in prep). Limited data suggest that typical freshwater concentrations for total PAHs are in the 0.1 – 1.0 µg/l range, with marine water column concentrations slightly lower. Total PAHs in freshwater and marine sediments are typically 100 – 1,000 µg/kg (dry weight) although mean concentrations in urban bays may be up to ten-fold higher.

Water

Ecology assesses water bodies in the state to determine which areas are so polluted that further discharges of certain chemicals into these waters can no longer take place. For the highest priority sites Ecology conducts a TMDL analysis or total maximum daily load and develops a cleanup plan for meeting water quality standards. These waterbodies are placed on the 303(d) list of impaired waters. There are no waterbodies in Washington on the 303(d) list due to elevated levels of PAHs. Due to their hydrophobic properties, PAHs have low solubility in water and are associated with particles.

Other Ecology studies have assessed PAHs in lake and river monitoring to evaluate trends in PBTs using semi-permeable membrane devices (SPMDs) for passive water quality sampling over a month period. SPMDs are a standardized way to mimic the bioconcentration of organic pollutants by aquatic organisms without the variability of living organisms. Ecology's monitoring involves sampling two times a year at 11 major rivers and one lake. Sampling in 2008 and 2009 found low levels of PAHs in rivers and lakes (Ecology 2010a and 2011a). At least one PAH was found in all samples. Total PAHs ranged from 11-6500 pg/L (ppq) in 2008 and 130 to 5300 pg/L (ppq) in 2009. The Queets River had the lowest concentrations of PAHs found in both studies and reflect the Queets River's remote location in the Olympic National Forest near the Pacific Coast. The highest concentrations were observed in the urban sites of Lake Washington, the Spokane River, and the Lower Columbia River.

Soil

There has been no comprehensive work to establish background levels of PAHs in soil in Washington. The many soil samples in EIM were collected for investigation and cleanup of hazardous sites and therefore do not represent background samples.

Sediment

PAHs adhere to particles in sediments and new sediment is overlaid each year, making it possible to assess the current status and history of PAH deposition by examining sediment core samples.

Puget Sound was included in a national study on trends in the accumulation of chemicals in US coastal and estuarine sediments (Lefkovitz *et al.* 1997). Age-dated sediment cores were collected from the main basin of Puget Sound and analyzed for several chemicals, including PAHs in three of the cores. Total PAH concentrations ranged from about 100 ug/kg in the deepest and oldest sediments to a maximum of 6788 ug/kg in the 1940s. The more recent concentrations were around 1,000 ug/kg. Similar results were found in a more recent study (Kuo *et al.* 2011). PAHs peaked in the 1930s and 40s with a maximum of 5144 ug/kg. The more recent concentrations were around 500-1,000 ug/kg. In the Kuo *et al.* (2007) study, lower levels were found in a Hood Canal sediment core, consistent with the more rural area.

The US Geological Service looked at PAHs in sediments in the last 20-40 years in ten lakes across the nation (Van Metre *et al.* 2000). The study included Lake Ballinger, an urban lake located north of Seattle. While older sediments have shown a peak earlier in the 20th century, this study on more recent sediments showed increasing PAH concentrations that are correlated with increasing vehicle use. PAH levels in Lake Ballinger ranged from 4,810 to 49,000 ug/kg.

Ecology has done two studies of PAHs in age-dated sediment cores in lakes (Ecology 2009 and 2010b). In the first study (Ecology 2009) PAHs were detected in sediments at concentrations ranging from 33-1117 ug/kg (ppb). As seen in the figure below, the time profiles for the three lakes were dissimilar. The higher levels of PAHs in Lake Washington sediment may be a reflection of the dense urban land use in Lake Washington's drainage area. Previous studies have identified a relationship between PAH concentrations and proximity to urban regions (such as Hafner *et al.* 2005). Using fluoranthene/(fluoranthene + pyrene) ratios, all three lakes are dominated by combustion-derived sources. Lake Washington was also included in a national USGS study on sediment cores (Van Metre 2004). In that study concentrations ranged from 19-285 mg/kg, peaking during the mid-1970s.

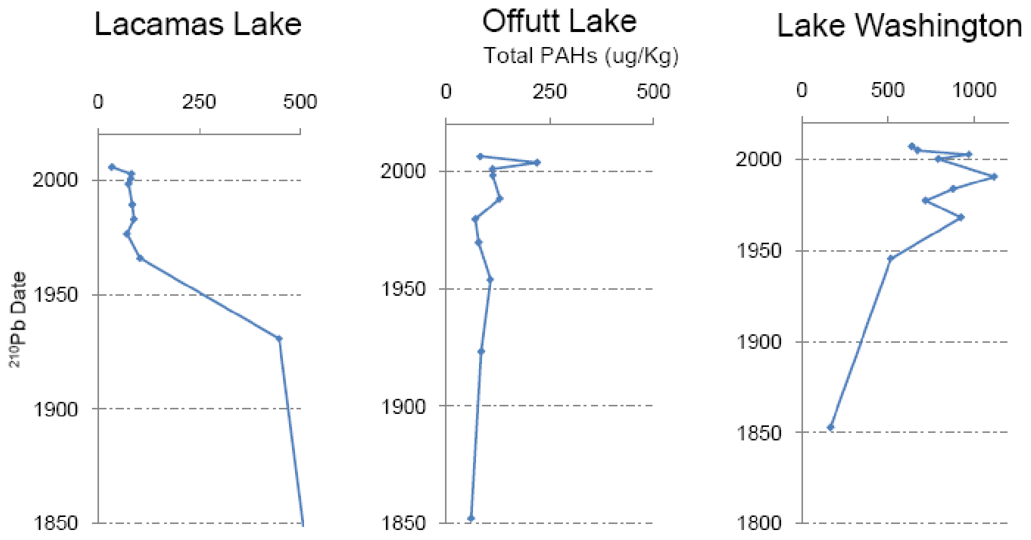


Figure 11- PAHs in lake sediments from Ecology 2009.

In the second Ecology study (Ecology 2010) PAHs were found in two of the three lake sediment cores. American Lake in Lakewood, Pierce Co. had the highest levels of PAHs and the report was able to describe trends. By 1900 elevated levels of PAHs are seen, with the maximum level of 1825 ug/kg in the first half of the 20th century. After the maximum there is an erratic pattern with an overall decline. This study used fluoranthene/(fluoranthene + pyrene) ratios to suggest earlier sources of grass, wood, and coal combustion, with petroleum combustion associated with vehicular traffic after 1950.

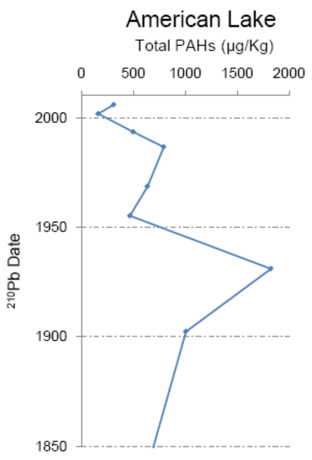


Figure 12- PAHs in American Lake sediments from Ecology 2010.

Puget Sound Assessment and Monitoring (PSAMP)

PAHs are included in the Puget Sound Assessment and Monitoring Program (PSAMP) monitoring efforts. The PSAMP has provided a scientific foundation for the conservation, recovery, and management of the Puget Sound Ecosystem since 1989. PSAMP is an extensive, network of regional scientists from numerous agencies, including Ecology. They monitor key indicators of water and sediment quality, near shore habitat, and the health or abundance of fish, seabirds, shellfish, and marine mammals.

In 2005 samples from ten long-term monitoring stations collected from 1989 through 2000 were summarized (Ecology 2005b). In general, detections of PAHs and PAH concentrations were higher in 2000 than in 1998-1996. There were significant overall increases at four stations, and a significant decrease at the Point Pully station. Mean total PAH concentrations (not normalized by sediment criteria values) ranged from a low of 46 ppb (range 17 to 76 ppb) at North Hood Canal to a high of 7727 ppb (range 4495 to 14,319 ppb) at Thea Foss Waterway. PAH concentrations at the Thea Foss Waterway station near Tacoma were one to two orders of magnitude greater than at the other sediment monitoring locations and persistently exceeded sediment quality standards.

Cross media

Western Airborne Contaminants Assessment Project (WACAP)

PAHs were one of the airborne contaminants studied in the Western Airborne Contaminants Assessment Project (WACAP), a multi-agency project to assess airborne contaminants in ecosystems and food webs in western national parks. The study included two primary parks in Washington State, Mt. Rainier National Park and Olympic National Park, and one secondary park, North Cascades National Park. Analysis of the concentration and biological effects of airborne contaminants in air, snow, water, sediment, lichen, conifer needles, and fish was conducted from 2002 through 2007. These seven ecosystem components were chosen to present a more complete picture of current contamination, historical patterns, spatial gradients, and biomagnification.

PAHs were identified as one of the six contaminants of highest concern for the study's eight core parks, which include the Mt. Rainier (MORA) and Olympic National Parks (OLYM). These six were emphasized because of the high concentrations detected, bioaccumulation, or persistence.

In the Washington parks PAHs were one of the dominant semi-volatile organic compounds in vegetation and decreased with increasing elevation. Other parks, most notably Glacier National Park, had high concentrations of PAHs from local sources, such as an aluminum smelter. Overall total PAH concentrations were lowest in the Arctic (<10 ng/g lipid) and in parks in central Alaska (<500 ng/g lipid), increasing in concentration and number of compounds with decreasing latitude along the Pacific Coast from southeastern Alaska (<5,000) to southern California (<20,000), peaking in Glacier National Park (up to 200,000 ng/g lipid), and lower in the rest of the Rockies (<1,100 ng/g lipid). The number of PAH compounds detected generally increased with total PAH concentration from 2 in the arctic to 17 in Glacier National Park. PAHs were also detected in sediments and snow. See Figure 12 for a summary of PAHs in vegetation, snow and sediment in all of the parks.

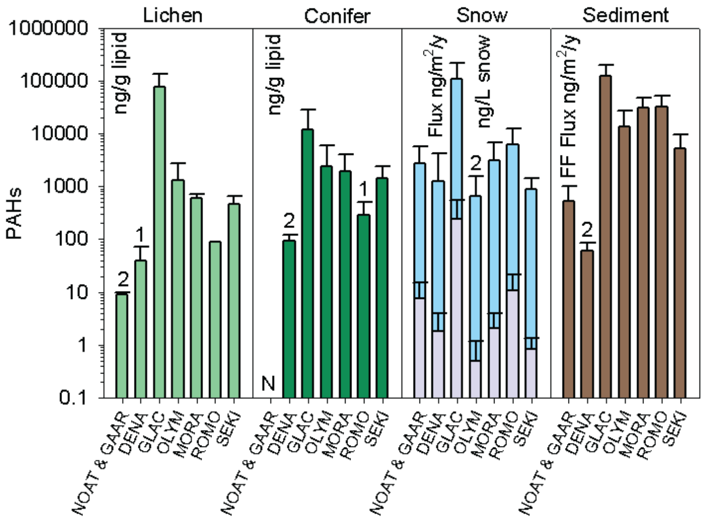


Figure 13- Figure 4-5 from WACAP report. PAHs: Average Concentrations and Fluxes of Sum PAHs across Parks and Media. MORA is Mt. Rainier National Park and OLYM is Olympic National Park.

The full 350 page report can be accessed on the National Park Service website at http://www.nature.nps.gov/air/Studies/air_toxics/wacap.cfm.

Cleanup Sites

There are about 375 sites on Ecology's hazardous site list with confirmed PAH contamination in air, water, soil, and/or sediment. These sites include former gas stations, wood mills, creosote treatment facilities, coal gasification plants, railway yards, tire pile fires, and other sites that are being cleaned up and converted to new uses. There are also landfills, gun clubs, military facilities, and other types of sites. Many of the sites are also contaminated with petroleum products, metals, and/or other chemicals.

Some large and complex cleanup sites are in urban bays. PAHs are often found accumulated in the sediment in these areas. The Urban Waters Initiative (http://www.ecy.wa.gov/urbanwaters/index.html) was created to address the special challenges of concentrated human activity. The 2007 legislature provided money to work in Elliot Bay/Lower Duwamish Waterway (Seattle), Commencement Bay (Tacoma), and Spokane River (Spokane). Chemicals, including PAHs, were measured in surface sediments and the composition of the organisms that live at the bottom of the bay (in the sediment) was also assessed. One of the tasks was to look at the conditions in urban bays over time to see how effective the localized clean up actions have been. For example, from 1998 to 2007 in Elliott Bay levels of most of the higher molecular weight PAHs and some of the lower molecular weight PAHs improved or stayed the same (Ecology 2009b). There was, however, an increase in the level of acenaphthylene. In the 2007 samples, PAHs were detected in all samples. The mean of each compound ranged from 16-1500 ppm. The highest PAH detected was 40,500 ppm for fluoranthene.

The chemistry section describes how PAHs are created during several industrial processes, such as coal gasification. As mentioned in that section, Gas Works Park on the North shore of Lake Union in Seattle is on the site of a major coal gas facility that closed down in 1956. To this day, however, the land around Gas Works Park remains heavily contaminated with PAHs from these processes, as measured by bioassays (Ecology, 2003).

The Wykoff/ Eagle Harbor former creosote wood treatment site is mentioned in the section on the toxics effects of PAHs on fish. A 1989 study by Ecology found variable levels of PAHs contaminants in 18 sediment samples near the Wyckoff facility (Ecology pub 89-E-03). The median level of LPAHs was 17 ppm dry weight, with a maximum of 180 ppm dry weight. The median level of HPAHs was 55 ppm dry weight, with a maximum of 868 ppm dry weight. The Eagle Harbor Superfund site has undergone extensive remediation since 1991, including removal of creosote sludges and other contaminated materials and capping contaminated sediments (USEPA 2007).

Brenner *et al.* (2002) examined ten sediment cores at the Wyckoff/Eagle Harbor Superfund site. All the upper sediments, representing the most recent depositions, had relatively lower levels of PAHs from urban runoff, with total PAH levels around 50 mg/kg. The deeper sediments, representing older depositions when the Wyckoff facility was in use, had higher levels of PAHs from creosote with varying amounts of weathering and total PAH levels around 6,000-20,000 mg/kg. One core, in an area that has since been capped, had unweathered creosote and the highest levels of PAHs (142,000 mg/kg dry weight). The deepest and oldest sediments had natural background PAHs of less than 1 mg/kg.

Biota

Mussel Watch is a national program conducted by the National Oceanic and Atmospheric Administration (NOAA) designed to monitor the status and trends of chemical contamination of US coastal waters, including the Great Lakes. The program is based on alternate year collections in winter of oysters, blue mussels and zebra mussels, but only blue mussels are sampled in Washington State. Mollusks, such as blue mussels, are not able to metabolize PAHs, thus PAHs accumulate in them. A report on two decades of monitoring showed PAH concentrations in Washington, specifically in Puget Sound, in the context of the national monitoring program (Kimbrough *et al.* 2008). They found that sites in Puget Sound have PAH concentrations that are among the highest in the nation with nearly 2/3 of the sites in the Puget Sound characterized as medium to high, nearly double what is observed nationally. They did not find a significant trend in Puget Sound or in the Northwest region. The 16 sites in Washington were mostly in Puget Sound with some sites on the Pacific Coast. PAHs ranged from 134 to 6962 ppb. Eight sites were low, seven medium and one high. Low was considered 63-1,187 ppb, medium 1,188-4,434 ppb, and high was 4,435-7,561 ppb. It is unknown as to why the Puget Sound PAH samples are among the highest the nation. It may be due to the sampling protocol (winter sampling), the relatively lower level of flushing of Puget Sound, or it may be due to a larger number of sources or other factors.

Hazard Evaluation

The Assessment of Selected Toxic Chemicals in the Puget Sound Basin, 2007-2011 (Ecology 2011b) included a hazard evaluation to estimate the relative hazard posed by the chemicals of concern assessed in the Puget Sound Toxics Loading Analysis 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. PAHs were found to be the highest level of concern for freshwater sediments and for human health, with variation among PAHs (note that generally eating seafood is not the major source of exposure to PAHs for people). A summary is presented here and more details are included in the Assessment report (Ecology 2001b).

The assessment included:

- Direct hazard to aquatic life through surface water exposure
- Direct hazard to benthic organisms through sediment exposure
- Hazard to human health through seafood consumption

The evaluation included the 16 PAHs on the Clean Water Act Priority Pollutant list, which includes some of the PAHs on the PBT list (see Table 2). Figures for the PAHs that are on the PBT list are found in Appendix B, while additional figures are in the Assessment report (Ecology 2011b).

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.

Surface water levels and direct effects to aquatic life

The primary source of surface water effects levels was the EPA ECOTOX database. Washington State water quality criteria were included when available.

The box plots in Appendix B are from the Assessment report (Ecology 2011b). Each shows a box plot of observed environmental concentrations in surface water (yellow) against a box plot of effects concentrations (blue). All concentrations are presented on a log scale and N represents the number of available measurements.

The box plots show that the observed environmental concentrations are lower than the effects levels. However, for some PAHs, there are some observed environmental concentrations that are close to the lowest effects levels.

Sediment and direct effects to benthic organisms

Observed environmental levels were compared to sediment guidelines to determine potential hazard to benthic organisms. Although pore water can be an exposure route, it was not considered because of lack of data.

Marine sediment data were compared to six guidelines (when available):

- the Washington State Sediment Management Standards (SMS) (173-204 WAC), which consist of
  - Sediment Quality Standards (SQS) and
  - Cleanup Screening Levels (CSL).
- The Apparent Effects Thresholds (AET), which includes
  - Lowest AET (LAET) and
  - Second Lowest AET (2LAET)
- The Canadian marine Sediment Guidelines, which consist of
  - Threshold effect level (TEL) and
  - Probable effects level (PEL)

The SQS represents the concentration below which no adverse effects are expected, while the CSL is less stringent and corresponds to the concentration at which minor adverse effects are expected.

An AET represents the concentration above which adverse effects have been demonstrated to always occur.

The TEL represents the concentration below which adverse effects are expected to occur in fewer than 25% of samples, while the PEL defines the level above which adverse effects are expected to occur in more than 50% of samples.

Freshwater sediment data were compared to three guidelines (when available):

- Ecology's 2003 Draft floating percentile (FP) based freshwater sediment guidelines
  - Sediment Quality Standards (FP-SQS)
  - Cleanup Screening Levels (FP-CSL)
- Canadian Freshwater Sediment Guidelines
- Consensus-based guidelines from MacDonald *et al.* 2000

The definition of each freshwater guideline is similar to the marine water guidelines described above.

The box plots in Appendix B are from the Assessment report (Ecology 2011b). Each shows a box plot of observed environmental concentrations in surface sediments against sediment thresholds. All concentrations are presented on a log scale and N represents the number of available measurements.

The box plots show that the 90th percentile of observed sediment concentrations was above the freshwater FP-SQS. The 90th percentile of observed sediment concentrations was not above the SQS for marine sediments, but was above other sediment guidelines.

Human Health

The effect threshold for human health was based on the National Toxics Rule (NTR) 40CFR131.36 water quality criteria and several national and regional fish consumption rates compared to observed tissue concentrations. Tissue criteria were back calculated from the NTR based water quality criteria. Only chemicals that are part of the NTR were assessed for human health. People's exposure to PAHs in water or sediment was not included in the assessment.

The box plots in Appendix B are from the Assessment report (Ecology 2011b). Each shows a box plot of observed tissue concentrations in offshore bivalves, fish (whole-body and filet) and other invertebrate tissues compared to five different human consumption scenarios derived from the NTR. The five daily fish consumption rates are NTR (6.5g), EPA recreational (17.5g), EPA subsistence (142.4 g), Tulalip Tribal/King County Asian Pacific Islander (242.5 g), and the Suquamish Tribal (769 g).

The box plots show levels of some PAHs in seafood tissue above threshold effects for human health. As discussed in the earlier section on human health, seafood consumption is not generally a major pathway of PAH exposure for people.

Production, Uses and Releases

General information on estimates that applies to the entire section

Many of these PAH releases were first estimated for the report on sources of selected toxic chemicals in the Puget Sound basin (Ecology 2011c), which estimated primary sources of selected toxic chemicals for Puget Sound as part of the Toxics Loading Studies. Several sections of this chapter have a high degree of similarity to that report, except source estimates are now included for the entire state.

There are hundreds of PAHs and they usually occur as mixtures, but many studies have focused on 16 compounds that were designated as priority pollutants in the Clean Water Act. Many estimates of PAHs in this report refer to these 16 PAHs or these 16 plus perylene, which were estimated in the 2007 report on sources of PAH in NY/NJ Harbor (Valle *et al.* 2007). The Clean Air Act includes polycyclic organic matter (POM), which are different PAH compounds, but are often the 7 PAHs that have been designated as probable human carcinogens by the EPA or a group of 15 PAHs that is the same as the 16 PAHs in the Clean Water Act, minus naphthalene. Another source of information was the Toxic Release Inventory (TRI), which collects information on releases of a different set of PAHs. The PAHs in the TRI are detailed below with the TRI data. See Table 2 for a comparison of the PAHs on the Washington PBT list, the TRI list and the Clean Water Act. Appendix A has a larger comparison of different lists of PAHs.

Many of the estimated releases to air come from Ecology's Air Quality Program (AQP) air emissions inventory which contains estimates of air pollution emitted by various sources. Every year, Ecology and the local air quality agencies inventory releases from large industrial sources. Every three years, Ecology inventories releases from many additional sources such as motor vehicles, woodstoves, outdoor burning, agricultural sources, and natural sources. This CAP uses the most recent more comprehensive inventory in 2005 for estimates of PAHs from the AQP inventory. Ecology's AQP estimated PAH air releases with the methods used by the EPA for its Consolidated Emissions Reporting, supplemented with various local and regional land use and demographic data to apportion emissions among different source categories, counties and seasons (Otterson, 2007). The estimates were given in tons/yr and converted to kg/yr for the CAP.

Anthropogenic Sources

Residential wood fuel combustion

This category includes home heating and residential uses of woodstoves and fireplaces, which release PAHs through the incomplete combustion of wood. Outdoor wood boilers are not allowed in Washington since they do not meet our state emission standards.

This estimate was based on a Washington State University telephone survey of wood heating and outdoor burning habits in Idaho, Oregon, and Washington. The survey included the type of device, such as whether it was a certified or non-certified woodstove.

How much is in Washington

Woodstoves and fireplaces make up the largest estimated PAH emissions in the AQ inventory, with 148,266 kg/yr.

Opportunities for Reduction

- Maintain existing state and local programs at current levels
- Enhance existing programs to achieve additional PAH reductions
- Create a technology challenge for the next generation of cleaner burning wood stoves
- Increase activities to educate consumers on use and maintenance of wood stoves as well as the health effects of burning wood
- Increase incentives to encourage consumers to switch to non-wood heat
- Expand incentives to include fireplaces
- Increase programs to encourage users of non-certified wood stoves to switch to certified devices
- Require replacement of uncertified wood stoves at the time of sale with certified stoves or non-wood devices
- Ban wood burning stoves in specified areas
- Subsidize existing non-wood heating sources
- Create a statewide number for enforcement of existing laws on visible smoke
- Support new federal standards for higher performing wood burning devices

Washington has stricter standards than the federal government for more efficient combustion by wood stoves and other wood burning devices. New stoves that are certified to meet both Washington State and federal EPA standards emit fewer PAHs. New technology for cleaner burning stoves is needed to get meaningful reductions in PAHs.

Proper installation, use and maintenance of existing wood stoves will reduce PAH emissions. Insulation and weather stripping can be used to make a house more energy efficient and reduce the amount of heat needed. Ecology and local air agencies have programs and incentives to encourage users to switch to cleaner burning stoves and use stoves more efficiently. Fireplaces should be included in these programs, since they emit more pollution than other wood burning devices and are inefficient for heating a house.

Public and political support to require removal of uncertified wood burning stoves in most parts of the state is unlikely at this time. Oregon passed a law to require this, but there were already different local laws across Oregon. There is also not currently public support for banning wood stoves in urban growth areas.

Currently local air agencies and Ecology regulate wood smoke locally, such as calling for burn bans during periods when wood smoke pollution reaches unsafe levels. Burn bans prohibit wood burning, except for homes with no other source of heat. There are also statewide regulations on opacity of wood smoke. It would be helpful for residents if there was a statewide number for enforcement of existing laws. The local air agencies would have to join together to create and fund this. Anonymous complaints could not be used for enforcement, but letters could be sent out. Local numbers are already in place in some areas of the state.

Natural gas and electricity are sources of heat that produce fewer PAHs. Electric heat sources do not emit any PAHs near the house, but there may be PAHs emitted where the electricity is generated, if combustion is used to generate the electricity. Natural gas and electricity can also be used for recreational (non-essential) fireplaces. Education and financial incentives would encourage more people to switch to non-wood sources of heat.

In order to completely eliminate PAHs from wood smoke, we would have to stop burning wood in Washington, including all heating and cooking, which is not a realistic or feasible action.

Creosote treated wood- Railroad ties

Coal tar is a by-product when coal is carbonized to make coke or gasified to make coal gas, and contains a complex mixture of PAHs (ATSDR, 2002). While creosote can be prepared from woods, creosote from coal tar is the most common form of creosote used in the US and the most widely used wood preservative (ATSDR, 2002). This CAP uses the term “creosote” to refer to coal tar creosote. About 300 chemicals have been identified in coal tar creosote, but as many as 10,000 other chemicals may be in this mixture (ATSDR, 2002). Creosote is an oil-borne wood treatment and is regulated by the EPA as a restricted use pesticide (see section on regulations). Creosote is forced into wood under pressure to treat the wood. PAHs are released from creosote treated wood through volatilization into the air and leaching into water.

How much is in Washington

Estimates of PAH releases from creosote-treated railroad ties were derived from release rates published in a 2007 study of PAH sources to New York/New Jersey Harbor and estimates of the number of railroad ties in the State.

The authors of the New York/New Jersey Harbor study estimated a PAH loss rate from creosote-treated railroad ties of 16.67 g/tie/yr over the lifetime of a tie (Valle *et al.* 2007). Assumed lifetimes were 30 years for railroad ties. Losses modeled by Valle *et al.* (2007) were equally split between air emissions and rainwater.

There are 3196 miles of freight rail lines in Washington (Blake 2007), with an average of 3,249 ties per mile of track (RTA, 2010), for a total of 10,384,129 ties. The PAH release rate applied to the total number of creosote treated railroad ties results in an estimated 173 MT/yr of PAH released to the State (Table 8). This estimate is likely an underestimate because it does not include passenger service and double tracks are counted the same as single tracks.

Table 8- Estimates of Total PAH Released from Creosote-Treated Railroad Ties

Product	Number of RR ties	PAH Release Rate (kg/tie/yr)	PAH release to air (kg/yr)	PAH release to soil (kg/yr)	Total PAH release (kg//yr)
Railroad Ties	10,384,129	0.01667	86,551.5	86,551.5	173,103

Opportunities for Reduction

- Opportunities to reduce releases from railroad ties all require substitution, either of materials or preservatives.
- Map railroad tie locations to see if they are close to sensitive habitats, such as nearshore areas
- Ban secondary uses

Creosote-treating of railroad ties is EPA-approved and this remains the primary treatment option for railroad ties, although concrete ties now comprise 6.5% of the market share in North America and the American Wood Protection Association has recently approved ammoniacal copper zinc arsenate (ACZA) as an accepted preservative for ties (RTA, 2010). Amtrak replaced wood ties with concrete ties in the Northeast corridor for its high speed Acela train, although it found concrete ties needed to be replaced earlier than expected in some areas. Some countries are moving towards concrete railroad ties, such as Switzerland and the Netherlands (Dutch Competent Authorities 2008).

Railroad ties are reused for landscaping and other uses. The EPA has not commented on the safety of creosote treated wood for these secondary uses. There is not enough information on these uses for us to restrict them at this time, but Ecology should continue to monitor re-uses to ensure they do not present a threat to human health or the environment.

Smith (2007) conducted a study for the Creosote Council which examined the costs of different alternatives and showed that the initial costs for creosote treated wood are less than for alternative materials or wood treatment. For example, Smith (2007) estimates that a mile of new track with creosote ties costs $236,000 compared to $308,000 for concrete or $356,000 for steel or plastic ties.

Table 9 lists alternatives to pressure-treated wood with advantages and disadvantages. There are additional products, such as TimberSIL, which combines wood with glass, and Kebony, which hardens soft wood using agricultural waste. Not all of these alternatives are appropriate for railroad ties. Compared to the initial costs, the advantages, disadvantages and environmental impacts of different materials are less agreed upon. In addition, they vary based on region and use. For example, the presence of natural resources, such as wood, and the need for transport will affect a life cycle analysis. The Dutch government submitted a life cycle analysis of creosote and alternatives for an EU consultation on including creosote as a wood preservative under their directive on biocides (Dutch Competent Authorities 2008). The Netherlands concluded there are alternatives for both railroad ties and utility poles that are less detrimental to human health and the environment.

Table 9- Alternatives to creosote treated wood from Valle *et al.* (2007).

Material	Description	Advantages	Disadvantages
Composites	Made of various discarded materials, including wood fibers, plastics, rubber, and steel.	-Doesn't warp, split, chip, or rot -Available in a variety of colors -Doesn't need sealing -Low maintenance -Resists moisture	-More expensive -Not rated for structural use -Susceptible to mildew, mold, and stains -Color fades in sunlight
Virgin vinyl	Hollow building material, a molecularly bonded blend of 100% virgin, hi-polymer resin.	-Doesn't warp, split, chip, or rot -Available in a variety of colors -Doesn't need sealing or staining	-More expensive -Not rated for structural use
Redwood	Examples include Cedar and Cypress	-Resistant to decay and insects -Dimensional stability -Doesn't need sealing -Easy to saw and nail	-More expensive -Soft surfaces are susceptible to denting -Susceptible to moisture
Exotic hardwood	Examples include Mahogany and a variety of Ironwoods	-Durable -Resistant to decay and insects -Doesn't need sealing	-More expensive -Difficult workability - Depleting supplies
High Density Polyethylene (HDPE)	Thermoplastic	-Weather resistant -Easy to cut or drill -No grain to split or chip	-Susceptible to stress cracking -High mould shrinkage -Poor UV resistance -Not rated for structural use
Rubber lumber	Composed of 50% plastic and 50% old tires	-Durable -Impervious to water -Resistant to insects -Resistant to UV rays -Available in a variety of colors -Uses recycled materials	-Not rated for structural use
Steel	Can be made from	-Durable	-More expensive

	discarded materials	-Can be recycled -Reduced risk of fire	-High energy use for manufacture
Concrete	Concrete	-Durable -Reduced risk of fire	-More expensive -Higher energy use for cement manufacture
Fiberglass	Fiberglass reinforced composite	-Low maintenance	-More expensive -Subject to damage

There are chemical alternatives to creosote that are registered as pesticides with the EPA. Chemical alternatives include pentachlorophenol and chromate copper arsenate (CCA), which are restricted use pesticides due to human health concerns and are no longer produced for residential use. Other chemical alternatives are ammoniacal copper zinc arsenate (ACZA), ammoniacal copper quaternary (ACQ), borates, copper azole, and naphthenates. Table 10 lists some chemical wood preservatives and their typical constituents and is adapted from Dickey (2003).

Table 10- Typical constituents of chemical wood preservatives adapted from Dickey (2003)

Material	Constituent	Percent
Creosote	Coal tar or distillate	50%
	Petroleum oil	50%
Pentachlorophenol (PCP)	pentachlorophenol	>95%
Acid Copper Chromate (ACC)	Copper as CuO	31.80%
	Hexavalent chromium as CrO_3	68.20%
Ammoniacal Copper Arsenate (ACA)	Copper as CuO	49.80%
	Arsenic as As_2O_5	50.20%
Chromated copper arsenate (CCA)	Hexavalent chromium as CrO_3	35.3-65.5%
	Copper as CuO	18.10-19.60%
	Arsenic as As_2O_5	16.40-45.10%
Ammoniacal Copper Zinc Arsenate (ACZA)	Copper as CuO	50%
	Zinc as ZnO	25%
	Arsenic as As_2O_5	25%
Ammoniacal Copper Quaternary (ACQ)	Copper as CuO	66.70%
	didecyldimethylammonium chlorides	33.30%
Borates	Sodium octaborate, sodium tetraborate, sodium pentaborate, or boric acid	varies
Copper Azole	Copper as CuO	49%
	Boron as boric acid	49%
	Tebuconazole	2%
Copper Naphthenate (CuN)	Copper	6-8%
	Naphthenic acid	varies
	Petroleum oil	varies
Zinc Naphthenate (ZnN)	Zinc	1.8-8%
	Naphthenic acid	varies
	Petroleum oil	varies

The city of San Francisco passed an ordinance requiring the use of safer alternatives to arsenic containing wood preservatives in city projects after June 30, 2003. The alternatives assessment eliminated pentachlorophenol, creosote and arsenicals as acceptable wood treatments for most uses. A list of acceptable materials was adopted on 9/10/03 and is divided by uses (Appendix C). They used the following nine criteria to evaluate potential alternatives to arsenicals:

1. If the product is pressure treated, treatment must be standardized by AWPA for the intended use.
2. Product must not be used in a manner that US EPA prohibits or discourages.
3. Product or use must not violate state or local law, policy, or published best management practices.
4. Product may not result in the release or creation of dioxins during manufacture or disposal.
5. Product, constituents, or contaminants may not be listed on the EPA Priority PBT list or the EPAWaste Minimization Priority Chemicals list.
6. Product (or components) should not contain known, likely, or probable human carcinogens listed by EPA, IARC, NTP, or State of California.
7. Product (or components) should not be listed as reproductive or developmental toxicants by the State of California.
8. For structures built in or over water, or where significant runoff is likely to occur, the use of copper should be minimized. If copper-based products are used, products with the lowest leaching potential should be chosen.
9. Products must not designate as a hazardous waste using criteria set by the State of California.

Creosote treated wood- Marine pilings

There is localized exposure to environment near creosote treated wood. Kenneth Brooks has conducted several biological studies for the Creosote Council, U.S. Western Wood Preservers Institute, Department of Agriculture, and other institutions that evaluate the organismal, population, and community effects associated with the use of creosote-treated wood. Specifically, Goyette and Brooks (1998) prepared a report on a study sponsored by Environment Canada, Fisheries and Oceans, British Columbia, and the wood treatment industry on creosote pilings in Sooke Basin, Vancouver Island, Canada. They found locally increased levels of PAHs in sediment, with significant biological effects within 0.65 meters.

Estimates of PAH releases from creosote-treated marine pilings were derived from release rates published in Valle *et al.* 2007 and estimates of the number of marine pilings in Puget Sound.

Rate of PAH loss from marine pilings is complex due to differences in exposure media (air, water, sediment) for each piling, and lack of uniformity in size and age for each piling. Stratus Consulting reviewed studies on leaching rates for NOAA Fisheries (2006) and found the rate of PAH leaching is greater:

- in freshwater than in saltwater
- at higher temperatures
- at higher flow rates

- from less dense wood
- from freshly treated wood
- from end grain compared to face grain
- with a higher surface area to volume ratio
- from wood that has not been treated to the industry's BMPs.

The authors of the 2007 New York/New Jersey Harbor study estimated a PAH loss rate from creosote-treated marine pilings based on how much PAH is in creosote treated marine pilings and lifetime losses of PAH using several different approaches based on two studies by Ingram *et al.* 1982 and Bestari *et al.* 1998. Leaching data from both studies were used in the NY/NJ Harbor report to estimate long term releases based on a first order decay model and a diffusion-based model leading to a final estimate of 23% loss. For this report we used the same value of 23% loss of PAH over the 30 year lifetime of a marine piling.

Dimensions of marine pilings vary due to their application; ranging from small diameter pilings used for private docks and finger piers in shallow water, to large pilings used for dolphins, wing walls, and navigation aids in relatively deep waters. Based on Washington State Department of Transportation's (WSDOT) Creosote Removal Initiative for state ferry terminals, the average piling removed was 63.5 ft^3 (WSDOT, 2010).

According to Valle *et al.* (2007), 8% of a typical piling is exposed to air (5.1 ft^3), 62% is exposed to water (39.4 ft^3), and 30% is buried below sediment (19.0 ft^3). Applying the PAH loss rates from Valle *et al.* (2007) to the average size piling in Puget Sound, gives a loss rate of 0.5134 kg PAH/piling, with 0.062 kg/piling/yr to air and 0.482 kg/piling/yr to water.

No data were found on the numbers of pilings in Washington. According to the U.S. Census Bureau, there are 79 marinas in the Puget Sound area and 115 in the state. Many of the marinas still contain creosote pilings, but the sum of these is not known. Creosote pilings used for commercial, industrial, and recreational piers likely numbers in the tens of thousands. There are numerous derelict pilings all around Puget Sound.

Permits are required to install marine pilings and creosote treated wood is currently not allowed, so new use of creosote treated marine pilings is minimal. State regulations exclude the use of creosote treated wood in lakes. Creosote piling removal is being conducted by a number of organizations. Washington State Department of Natural Resources has removed 6,756 pilings as of April 27, 2010 (personal communication with Lisa Kaufman at DNR). WSDOT's Creosote Removal Initiative removed 1.5 million board feet of pilings and timber (approximately 2,000 pilings) from its ferry terminals, representing one-tenth of the amount planned for removal the coming decade (WSDOT, 2010).

Given the rate of ongoing piling removal, the number of marinas in Washington, and the amount of industrial, commercial, and recreational waterfront, a rough estimate of 100,000 creosote-treated piling remaining in the Puget Sound area seems reasonable, although this could easily differ by several factors above or below the actual number. It would be possible to get a better estimate using local Shoreline Master Plans and GIS mapping, as was done in San Francisco Harbor (Werme, *et al.* 2010).

Table 11- Estimates of Total PAH Released from Creosote-Treated Marine Pilings

Product	Number	PAH Release Rate (kg/piling/yr)	PAH releases to water (kg/yr)	PAH release to air (kg/yr)	Total PAH Release (kg/yr)
Marine Pilings	100,000	0.482 (water) 0.062 (air)	48,200	6,200	54,400

<u>Opportunities for Reduction</u>

- Continue removal of creosote pilings and beach debris
- Write a state rule to consolidate permits for creosote treated wood
- Allow mitigation credits for removing creosote treated wood when new docks are permitted.
- Recommend BMPs for removal
- Inventory marine pilings and wood beach debris

Table 9 lists alternatives to pressure-treated wood with advantages and disadvantages and Table 10 lists other chemical wood preservatives. Not all of these alternatives are appropriate for marine pilings. EPA has more information on on CCA and alternatives at:http://www.epa.gov/oppad001/reregistration/cca/index.htm#alternatives.

New creosote treated wood pilings are generally not installed in marine waters and are not allowed in lakes. We should continue to remove existing creosote treated wood. The Washington State Department of Natural Resources has been leading efforts to remove creosote treated wood in marine environments. Washington State Ferries have been replacing creosote treated wood structures with steel and concrete. The Port of Seattle has been removing creosote pilings and replacing them with fewer concrete pilings for decades; more than 70,000 pilings over the last 35years (http://www.portseattle.org/Environmental/Pages/default.aspx).

While removing creosote treated wood pilings takes away an ongoing source of PAHs, during demolition there may be increases in PAHs. For example, during a DNR piling removal project on Commencement Bay in Tacoma PAH concentrations in nearby mussels and sediment may have increased (Parametrix 2011). This study also found that freshly exposed sections of aged creosote treated wood pilings release PAHs.

While it would be useful to have consolidated permits for creosote treated wood, we do not currently have the resources to promulgate a new rule. It would also be useful in the future to allow mitigation credits for removing creosote treated wood when new docks are permitted.

Creosote treated wood- Utility poles

Estimates of PAH releases from utility poles were derived from release rates published in a 2007 study of PAH sources to New York/New Jersey Harbor and estimates of the number of utility poles in Washington.

According to Feldman and Shistar (1997) there are 1,531,622 utility poles in Washington State based on 28.5 poles per distribution mile. Based on the assumption that the percentage of utility poles in the state that are creosote-treated is identical to that of the NY/NJ Harbor (13% in Valle *et al.* 2007), the total number of creosote-treated poles in the state is 199,111.

The authors of the New York/New Jersey Harbor study estimated a PAH loss rate from creosote-treated utility poles of 212 g/pole/yr over the 35 year lifetime of a pole (Valle *et al.* 2007).

The PAH emission rate applied to the total number of creosote treated poles results in an estimated 42,172 kg/yr of PAH released from the above ground portion of utility poles to the air (Table 12).

Table 12- Estimates of Total PAH Released from Creosote-Treated Utility Poles

Product	Number of creosote treated utility poles	PAH Release Rate (kg/pole/yr)	Total PAH Release (kg/yr)
Utility Poles	199,111	0.212	42,172

Opportunities for Reduction

Although creosote is still approved for use in utility poles, utilities in Washington State are no longer installing new creosote treated poles. Most new utility poles in Washington are treated with pentachlorophenol, with a few areas using copper naphthenate. Old poles continue to be taken out of service and disposed of according to our state laws on waste disposal.

Table 9 lists alternatives to pressure-treated wood with advantages and disadvantages and Table 10 lists other chemical wood preservatives. Not all of these alternatives are appropriate for utility poles.

Vehicle emissions

Combustion

How much is in Washington

Emissions from fuel combustion and evaporation are estimated using the AQ inventory based on the WSDOT information from the national Department of Transportation's Highway Performance Monitoring System to estimate the average daily vehicle miles traveled (ADVMT). The AQ inventory also took into account different fuels and variations within a calendar year.

AQP modeled 15 PAHs, which is the common list of 16 without fluorene. The largest source within this category was light duty gasoline vehicles as shown in Table 13.

Table 13- Estimates of Total PAH Released from Vehicle Combustion

Source	PAHs (kg/yr)
Light duty gasoline vehicles	46,744
Heavy duty gasoline vehicles	16,813
Heavy duty diesel vehicles	2,744
Light duty diesel vehicles	328
Total for all vehicles	66,629

Opportunities for Reduction

- Continue the current diesel reduction strategy
- Increase efficiency of fuels and vehicles
- Improve auto maintenance
- Replace older vehicles including financial incentives to encourage this replacement
- Encourage use of alternative fuels
- Reduce vehicle miles through public transportation, carpooling or other means
- Reduce the amount of engine idling by promulgating a statewide anti-idling rule
- Reduce idling at drive thrus using education and outreach with a corporate partner
- Electrify truck stops and ports
- Encourage the use of powerpacks by ferries to reduce midnight idling
- Change ferries to liquefied natural gas
- Encourage all ports to follow the example of ports with emissions reduction goals
- Retrofit diesel engines to burn more cleanly
- Washington State Patrol could enforce existing laws on visible vehicle exhaust
- Improve traffic flow management to reduce time spent idling at traffic lights
- Support new federal actions

The amount of PAHs released per mile is affected by fuel type, vehicle class and driving mode. In general, factors that decrease fuel efficiency and result in more fuel burned will also increase the generation of PAHs. For example, more PAHs are released per mile of stop-and-go driving compared to uncongested driving.

Idling contributes to lowered fuel efficiency and wastes money. Education and outreach, especially with a corporate partner for drive thrus, will reduce idling. Further reductions can be achieved with an anti-idling rule that applies to both gasoline and diesel engines.

Vehicles with better gas mileage will use less fuel and emit fewer PAHs. Proper maintenance of existing cars will also increase gas mileage and decrease PAH emissions. Replacing older vehicles with newer, more fuel efficient vehicles will also decrease PAH emissions. Several local initiatives have focused on this. The Port of Seattle has been increasing fuel efficiency requirements for trucks that are allowed to work at the port. Seattle City Light has been introducing hybrid diesel-electric vehicles, which have yielded 60-70% reductions in fuel consumption compared to non-hybrid bucket trucks. The City of Tacoma and Cascade Sierra Solutions are providing financial incentives for this. Electric cars do not emit PAHs from the car, although there will be PAH emissions from the electricity generation, if combustion is used to generate the electricity. Biodiesel may emit fewer PAHs than regular diesel (reviewed in McCormick 2007).

Any alternative to driving, especially in single occupant vehicles, will decrease PAH emissions. Alternatives to driving in single occupant vehicles include use of public transportation, carpooling, bicycling, and walking. People can also reduce the number of miles driven by telecommuting. Washington State should continue to support our state commute trip reduction program, which is overseen by the state Department of Transportation.

The 2005 Washington Clean Car Act will improve emissions of several pollutants as new cars are purchased, since 2009 and newer model year vehicles must meet California emission standards.

Ecology’s Diesel Reduction Strategy has many actions to reduce emissions from diesel engines. In addition to gains in fuel efficiency, diesel emissions from trucks can be reduced by reducing idling and retrofitting older engines to burn more cleanly. The City of Seattle has a no idling policy that has reduced fuel consumption for the city fleet by over 100,000 gallons a year within 2 years of adopting the policy. Ecology is participating in several programs to reduce idling. Examples include electrification of truck stops and ports, retrofitting diesel engines in public fleets, and installing anti-idling technology on emergency vehicles. The Washington Clean Diesel Program has put 9,100 emission controls on 6,400 school bus engines, plus helped pay for the replacement of 80 school buses with new buses equipped with the latest pollution reduction technology. The grant program has also funded 2,200 retrofits on 1,900 engines on public vehicles and equipment (garbage, port, city maintenance, etc.). The Clean Diesel Grant Program has begun putting anti-idling technology on emergency vehicles. Poulsbo was the first fire department in the state to install idle reduction technology in its ambulances and fire trucks, using a $39,000 clean diesel grant from Ecology. The savings are estimated to average $20,000 per year for the four vehicles. In addition to saving money and reducing toxic emissions, fire fighters have found the technology to reduce noise, making it possible to communicate more easily. These programs save money and reduce diesel emissions and should be expanded, but additional funding is needed.

As a demonstration project, Ecology and other agencies electrified 76 commercial truck parking spaces in two truck stops in Washington, so that truckers can turn off their main engines and plug in for power needed to run cab amenities and equipment while taking their rest period. This project is being done with Oregon in a joint effort to reduct idling along the West Coast.

The Port of Seattle, the Port of Tacoma, and Port Metro Vancouver (BC) have joined together in a Northwest Ports Clean Air Strategy to voluntarily reduce air emissions. While the strategy is focused on diesel emissions, the reductions they bring about will also reduce PAHs. The 2010 progress report included the use of low sulfur fuel, electrical shore power connections, diesel engine retrofits, replacement of older engines, and idle-reduction. An example of a specific project is the Princess Cruise Shore Power Project at Port of Seattle. In 2004, the EPA, Princess Cruises, Port of Seattle, Puget Sound Clean Air Agency (PSCAA), and Seattle City Light invested in shore power technology so that two cruise ships don't have to run diesel engines while docked at port. In the 2010 progress report, all of the frequent cruise vessel calls at the Port of Seattle used either shore power or low sulfur fuel. This effort should be used as a model for other ports to reduce emissions. The Port of Seattle funded SCRAPS program, administered by PSCAA, scrapped 180 of the oldest heavy duty diesel trucks serving the ports and provided incentives to replace them with newer, cleaner vehicles. The Port of Seattle terminals required the newer trucks in order for drivers to access the terminal as of 1/1/11. Estimated annual reductions from the 180 vehicles is 3.5 tons of diesel PM.

Other actions by ferries that will reduce PAHs include the use of powerpacks at night and changing from diesel to natural gas as a fuel.

In order to completely eliminate PAHs from vehicle exhaust, we would have to stop using internal combustion engines in Washington, which is not a realistic or feasible action.

Non-combustion vehicle sources

In addition to combustion, there are other non-combustion vehicle related sources of PAHs. These other sources include motor oil leaks, improper disposal of motor oil, and tire wear.

Motor oil leaks

PAHs released through leaks and drips of crankcase oil, combustion, and other releases from vehicles were estimated using data on vehicle miles travelled and estimates of motor (crankcase) oil loss between oil changes.

How much is in Washington

Based on data from the WSDOT, there are 90,338,376,000 annual kilometers traveled on state roads (http://www.wsdot.wa.gov/mapsdata/tdo/annualmileage.htm). WSDOT also has data on vehicle kilometers traveled for motorcycles, passenger cars, light trucks, buses, single unit trucks, and combo trucks (WSDOT personal communication, 10/20/10).

The concentration of PAHs in motor oil of 1375 mg/kg from Valle *et al.* (2007) was used to estimate PAHs, along with loss rates of one-half quart per 5,000 mile oil change for motorcycles, one quart per 5,000 mile oil change for passenger cars and light trucks, and two quarts per 10,000 mile oil change for heavy trucks and buses (Ecology 2011c).

The quantities of motor oil released from vehicles and associated PAH releases are shown in Table 14. Releases from non-road vehicles were not estimated.

Table 14- Estimates of Motor Oil Released through Motor Oil Leaks, Incidental Drippage, and Other Releases from Vehicles

Vehicle Type	Vehicle Kilometers Travelled (km/yr)	Release Rate (mg/km)	Motor Oil Released (kg/yr)	PAHs released (kg/yr)
Motorcycle	3.5 x10^{8}	54 (a)	18,733	26
Passenger car	5.7 x10^{10}	108 (b)	6,152,770	8460
Light truck	2.33 x10^{10}	108 (b)	2,516,115	3460
Bus	2.3 x10^{8}	108 (b)	24,294	33
Single unit truck	4.5 x10^{9}	108 (b)	482,656	664
Combo. truck	5.0x10^{9}	108 (b)	543,244	747
Total	9.03 x 10^{10}		9,737,812	13,389
Estimate of Total Motor Oil Release from Leaks, Incidental Drippage, and Other Releases from Vehicles (kg/yr)				13,389

(a) Equivalent to one-half quart loss per 5,000 miles. Specific gravity of 0.91 used to convert from volume to mass.
(b) Equivalent to one quart loss per 5,000 miles. Specific gravity of 0.91 used to convert from volume to mass.

Opportunities for Reduction

- Expand outreach on proper car maintenance
- Require inspections of all registered vehicles to check for leaks and drips
- Increase street sweeping to prevent PAHs in leaked motor oil from reaching aquatic systems
- Encourage use of readily available biodegradable bio-based motor oils for some vehicles

Public support for mandatory inspections does not current exist, so expansion of voluntary programs on car maintence should be expanded to further reduce drips and leaks.

Management actions such as street sweeping will prevent some PAHs from being transported to aquatic organisms, but prevention programs are more effective in the long term.

Improper disposal of used motor oil

How much is in Washington

Oil released from vehicles through improper disposal by vehicle owners/operators following oil changes was estimated by applying survey results of oil disposal habits to the estimated number of oil changes performed annually in Washington. These estimates used the same estimates of vehicle distance travelled as used for calculated releases from leaks and drippage (see previous section) except the heavy duty vehicle categories were excluded.

Rates of improper disposal of motor oil from motorists performing oil changes were based national survey published in 2002 by U.S. Department of Transportation (USDOT, 2002). The survey found 21% of adults changed their own oil and 16% of people who change their own oil disposed of the used oil improperly, yielding an improper disposal rate of 3.4%.

The number of oil changes was based on an assumption of 5,000 mile intervals between changes. When applied to travel distances estimated for each vehicle categories, there are 7.1 million oil changes per year for passenger cars, 2.9 million changes per year for light trucks, and 43,362 changes per year for motorcycles.

Oil volume per disposal event was assumed to be the full crankcase oil capacity (including filter) of the vehicle. A review of the 74 passenger vehicles and 17 light-duty trucks for which Motorcraft supplies filters had median oil capacities of 5.0 quarts and 6.0 quarts, respectively. An internet search of motorcycle oil capacities suggests that 2.5 quarts is a reasonable estimate average.

The concentration of PAHs in used motor oil of 1375 mg/kg from Valle *et al.* (2007) was used to estimate PAHs.

Table 15 shows annual rates of PAHs released due to improper disposal of used motor oil. Releases from non-road vehicles, such as lawn and garden, marine, or commercial equipment, were not estimated.

Table 15- Estimates of Motor Oil Released through Improper Disposal of Used Oil

Vehicle Type	Vehicle Kilometers Travelled (km/yr)	Oil Changes per Year (Total)	Oil Changes per Year (Improper)	Oil Change Volume (Qts)	Motor Oil Released (kg/yr)**(a)**	PAHs released (kg/yr)
Motorcycle	3.4 x10^{8}	43,362	1,474	2.5	3,170	4.6
Passenger car	5.7 x10^{10}	7,121,123	242,118	5.0	1,041,108	1431.5
Light truck	2.3 x10^{10}	2,912,114	99,012	6.0	510,901	702.5
Estimate of Total PAHs Released Due to Improper Disposal of Used Motor Oil (kg/yr)						2,138.4

(a) Specific gravity of 0.91 used to convert from volume to mass.

Opportunities for Reduction

- Education and outreach to get people to dispose of the used oil safely and legally
- Any actions that reduce driving will also reduce oil changes

Vehicle tire wear

Tire tread contains a variable amount of extender oil, from 11-16% in cars and up to 28%, with a concentration of 17-357 mg/kg total PAHs (European Commission 2003). High aromatic extender oils that contain PAHs improve the viscoelasticity of the rubber compound and contribute to the tread rubber compound grip, wear, and endurance of tires (Valle *et al.* 2007).

People are most directly affected by the percentage of tire particles that are small enough to be inhaled (PM10). Larger particles will be transported in surface runoff to water bodies, and impact aquatic ecosystems, especially sediment dwelling organisms. Stephensen *et al.* (2003) found effects of submerged tires on rainbow trout (European Commission 2003).

How much is in Washington

Tire wear was estimated based on WSDOT annual reporting on vehicle kilometers traveled for motorcycles, passenger cars, light trucks, buses, single unit trucks, and combo trucks (WSDOT personal communication, 10/20/10). Based on data from the WSDOT, there are 90,338,376,000 annual kilometers traveled on state roads (http://www.wsdot.wa.gov/mapsdata/tdo/annualmileage.htm). An annual tire wear rate of 38 mg/tire/km travelled (Washington State Department of Ecology 2011c) was used, with different vehicle classes having different numbers of tires. The tire loss estimate was used with the concentrations of 5 PAHs in tire wear (Valle *et al.* 2007) to get an estimate of 1490 kg/year. This estimate does not include off road vehicles. This estimate also does not include vapor emissions of PAHs during use.

Table 16- Estimates of Total PAH Released from Vehicle Tire Wear

Vehicle Type	Number of Tires per Vehicle	Tire Wear Rate (mg/km/tire)	PAH Concentration in Tire Material (mg/kg)	Vehicle Kilometers Travelled (km/yr)	Annual PAH Release (kg)
Motorcycle	2	38	89	346,899,364	2
Pass. Car	4	38	89	56,970,090,057	771
Lt. Truck	4	38	89	23,297,363,787	315
Bus	8	38	89	224,942,556	5
Sgl. Unit Truck	8	38	89	4,469,039,461	91
Combo Truck	18	38	89	5,030,040,776	306
Estimate of Total PAH Release from Vehicle Tire Wear (kg/yr)					1490

Opportunities for Reduction

- Continue incentives to reduce vehicle miles driven
- Encourage development of tires that don't include PAHs or that don't wear and release particles containing PAHs.
- Anything that reduces miles traveled will reduce tire wear.

In addition to driving fewer miles, other factors affect the rate of tire wear, such as tire inflation, vehicle load, speed, and driving style.

PAHs in tires can be reduced by using extender oils with lower concentrations of PAHs, as is being done in the EU as of January 1, 2010 (Directive 2005/69/EC).

Lawn and garden and recreational equipment

These non-road mobile sources include emission estimates from gasoline, diesel, compressed natural gas, and liquefied petroleum gas fueled equipment. It also includes both 2- and 4-stroke engines. Two-stroke engines can be lighter and more portable, so are used in applications such as chainsaws and leaf blowers. However, two-stroke engines are less fuel efficient than four-stroke engines, meaning they both use more fuel and emit more PAHs. Two-stroke engines also don't have a separate lubrication system, but instead burn oil mixed with fuel. Because of the design of two-stroke engines, incoming unburned fuel can leave with the outgoing exhaust. The AQ Inventory did not estimate emissions from the unburned fuel, which may be a significant source of PAHs.

How much is in Washington

The largest source within this category is lawn and garden equipment, followed by recreational equipment , and recreational marine vessels (Table 17).

Table 17- Estimates of Total PAH Released from Lawn and garden and recreational equipment

Source	Kg/yr
lawn and garden equipment	6,380
recreational equipment	2,279
recreational marine vessels	1,298
Total	9,957

Opportunities for Reduction

- Reduce use of gas powered garden equipment, especially two-stroke engines, through education and incentives
- Ban the use of two-stroke engines
- Improve combustion efficiency
- Educate people on how to avoid petroleum spills from recreational boats

Lawn and garden equipment is the largest source in this category. Alternatives include using machines that are electric or manually powered, such as rakes instead of leaf blowers. There are technologies that improve combustion efficiency and reduce emissions from lawn and garden equipment. These technologies allow equipment to meet California's more stringent emission standards from 2010 (http://www.arb.ca.gov/msprog/offroad/sore/sore.htm). There are many vendors of electric lawn and garden equipment for both residential and commercial uses. Electric powered equipment do not generate emissions, but there are emissions from electricity generation.

There are alternative recreational activities that do not use PAH emitting equipment.

Residential Trash Burning

The AQP estimated the number of households burning trash based on a Washington State University telephone survey in Idaho, Oregon and Washington on wood heating and outdoor burning habits.

How much is in Washington

The amount of trash burned was estimated at 3.38 lbs per household per day. The total PAH estimate for this category was 9,061 kg/yr.

Opportunities for Reduction

- Increase education and enforcement of the current ban

It is illegal to burn garbage in Washington. Garbage must be disposed in accordance with each county's waste management plan. There are alternatives to create less garbage, such as recycling some materials and composting food waste.

Non-Road Mobile Sources- Business equipment

How much is in Washington

The largest source within this category is commercial equipment (Table 18), followed by construction and mining equipment, agricultural equipment industrial equipment, logging equipment, airport service equipment railroad maintenance equipment and oil field equipment.

Table 18- Estimates of Total PAH Released from Business Equipment

Source	PAHs (kg/yr)
commercial equipment	2774
construction and mining equipment	1739
agricultural equipment	936
industrial equipment	413
logging equipment	161
airport service equipment	20
railroad maintenance equipment	9
oil field equipment	6
Total	6,058

Opportunities for Reduction

- Improve combustion efficiency
- Increase use of electric vehicles, particularly diesel electric hybrids

Heavy duty commercial, industrial, etc. equipment does not always lend itself to manually powered alternatives, so alternatives for those types of equipment are often equipment that has better combustion efficiency. However, SeaTac Airport is in the process of electrifying its entire ground fleet of 200 support vehicles in concert with the Department of Energy. They estimate a reduction of 400,000 gallons of fuel annually.

Silvicultural and agricultural burning

Silvicultural burning is controlled burning that is permitted by DNR for logging debris and forest health burns. The burning of small piles of vegetation does not require a DNR permit and was estimated in the category of yard waste.

Agricultural burning is the burning of vegetative debris for disease or pest control, crop propagation and/or crop rotation, or where identified as a best management practice. All agricultural burning in Washington requires a permit and Ecology maintains an agricultural burn permit database. The AQ inventory listed PM10 and PM2.5 releases, but did not estimate PAHs for agricultural burning due to lack of data. One study tested four samples for seven PAHs and only detected two PAHs (dibenzo(a,h)anthracene and indeno(1,2,3-cd)pyrene) in two samples.

How much is in Washington

The AQP inventory used the DNR 2005 burn permit database to estimate polycyclic organic matter (POM) emissions of 1274 kg/yr for the state.

The AQ inventory also estimated that 281,830 tons of material was burned. Using pine forest emission factors (Valle *et al.* 2007) gives an estimate of 9205 kg of PAH.

The two estimates were for different groups of PAHs. The Air Quality Inventory includes an estimate for polycyclic organic matter (POM), pollutant code 246. Valle *et al.* 2007 used emission factors for 10 PAHs. The average of the two estimates is 5,240 kg/yr.

Table 19- Estimate of Total PAH Released from Silvicultural Burning

Estimate based on	PAH Release (kg/yr)
POM	1274
Tons of material burned	9205
Average	**5240**

Opportunities for Reduction

Opportunities to reduce PAHs from agricultural and silvicultural burning include identifying methods to reduce the need for burning.

Locomotives

Emissions from Class I freight railroads were estimated in the AQ Inventory. This estimate includes the Burlington Northern Santa Fe, the Union Pacific Railroad, and Amtrak. Class 2 and 3 railroad locomotives were not included because emissions from Class 2 and 3 locomotives were a small percentage of total locomotive emissions according to a study in Oregon cited in the AQ Inventory. The emissions estimates were derived from the amount of diesel fuel used.

How much is in Washington

The estimate for locomotives is 2314 kg/yr.

Opportunities for Reduction

- Improve combustion efficiency
- Retrofit existing engines

Locomotives are an efficient way to transport goods and people. As with other diesel engines, there is newer technology that reduces PAH emissions. EPA is phasing in emission standards that will make locomotives less polluting (www.epa.gov/otaq/locomotives.htm).

Industrial Point Sources

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.

The data on releases from the TRI are for individual compounds and a category of PAHs. The N590 category of polycyclic aromatic compounds (PACs) includes the 20 compounds in Table 20. N590 is considered a PBT and has a reporting threshold of 100 lbs.

Table 20- PAHs in N590 category

CAS	Name	WA PBT list
56-55-3	Benz(a)anthracene	
205-99-2	Benzo(b)fluoranthene	X
205-82-3	Benzo(j)fluoranthene	X
207-08-9	Benzo(k)fluoranthene	X
206-44-0	Benzo(j,k)fluorene	X
189-55-9	Benzo(r,s,t)pentaphene	X
218-01-9	Benzo(a)phenanthrene	X
50-32-8	Benzo(a)pyrene	
226-36-8	Dibenz(a,h)acridine	X
224-42-0	Dibenz(a,j)acridine	X
194-59-2	7H-Dibenzo(c,g)carbazole	X
5385-75-1	Dibenzo(a,e)fluoranthene	
192-65-4	Dibenzo(a,e)pyrene	X
189-64-0	Dibenzo(a,h)pyrene	X
191-30-0	Dibenzo(a,l)pyrene	
57-97-6	7,12-Dimethylbenz(a)-anthracene	
193-39-5	Indeno(1,2,3-cd)pyrene	X
56-49-5	3-Methylcholanthrene	X
3697-24-3	5-Methylchrysene	
5522-43-0	1-Nitropyrene	

In addition to the compounds in category N590, there are additional PAHs reported in the TRI. Benzo(g,h,i)perylene is considered a PBT and has a reporting threshold of 10 lbs. The other three compounds are not considered PBTs and have *de minimis* concentrations of either 0.1 % for a carcinogen or 1% for other compounds. The three non-PBTs were not included in our estimates, but are mentioned here as additional PAHs in the TRI. Creosote is a mixture of chemicals, including PAHs, and is also required to be reported in the TRI. There are no Washington facility TRI reports for creosote in the last several years.

Table 21- Additional PAHs reported in TRI

CAS	Name	Reporting threshold
191-24-2	Benzo(g,h,i)perylene	10 lbs
91-20-3	Naphthalene	0.1 %
120-12-7	Anthracene	1.0 %
85-01-8	Phenanthrene	1.0 %
8001-58-9	Creosote	0.1 %

The estimates in Table 22 include the N590 category described above (Table 20), and benzo(g,h,i)perylene for 2009. The three individual compounds that are not on the Washington State PBT list were not included.

Industries that require a lot of energy also report larger PAH releases, which is not surprising, because PAHs are formed during combustion. Aluminum smelters release more PAHs than other large energy users because of the chemistry of aluminum production. Aluminum production uses sacrificial anodes, which are made from coal tar pitch and carbon. In the chart below, one aluminum smelter, Alcoa Wenatchee, is responsible for most of the land releases in the state. All of the offsite land releases (19,181.5 kg) are from Alcoa Wenatchee and all of the onsite land releases (19.3 kg) are from Intalco. The land releases were not included in the totals for the summary tables and charts, because they are contained releases.

Table 22- 2009 TRI releases by type of facility and media in kg in Washington State.

Type of facility	fugitive air	stack air	water	onsite land	offsite land	total
aluminum smelters	478.43	821.69	0.00	19.30	19,181.50	20,500.91
pulp and paper mills	0.91	278.31	17.07	33.60	108.78	438.66
oil refineries	17.81	18.56	0.91	54.48	1,013.46	1,105.22
asphalt paving	0.70	164.35	0.00	1.14	0.00	166.19
other	0.09	2.45	0.11	0.00	656.06	658.71
total	497.94	1,285.35	18.09	108.47	20,959.80	22,869.66

The releases reported in 2008 and 2007 were very similar to those in 2009, with one exception. In 2007 Welch's and Treetop reported 6850 lbs (3110 kg) of PAHs in stack air emissions. They switched to natural gas from #6 oil and no longer have PAH air emissions to report (personal communication).

Table 23- 2008 TRI releases by type of facility and media in kg in Washington State.

Type of facility	fugitive air	stack air	water	onsite land	offsite land	total
aluminum smelters	497.95	1,468.37	0.00	32.96	23,470.89	25,470.17
pulp and paper mills	0.91	416.33	17.25	35.41	58.88	528.78
oil refineries	15.76	18.52	0.77	12.12	847.89	895.07
asphalt paving	0.95	321.23	0.00	1.73	0.00	323.91
other	0.56	3.64	0.10	0.00	797.44	801.73
total	516.13	2,228.08	18.12	82.23	25,175.10	28,019.67

Table 24- 2007 TRI releases by type of facility and media in kg in Washington State.

Type of Facility	Fugitive Air	Stack Air	Water	onsite land	Offsite Land	total
aluminum smelters	497.72	1,209.55	0.00	40.04	18,909.10	20,656.41
Fruit canning	0.00	3,109.82	0.00	0.00	0.00	3,109.82
Pulp and paper mills	1.36	307.56	28.61	44.40	87.12	469.05
Oil refineries	18.35	9.40	0.86	114.38	20.18	163.16
asphalt paving	0.08	196.18	0.00	1.34	0.82	198.43
other	0.18	3.15	0.22	0.00	627.49	631.04
total	517.69	4,835.65	29.69	200.16	19,644.71	25,227.90

The national releases are similar to the releases we see in Washington State. The National Priority Chemicals Trends Report for 2005-2007 (USEPA 2010) found 26.7% of the reported PACs were from primary aluminum production. The largest national category is carbon black manufacturing, but there are no such facilities in Washington.

AQ Inventory of Point Sources

Ecology and the local air quality agencies inventory large industrial facilities annually for the emissions inventory. Point sources are defined as industrial, commercial or institutional stationary sources. All major point sources are included, but not all minor sources may be included in the inventory. Data is collected by local air agencies, Ecology regional offices, and Ecology's Industrial Section, and Ecology enters the data into the Washington Emissions Data System. The estimates are similar to, but not exactly the same as the TRI estimates, due to different methods of estimating the releases.

Emissions on different PAHs are included. Naphthalene had the most lbs emitted (11,361 for 2008) but naphthalene is not on the PBT list, so those emissions were not included. Other PAHs that are not on the PBT list also were not included. Benzo(a)anthracene and benzo(a)pyrene were included to allow a better comparison to the TRI estimates. Most of the emissions were reported under a variety of synonyms for PAHs, including POM, PAC and PNA. Some referenced the TRI N590 category for PACs.

Table 25- 2008 Air Emissions Inventory by Chemical (in kg)

CAS	Chemical	kg
56-55-3	Benzo(a)anthracene	1.8
50-32-8	Benzo(a)pyrene	6.4
191-24-2	Benzo(g,h,i)perylene	0.9
206-44-0	Fluoranthene	0.5
193-39-5	Indeno(1,2,3-cd)pyrene	0.9
various	PAHs, POMs, PACs, PNAs	3,261

As in the TRI reporting for air emissions, aluminum smelters had the largest emissions.

Table 26- 2008 Air emissions Inventory by type of facility (in kg)

Type of Facility	kg
Aluminum smelter	2,614.59
Energy production, storage, and transmission	390.44
Asphalt products and paving	126.21
Medical, military and educational facilities	102.15
Oil refineries	28.60
Paper and wood	9.08
Airplane production	0.45
total	3,271.52

Opportunities for Reduction

There are currently limited opportunities for reduction. Large industrial facilities have made large gains in efficiencies to reduce PAH emissions and are closely regulated to make sure they operate in the intended manner.

The invention of non-sacrificial anodes for aluminum smelting would be greatly reduce PAHs. This is not currently feasible, but is being worked on by the industry.

To completely eliminate PAHs from large industrial facilities, we would not be able to have such facilities in our state, which is neither feasible nor desireable.

Coal tar and asphalt sealants

Coal tar and asphalt-based sealants are black liquids that are sprayed or painted on asphalt parking lots and driveways. Sealants are designed to extend the life of asphalt from damage caused by UV degradation, gas and oil, and water entering the pavement. Coal tar is a by-product when coal is carbonized to make coke or gasified to make coal gas (ATSDR, 2002).

Studies published by the USGS first identified coal tar sealant as a potentially important PAH source in 2005 (Mahler *et al.* 2005). Subsequent research seemed to limit the major impacts to east of the Rockies (Van Metre, *et al.* 2008). In the 2008 paper PAH concentrations in dust from seal coated pavement in six U.S. cities east of the Rockies were about 1000 times higher than in dust from seal coated pavement in three western cities, including Seattle, where asphalt-based sealant is more commonly used. Asphalt sealants have about 1000 times fewer PAHs than coal tar sealants; about 50 mg/kg compared to 50,000 mg/kg (City of Austin, 2005). A 2010 paper (Van Metre and Mahler) expanded their analysis of PAH sources to 40 urban lakes across the U.S. that are among those sampled by the USGS National Water Quality Assessment (NAWAQ) Program. Surprisingly, this recent study suggests that about half of PAHs in sediments in urban lakes come from coal tar sealants, including two urban lakes in western Washington. However, the total levels of PAHs were consistently much lower west of the Rockies.

Sealants are not a major source of PAHs to most people, but some individuals have higher exposures. Children who live in apartments with coal tar sealed driveways may have higher exposures. PAHs in house dust are particularly important for children, who spend more time on the floor and put their hands and objects into their mouths. Coal tar sealants on driveways contribute PAHs to indoor house dust (Mahler *et al.* 2010). This study looked at house dust in 23 apartments that had parking lots with different surfaces and found significantly higher levels of PAHs in the house dust of apartments with driveways that had a coal-tar based sealcoat. The study found a median concentration of PAHs in dust from coal tar sealed parking lots of 4760 ug/g, which was more than 500 times higher than that of unsealed or asphalt sealed parking lots. The levels of PAHs in the settled house dust were 25 times higher in apartments with coal tar sealed parking lots. There are no US regulations on PAHs in dust, but there is a German guideline for benzo(a)pyrene of 10 ug/g. In the USGS study, about a third of the apartments with coal tar sealed parking lots and all of the coal tar sealed parking lots had concentrations of this PAH in dust above the German guideline of 10 ug/g.

How much is in Washington

It is thought that asphalt based sealcoats are used more commonly than coal tar based sealcoats in Washington and other areas west of the Continental Divide. In 2011, Washington became the first state to ban the purchase and use of coal tar sealants. A retailer may not sell coal tar pavement products after January 1, 2012, and no person may apply a coal tar pavement product on a driveway or parking area after July 1, 2013 (RCW 70.295).

Valle *et al.* (2007) estimated that 1.4 million gallons of coal tar sealant are sold in the NY Harbor watershed each year. Using the release rates from Mahler *et al.* (2005), and assuming a constant release rate for all annual storm events, they estimated an annual release of 900-5800 kg of PAHs for their watershed, or 0.64 to 4.14 g PAH/ gallon of sealant.

We do not have exact estimates for how much coal tar sealant is used in Washington, but industry estimated that 400,000-600,000 gallons were used in Washington in 2004 (WSDOT, 2007). Annual use may have gone down, because all public and private users in Washington are moving towards a blended product of 20% coal tar pitch and 80% asphalt emulsion, which greatly reduces the release of PAHs (WSDOT 2007). WSDOT has stopped using coal tar sealants (Jeff Uhlmeyer, WSDOT, personal communication).

Using the concentration of 50,000 mg/kg for PAHs in coal tar sealants (City of Austin 2005), the 400,000 to 600,000 gallons (approximately 2,270 metric tons) of coal tar sealants estimated to be used in Washington each year contain about 113.5 metric tons of PAHs. Based on the release rates calculated in the NY Harbor study, approximately 256-2484 kg/year is released in the state. This estimate does not account for a shift to asphalt based sealants and mixtures of coal tar and asphalt since 2004, so the current use in Washington may be lower. This estimate is just for the first year and does not account for releases in later years. The sealants are leaching PAHs for several years, but the rate of leaching is likely to go down over time. Coal tar sealants are often recommended to be reapplied every 2-5 years (Asphalt Institute 2011, Mahler *et al.* 2005, Valle *et al.* 2007) and WSDOT found coal tar sealants to last 8-10 years (WSDOT 2007), so the actual amount of PAHs released could be several times higher. This estimate also does not account for volatization of PAHs from the sealant.

Table 27- Estimate of Total PAH Released from Coal Tar Sealants

Product	Amount used (gallons)	PAH Release Rate (gram/gallon)	PAH Release (kg/yr)
Sealant	400,000	0.64-4.14	256-384
	600,000	0.64-4.14	1656-2484
Estimate of Total PAH Release from coal tar sealants (kg/yr)			1195

Opportunities for Reduction

The sale and use of coal tar sealants has already been banned in Washington.

Asphalt-based sealants are an alternative with lower levels of PAHs. The City of Austin, Texas measured PAH content of several different coat tar and asphalt sealants and found that the median PAH content of asphalt-based sealants was 50 ppm, while that of coal-tar based sealants was more than 50,000 ppm (City of Austin, 2005). The city of Austin has a list of alternatives on its website (http://www.ci.austin.tx.us/watershed/coaltar_altproducts.htm) to assist with compliance with the city’s Coal Tar Ban Ordinance.

There are also alternatives that are not asphalt-based. E-Krete is a polymer composite micro-overlay that is recognized by the EPA Design for the Environment program. AROS^{TM} is a product made from ground tires and polymer modified asphalt (http://www.coepolymer.com/Technology.html).

Petroleum spills

PAHs are a component of petroleum, in addition to being formed by incomplete combustion of petroleum and other substances.

How much is in Washington

Concentrations of PAHs in petroleum materials were available in the literature and cited in Valle *et al.* (2007). The concentration of PAHs in unknown petroleum materials was estimated using the average concentration of PAHs in known petroleum materials.

Estimates of petroleum released via spills were obtained from the Washington Oil Spill Resource Damage Assessment (RDA) account and from Ecology's Environmental Report Tracking System (ERTS).

The RDA data are an accounting of compensation paid by liable parties that have spilled oil into state waters. Damages are assessed on a case-by-case basis, but in general appear to be proportional to the volume of material spilled, and take into account information such as estimates of how much was recovered. Data from 2000-2010 was used to estimate annual spills. The largest spill in the state was the June 1999 Bellingham gasoline pipeline leak. This spill is not included because it was more than 10 years ago, and gasoline does not contain many PAHs.

Table 28- Average Annual PAHs from spills based on RDA from 2000-2010

Material spilled	average gallons/yr	average mass/yr (MT)	PAH conc. (mg/kg)	total PAH (kg)
Diesel	6,762	22.0	8,111	176.0
Heating oil	48	0.2	8,111	1.3
Crude oil	929	3.4	497	1.5
Lube oil	118	0.4	1,012	0.4
Other(a)	2,265	7.0	4,069	17.0
Total from RDA	10,122	33.0		196.2

(a) Other includes transformer oil, hydraulic oil, bunker oil, waste oil, and turbine oil.
(b) A specific gravity of 0.85 was used to convert volume to mass.

ERTS contains data are collected largely through a telephone hotline and online reporting approach to response of material spills and other complaints regarding chemical releases (e.g. odor complaints). Information from the hotline calls and online submittals are placed in a database and prioritized for subsequent investigation. While this database contains a fairly comprehensive inventory of spill events, data on release amounts are generally un-quantified. For instance, oil sheens may be reported on water surfaces which pose difficulties for investigators attempting to estimate the quantity, and sometimes the type, of material spilled. There may be spills that are not reported.

The last three complete years of ERTS data was used, 2008-2010, to get an average annual estimate. Since a complete tally of the material quantities listed in ERTS could potentially result in an over-estimate, some of the ERTS data were excluded. Data for spills of more than 42 gallons to land and water that had been looked at and corrected were used. This may lead to an underestimate, since small spills were not included. However, the spills that were included are more likely to be more accurate. Spills that are included in the RDA are also in the ERTS database, so those spills were removed from the ERTS estimate. We did not account for the small percentage of volume spilled that is typically recovered.

Table 29- Average Annual PAHs from spills based on ERTS from 2008-2010

Material spilled	average gallons/yr	average mass/yr (MT) (b)	PAH conc. (mg/kg)	total PAH (kg)
Diesel	25,237	81	8,111	657
Heating oil	1,209	4	8,111	31
Lube and motor oil	796	3	1,012	3
Other (a)	8702	28	4,069	114
Total PAHs from oil spills in ERTS database				805

(a)Other includes chlorinated oil, hydraulic oil, bunker oil, waste oil, fuel oil, mineral oil, transformer oil, other, and unknown oil.

(b)A specific gravity of 0.85 was used to convert volume to mass.

Table 30- Average annual PAHs from spills

	Water	Land	Total PAHs (kg)
ERTS	54	750	804
RDA	196	0	196
Total	**250**	**750**	**1000**

While the RDA is only for spills to state waters, the majority of the spills in the ERTS database were to land. Of the approximately 1,000 kg of PAHs from oil spills over 42 gallons, 750 kg were to land and 250 kg were to water.

Opportunities for Reduction

Ecology will continue to work on spill prevention and response to minimize effects.

Asphalt roofs and pavement

The report on sources of selected chemicals to the Puget Sound (Ecology 2011c) estimated 568 kg of PAHs are released from roof runoff and 20 kg from asphalt pavement in the twelve counties surrounding Puget Sound. The Puget Sound area has approximately 70% of the population of Washington State. Using the population to scale up the estimate for the entire state, results in approximately 800 kg from roof runoff and 30 kg from asphalt pavement.

Opportunities for Reduction

- Conduct additional research into releases from roofing materials
- Investigate PAH content of different paving and roofing materials
- Encourage use of materials with fewer PAHs

Roofing may be a significant source of PAHs and other chemicals to our environment, but we need more research into the materials used for roofing and paving.

Residential yard waste burning

The AQ Inventory estimated the number of households burning yard waste and the size of the piles based on a Washington State University telephone survey in Idaho, Oregon and Washington on wood heating and outdoor burning habits.

How much is in Washington

There were no direct estimates for PAHs, but they can be estimated from PM10. PM10 estimated for this source category is 573.52 tons per year. PM10 is approximately 60% of the total particulate, making the total particulate 956 tons. Using the EPA estimate for land clearing burning, 0.000345 tons PAH per ton of total particulate (EPA Emission Inventory Improvement Program, 2001), results in 0.33 tons of PAH or 300 kg/yr.

Opportunities for Reduction

- Reduce yard waste burning and encouraging waste reduction through activities such as composting
- Provide more free opportunities for people to dispose of yard waste without burning, especially after storms
- Increase enforcement of existing bans

Because of air emissions concerns, outdoor burning is banned in urban growth areas in Washington State. Burn barrels have been illegal everywhere in Washington since 2000, but small burn piles are legal in some areas. During periods when wood smoke pollution reaches unsafe levels, local air agencies call for burn bans to prohibit outdoor burning. Ecology also has a program to exchange burn barrels for compost bins.

There are other ways to dispose of yard waste, such as chipping or composting. These can be done by homeowners in their own yard or on a larger community scale with curbside pickup or collection sites. Ecology maintains information on locations in each county that collect yard waste (http://www.ecy.wa.gov/programs/air/outdoor_woodsmoke/alternativestoburn.htm).

Residential fuel combustion- Petroleum, coal, natural gas, and kerosene

In the AQ Inventory, Washington State fuel use for 2005 was obtained from the Energy Information Administration. The region use was estimated using temperature, population and other parameters. Coal was not considered, since less than 500 housing units in the state use coal as their heating source.

How much is in Washington

The estimate of PAHs from this category was 54 kg/yr.

Opportunities for Reduction

- Provide incentives for newer heating units that are more efficient and release fewer PAHs
- Increase education and outready on proper installation, use and maintenance of existing furnaces
- Increase programs for insulation and weather stripping to make houses more energy efficient and reduce the amount of heat needed

Cigarette smoke

PAHs are in cigarette smoke due to incomplete combustion. PAH emissions are estimated using per-cigarette PAH emission factors provided by Valle *et al.* (2007) and estimates on the number of cigarettes consumed in the state. Smokers of unfiltered cigarettes may have twice the exposure to PAHs as the general population (ATSDR 1995).

How much is in Washington

In Valle *et al*. (2007) the total PAH quantity in cigarette smoke was reported to be 6.79 µg/cigarette.

Two estimates of cigarette numbers consumed annually in the state are calculated using data from WDOH and Department of Revenue (DOR). WDOH estimated there were 840,000 smokers in Washington State (WDOH, 2010). The Centers for Disease Control estimates that each smoker consumes 16.8 cigarettes per day (CDC, 2005), yielding a total state consumption rate of 5.15 billion cigarettes/yr.

A higher cigarette consumption rate is provided by DOR which reported a state per capita consumption of 1,106 cigarettes/yr during 2006 (DOR, 2007). For the current population of Washington State of 6,733,250, the rate would be 7.8 billion cigarettes/yr.

Estimated release rates based on PAH emissions and cigarette consumption rates are shown in Table 31. PAH release estimates ranged from 35 kg/yr to 53 kg/yr. The mid-point of this range was 44 kg/yr. Total PAH emissions may be underestimated because the emission factors are only for seven PAHs.

Table 31- Estimates of Total PAH Released from Cigarette Smoke

Source of estimate	cigarette consumption (cigarettes/yr)	Total PAH emission rate (ug/cigarette)	PAH release (kg/yr)
WDOH and CDC	5.15×10^9	6.79	35
DOR	7.8×10^9	6.79	53
average	**6.475×10^9**	**6.79**	**44**

Opportunities for Reduction

- DOH should continue and enchance anti-smoking programs

Washington has laws on cigarette smoke in public areas to protect the general public. This reduces PAH exposure to smokers and bystanders but doesn't reduce the amount of tobacco-PAH emissions, except as it deters overall tobacco use.

To eliminate PAHs from cigarette smoke, we would have to ban smoking in Washington,which is not a feasible action.

Cigarette butts

Using the average estimate from the earlier section of 6.475×10^9 cigarettes smoked in Washington each year and the estimate that a third of all butts are littered, 2.137×10^9 butts are discarded in Washington each year. One pound of dry cigarette butts equals approximately 2,000 cigarette butts (Ecology 2000b), which leads to an estimate of 534 tons of cigarette butts discarded in Washington each year. The Washington State Litter Study (Ecology 2000b) estimated 123 tons of cigarettes are thrown away each year on the side of roads, in state and county parks, public recreation access areas, and rest areas. The statistics do not include packaging. Moriwaki *et al.* (2009) measured the elution of eleven PAHs from cigarette butts in roadside litter to be 0.032 mg/150 butts. Based on the estimate of 2.1 billion discarded butts, the PAH load would be 0.45 kg/year.

Miscellaneous Combustion Not Quantified

Structure and vehicle fires

According to the Air Quality Program 2005 inventory (Otterson 2007), there were 10,786 structure fires and 6,121 accidental vehicle fires in the state. The numbers of fires nationally was allocated to each county based on population for structure fires and vehicle miles traveled for vehicle fires. PAHs were not measured or estimated with emission factors, but are expected to be present in the particulate matter.

Tire fires

Washington currently has no known tire pile fires, but there are unknown numbers of fires in the state that may contain tires. In 2005, the Washington State Legislation created a Tire Removal Account to fund tire pile clean ups. A $1 fee is collected for each new vehicle tire sold in Washington. All of the tire piles identified in the 2005 study (Ecology 2005a) have been cleaned up along with many others. A portion of the fee continues to go towards cleaning up tire piles each year to prevent future tire pile fires and other hazards of tire piles, such as mosquito-borne disease.

Historically, tire pile fires have been sources of PAHs. The most well known tire pile fire started in Everett in 1984 on the former city landfill site. The landfill was closed in 1975 and in 1977 someone began storing tires on the site. Eventually there were more than one million tires on the site. There was a small fire in 1983, but the September 1984 fire was unable to be suppressed and burned until April 1985. The smoke from the Everett tire fire temporarily closed Interstate 5. The site was put on Ecology's Hazardous Site list in 1990 and has been cleaned up. Tire fires have hazardous emissions to the air, water and soil. There have been other large tire pile fires, such as the Winlock and Dorman tire pile fires.

Fireworks, Campfires, and Grilling

While PAHs are expected to be present in emissions from fireworks, campfires, and grilling, we have not attempted to quantify the PAHs released.

Other sources not quantified

General consumer products

The Danish Ministry of the Environment (2011) investigated PAHs in toys and childcare products. Based on earlier German studies, they focused on products with extender oils and/or carbon black. Such products included rubber and flexible plastics that may use extender oils as plasticisers and black plastics that may use carbon black as a pigment. Foam products were avoided, since they were not expected to contain extender oils. According to the Danish Ministry of the Environment (2011), extender oils and carbon black with low levels of PAHs are available and there are other materials that do not contain extender oils.

PAHs were found in all 20 products analyzed by the Danish Ministry of the Environment (2011). The products included a toothbrush, shoes, bicycles, eraser, rubber duck, doll, and balls. About half of the samples contained <1 mg/kg (ppm) total PAHs, 40% contained 1-10 mg/kg and one sample contained 100-1000 mg/kg. There are no current specific limits on PAHs in toys, but Germany has proposed a limit of 0.2 mg/kg for a set of 8 PAHs (see regulation section). Two products, a bicycle tire and a scooter grip, exceeded those proposed limits.

Shampoo

PAHs are found in coal tar shampoos used for anti-dandruff therapy, in coal tar ointments used for treatment of eczematous dermatitis, and in treatments for psoriasis (ATSDR 2002). Coal tar is FDA approved for treatment of dandruff, seborrheic dermatitis, or psoriasis at 0.5 to 5 percent.

Clay pigeons

A clay pigeon is the target used in skeet or trap shooting. The disks are not made of clay, but are usually made from petroleum. There are examples in Washington of sites on the Hazardous Site List that are shooting ranges contaminated with PAHs from clay pigeons, such as the Issaquah Sportsmen Club in King County (FS IS 98935455).

There are non-toxic clay pigeons for sale. For example White Flyer has a biodegradable target that meets the same strict performance standards for competitions, including the Olympics. There are concerns about the effect of non-toxic clay pigeons on grass when a lot of targets are used, but other users report no problems.

Specialty oils and greases

Like other petroleum products, specialty oils and greases will contain petrogenic PAHs.

Leaking underground storage tanks (LUSTs)

The LUST List contains 4655 records with information on underground storage tank facilities that require cleanup and their cleanup history.

Opportunities for Reduction of Unquantified Sources

- Increase research into releases from these unquantified sources to determine how much PAH they release
- Increase research into alternatives that do not contain PAHs
- Educate consumers on which products contain PAHs and what alternatives are available
- Develop outreach materials on ways people can individually reduce their own exposure to PAHs

Natural Sources

Forest fires

How much is in Washington

The 2005 AQ Inventory (Otterson 2007) estimated 25,776 tons of PM10 from wildfires statewide. The EPA estimate for land clearing burning is 0.000345 tons of POM per ton of total particulate and PM10 is approximately 60% of total particulate for silvicultural emissions. This leads to an estimate of 13,474 kg PAH.

The most recent available statistics from the Washington State Department Natural Resources (DNR) is for the 2008 fire season, for which DNR reported 32,679.14 acres of classified fires in the state at least partially on DNR lands (WDNR 2009). A classified fire is an uncontrolled fire that required suppression action. The National Interagency Fire Center reports national estimates for all wild fires in Washington. We used the larger national estimates, since they include fires on more lands. The National Interagency Fire Center has more recent information for 2010, when there were 56,820 acres of wildfires in Washington. We used 10 tons/acre for wildland fires and EPA emission factors for pine forests (Valle *et al.* 2007) to estimate 18,558 kg of PAH for the state. Emission factors will vary by factors such as fuel type, age of material, moisture content, pesticides and herbicides.

Table 32- Estimates of Total PAH Released from Forest Fires

source	Type of information	PAH Release (kg/yr)
2005 AQ inventory PM10	25,776 tons PM10	13,474
2010 National Interagency Fire Center	56,820 acres burned	18,558
Average		**16,016**

Petroleum deposits

PAHs are naturally occurring in petroleum deposits and may be released to water and soil through seeps. We did not estimate how much petroleum is in the state.

Volcanoes

We did not quantify the amount of PAHs released by volcanoes, but the amount is likely to be small. The Toxicological Profile on PAHs (ATSDR 1997) states that natural sources include volcanoes and references the Hazardous Substance Data Bank entry on PAHs (HSDB 1994). In the HSDB entry on PAHs, they also state that volcanoes are natural sources of PAHs, but their reference is to the ATSDR Toxicological Profile for PAHs. The two sources point to each other and we were unable to find another source that showed a significant amount of PAHs from volcanoes.

There are no published measurements of PAHs released from the more recent eruptions of Mount St. Helens (Sherrod 2008). We could not find any measurements of PAHs in any of the USGS information on volcanoes, particularly Mount St. Helens. The USGS information on volcanoes (USGS 1995) states that “water vapor is typically the most abundant volcanic gas, followed by carbon dioxide and sulfur dioxide. Other volcanic gases are hydrogen sulfide, hydrochloric acid, hydrogen, carbon monoxide, hydrofluoric acid, and other trace gases and volatile metals.” A 1977 paper by Ilnitsky *et al.* estimated that worldwide release of benzo(a)pyrene from volcanoes was 1.2-14 tons/year. There is also a paper by Stracquadanio *et al.* (2003) that volcanic ash from Mt. Etna scavenges anthropomorphic PAHs from the air, but this paper does not mention any PAHs being emitted from the volcano itself.

Table 33- Summary of annual PAH releases by media in kg/year

	Air	**Water**	**Soil/surface**	**Total**
Residential wood burning	148,266			148,266
Creosote treated wood	134,924	48,200	86,552	269,676
Railroad ties	*86,552*		*86,552*	
Marine pilings	*6,200*	*48,200*		
Utility poles	*42,172*			
Vehicle emissions- total	66,629		17,017	83,646
Light duty gasoline vehicles	*46,744*			
Heavy duty gasoline vehicles	*16,813*			
Heavy duty diesel vehicles	*2,744*			
Light duty diesel vehicles	*328*			
Motor oil leaks			*13,389*	
Improper disposal of used motor oil			*2,138*	
Vehicle tire wear			*1,490*	
Lawn, garden, and recreational equipment	9,957			
Lawn and garden equipment				
Recreational equipment	*6,380*			
Recreational marine vessels	*2,279*			
	1,298			
Residential trash burning	9,061			9,061
Business Equipment	6,058			6,058
Commercial equipment	*2,774*			
Construction and mining equip.	*1,739*			
Agricultural equipment	*936*			
Industrial equipment	*413*			
Logging equipment	*161*			
Airport service equipment	*20*			
Railroad maintenance equipment	*9*			
Oil field equipment	*6*			
Silvicultural burning	5,240			5,240
Locomotives	2,314			2,314
Industrial point sources (a)	1,783	18		1801
Coal tar sealants			1,195	1,195
Peroleum spills		250	750	1000
Asphalt roofs and pavement			830	830
Residential yard waste burning	300			300
Residential fuel, non-wood	54			54
Cigarette smoke	44			44
NATURAL SOURCES				
Wild fires	16,016			16,016

(a) Does not include releases to landfills.

Pathways of PAHs and Source Apportionment

The major pathways for PAHs to reach people and the environment are air and surface water. Different sources of PAHs will reach different receptors at different rates through the two major pathways. This has been estimated in different places using different methods, such as ratios of specific PAHs and markers for wood. Some of the following information is included to give a general sense of the methods used and what was found, even if it is not exactly what would be needed to estimate pathways of PAHs from all sources for Washington State. The PAH CAP is different from many studies, because we care about the entire state, and not just one receptor, such as a particular water body or air monitor.

Puget Sound Air Deposition Study

One part of the Puget Sound Toxics Loading Study assessed air deposition of PAHs directly to Puget Sound marine waters (Ecology 2010c) and this information was included in the final assessment report (Ecology 2011b). Within the report on air deposition the authors looked at apportioning PAHs to different sources using PAH diagnostic ratios.

The report plotted the diagnostic ratios for the PAHs collected at the eight stations and some sediment core samples from Puget Sound/Hood Canal and the Strait of Georgia from other published reports. Figure 14 shows the methylphenanthrene to phenanthrene ratio (MP/P) vs. fluoranthene over the sum of fluoranthene and pyrene (FL/(FL+Py). They found the atmospheric particles were pyrogenic, from a mixture of petroleum and biomass combustion. While it is hard to distinguish between coal and biomass combustion using these ratios, there is little coal combustion in Washington. They also found sediment received a slightly higher proportion of PAHs from petrogenic and petroleum combustion sources compared to the air deposition, which the report suggested could be due to motor oil. Other diagnostic ratios had similar findings, but suggested more of the PAHs came from wood combustion.

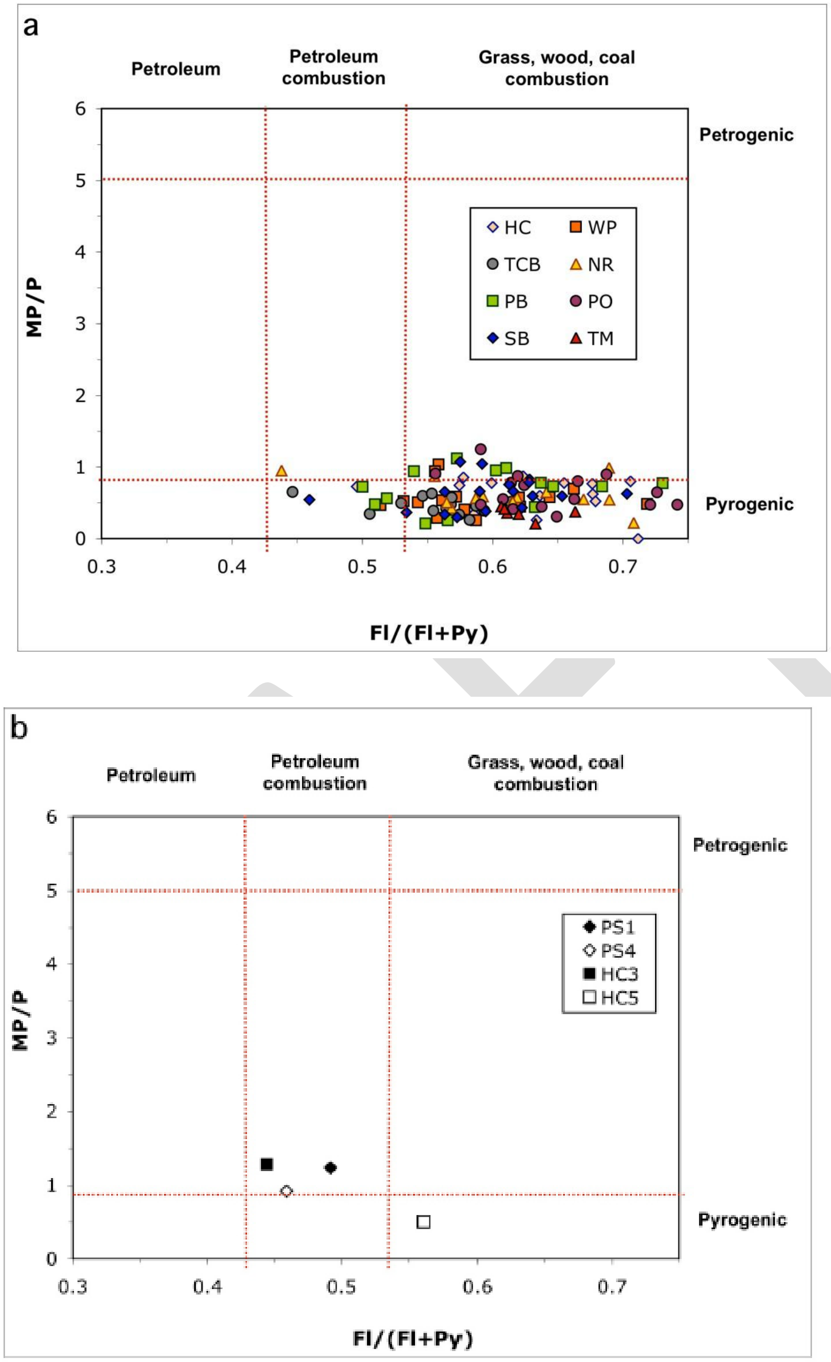


Figure 14 PAH diagnostic ratios in a) atmospheric deposition samples and b) surface sediments in the Puget Sound Main Basin (PS) and Hood Canal (HC).

The air deposition report also used principal component analysis using parent and alkylated PAHs and levoglucosan, which is a marker for biomass combustion. Using the principal component analysis and the Ret/ (Ret + Chy) ratio, the authors apportioned source at each of the eight collection stations. Both models agree on the importance of biomass combustion, especially in the rural and suburban stations, where it was about 50%. The urban stations had more petroleum combustion.

NY Harbor Study

The NY/NJ Harbor Study (Valle *et al.* 2007) constructed a fate and transport model to estimate transmission of each PAH compound from major emission sources in the region to the harbor. The authors made a series of simplifying assumptions, such as zero PAHs that fall on pervious surfaces are transported to the harbor, while 90% of PAHs that fall on impervious surfaces are transported to the harbor. They found that only a small percentage of atmospheric emissions ever reach the harbor, while the majority of PAHs that reach the harbor come from sources that emit PAHs onto impervious surfaces, such as oil leaks and tire wear, and direct sources to the harbor such as creosote pilings.

USGS study

As mentioned earlier in the section on levels of PAHs in sediments, the U.S. Geological Service looked at PAHs in sediments in the last 20-40 years in ten lakes across the nation (Van Metre *et al.* 2000). The study included Lake Ballinger, an urban lake located north of Seattle, and Lake Washington in Seattle. The authors used a mass-balance model to compare PAH profiles of sources and sediments. This was the first study to include coal tar sealants as a possible source and they found large contributions to sediment from coal tar sealants in most of the lakes studied, including the two lakes in Washington. This result does not match with what we know about the limited use of coal tar sealants in Washington.

Ecology studies

As mentioned earlier in the section on levels of PAHs in sediments, Ecology has done two studies on PAHs in sediment cores in lakes (Ecology 2009 and 2010b). The studies used the Fl/(Fl+Py) ratio to determine that the lakes were dominated by combustion-derived sources.

Some Ecology studies have looked at PAH profiles near contaminated sites. One example is a study of PAHs in sediments near the Wyckoff wood treatment facility on the south shore of Elliott Bay (Ecology 1989). The study looked at the levels of total PAHs and the profiles of 6 PAHs at different sites closer and farther from the facility. They found PAH profiles closest to the facility had a similar profile to creosote compared to samples from sediments located farther from the facility. The study also found higher levels of PAHs in sediments closer to the facility.

New information from Ecology modeling

To make recommendations to reduce PAHs in Washington, we'd like to know more specifically which combustion sources contribute the most to PAHs in sediments.

We used a chemical mass balance model from the EPA, CMB8.2 (USEPA 2004), to apportion source contributions to sediment in Puget Sound. This model was originally developed for air monitors, but has been used for sediments by others, notably Li *et al.* (2003) used it to look at sediments in Lake Calumet in Chicago and Van Metre *et al.* (2010) used it to look at sediments in 40 lakes across the country. Van Metre *et al.* added coal tar sealants as a source profile in the model. We have added creosote as a source profile, using measurements of PAHs in creosote contaminated soil in a Wisconsin river (Stout and Graan 2010). One caveat of the CMB model is that it does not take degradation into account, so it seemed better to use the creosote profile from contaminated sediment instead of from new creosote. The other source profiles come from Li *et al.* (2003) and Van Metre *et al.* (2010). The other source profiles included diesel and gasoline engine emissions, tire particles, coal burning, residential heating, and wood burning.

We have not been able to get the model to work well without using the coal tar sealant profiles. When coal tar sealants are considered as a possible source, the model predicts that they are a major source. This does not agree with what we know about the limited use of coal tar sealants in Washington.

Current Regulatory Approaches for PAHs

This chapter describes the existing regulations relevant to PAHs and the activities that generate them at the federal, state, local, and international levels. It includes a brief summary of many known laws and regulations directly related to management of processes that produce PAHs (combustion and burning), the production, use, and disposal of products that contain PAHs (such as creosote, coal tar, and used oil), and exposure limits and cleanup levels for PAHs themselves.

While this chapter aims to be comprehensive, it is not an exhaustive review of all of the regulations pertinent to PAHs.
In many instances, federal laws and regulations delegate the authority for implementing these laws and regulations on 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

Water Regulations

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

EPA has established water quality criteria for these 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 must include conditions to protect water quality. The EPA and authorized states 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.

16 PAHs are listed in the Clean Water Act as priority pollutants.[13] National Recommended Water Quality Criteria for these PAHs can be found in Table 34. In addition, certain states, including Washington, are subject to necessary water quality criteria under the National Toxics Rule (40 CFR 131.36).[14] These criteria are also found in Table 34.

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

[14] US EPA. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliances. 57 FR 60848. Available at: http://www.epa.gov/waterscience_keep/standards/rules/ntr.html (accessed 9 June 2011).

Table 34- National Recommended Water Quality Criteria

					National Recommended Water Quality Criteria (NRWQC)[15]		**National Toxics Rule (NTR) Criteria**[16]	
					Human Health for the Consumption Of			
CAS	Name	WA PBT list	TRI PBT list	Clean Water Act Priority Pollutant #	Water + Organism (µg/L)	Organism Only (µg/L)	Water & Organisms (µg/L)	Water & Organisms (µg/L)
83-32-9	acenaphthene			56	670	990		
208-96-8	acenaphthylene			57				
120-12-7	anthracene			58	8,300	40,000	9600	110000
56-55-3	benzo(a)anthracene		x	60	0.0038	0.018	0.0028	0.031
50-32-8	benzo(a)pyrene		x	61	0.0038	0.018	0.0028	0.031
205-99-2	benzo(b)fluoranthene	x	x	62	0.0038	0.018	0.0028	0.031
191-24-2	benzo(g,h,i)perylene	x	x	63				
207-08-9	benzo(k)fluoranthene	x	x	64	0.0038	0.018	0.0028	0.031
218-01-9	benzo(a)phenanthrene (chrysene)	x	x	73	0.0038	0.018	0.0028	0.031
53-70-3	dibenzo(a,h)anthracene	x	x	74	0.0038	0.018	0.0028	0.031
206-44-0	fluoranthene	x	x	86	130	140	300	370
86-73-7	fluorene			87	1,100	5,300	1300	14000
193-39-5	indeno(1,2,3-cd)pyrene	x	x	92	0.0038	0.018	0.0028	0.031
91-20-3	naphthalene			94				
85-01-8	phenanthrene			99				
129-00-0	pyrene			100	830	4,000	960	11000

Acenaphthene (CAS# 83-32-9) also has criteria for organoleptic (taste and odor) effects of 20 µg/L.

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

[16] US EPA. Toxics criteria for those states not complying with Clean Water Act section 303(c)(2)(B). 40 CFR 131.36. Available at: http://www.gpo.gov/fdsys/pkg/CFR-2009-title40-vol21/xml/CFR-2009-title40-vol21-sec131-36.xml (accessed 9 June 2011).

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.

The SDWA specifies a MCLG for benzo(a)pyrene (PAHs) of 0, and a MCL of 0.002 mg/L.[17]

Air Regulations

42 USC 7401, Clean Air Act and Amendments

PAHs are regulated under Section 112 of the Clean Air Act as Hazardous Air Pollutants (HAPs). They are regulated as a class of compounds referred to as Polycyclic Organic Matter (POM), which includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100 ºC.[18] EPA's guidance for locating and estimating sources of POM recommends using the common list of 16 PAHs to estimate emissions of POM.[19] A 2000 EPA memorandum suggests several other specific compounds may also appropriately be included in calculating emissions of POM.[20]

Regulation under Section 112 of the Clean Air Act requires major sources of HAPs to meet standards based on Maximum Achievable Control Technology (MACT). 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.

POM is 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.[21]

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

[18] US EPA. Original list of hazardous air pollutants. Available at: http://www.epa.gov/ttn/atw/188polls.html (accessed 9 June 2011).

[19] US EPA. Locating and Estimating Air Emissions from Sources of Polycyclic Organic Matter. EPA-454/R-9-014. July 1998. Available at: http://www.epa.gov/ttn/chief/le/index.html (accessed 9 June 2011).

[20] http://www.epa.gov/ttn/atw/agghapsmemo3.html

[21] 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.

PAHs are also among the compounds emitted by mobile sources that are subject to EPA rules. PAHs on the EPA's Master List of Compounds Emitted by Mobile Sources are found in Table 35.

Table 35- PAHs on EPA's Master List of Compounds Emitted by Mobile Sources[22]

CAS	Name
50-32-8	benzo(a)pyrene
53-70-3	dibenzo(a,h)anthracene
56-49-5	3-methyl chlolanthrene
56-55-3	benzo(a)anthracene
83-32-9	acenaphthene
85-01-8	phenanthrene
86-73-7	fluorene
91-20-3	naphthalene
120-12-7	anthracene
129-00-0	pyrene
189-55-9	benzo(r,s,t)pentaphene
191-24-2	benzo(g,h,i)perylene
191-30-0	dibenzo(a,l)pyrene
192-65-4	dibenzo(a,e)pyrene
193-39-5	indeno(1,2,3-cd)pyrene
198-55-0	perylene
205-82-3	benzo(j)fluoranthene
205-99-2	benzo(b)fluoranthene
206-44-0	fluoranthene
207-08-9	benzo(k)fluoranthene
208-96-8	acenaphthylene
218-01-9	benzo(a)phenanthrene (chrysene)
3697-24-3	5-methyl chrysene
5522-43-0	1- nitropyrene

The Clean Air Act is also used to regulate specific sources of PAHs. EPA's wood stove regulations create new source performance standards for residential wood stoves. Wood stoves must undergo emissions testing at EPA-accredited laboratories and carry labels indicating they comply with emissions standards.[23]

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[22] US EPA. Master List of Compounds Emitted by Mobile Sources. EPA420-B-06-002. Available at: http://www.epa.gov/oms/toxics.htm (accessed 10 June 2011).

[23] US EPA. Standards of Performance for New Residential wood Heaters. 40 CFR Part 60 Subpart AAA. Available at: http://www.epa.gov/Compliance/monitoring/programs/caa/whregs.html (accessed 10 June 2011).

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. Examples of these different codes pertinent to PAHs include:

Table 36- Dangerous Waste Designation codes

Dangerous Waste No.	Sources
Nonspecific Sources	
F024	Process wastes, including but not limited to, distillation residues, heavy ends, tars, and reactor clean-out wastes from the production of certain chlorinated aliphatic hydrocarbons by free radical catalyzed processes. These chlorinated aliphatic hydrocarbons are those having carbon chain lengths ranging from one to and including five, with varying amounts and positions of chlorine substitution. (This listing does not include wastewaters, wastewater treatment sludges, spent catalysts, and wastes listed in this section.) (T)
Coking:	
K087	Decanter tank tar sludge from coking operations. (T)
K141	Process residues from the recovery of coal tar, including, but not limited to, collecting sump residues from the production of coke from coal or the recovery of coke by-products produced from coal. This listing does not include K087 (decanter tank tar sludges from coking operations).

K142	Tar storage tank residues from the production of coke from coal or from the recovery of coke by-products produced from coal.
K147	Tar storage tank residues from coal tar refining.
K148	Residues from coal tar distillation, including but not limited to, still bottoms.

A variety of PAH-containing wastes are specifically listed on the RCRA lists, including wastes from production and use of creosote and coal tar. Wastes produced from the burning of fossil fuels, including ash, slag, and particulates removed from flue gas, are exempted from RCRA hazardous waste requirements.[24] When recycled, used oil is exempt from RCRA and conditionally regulated under less stringent standards (40 CFR Part 279)[25]. Creosote-treated wood is generally not subject to regulation as a hazardous waste under RCRA, and is discussed further in the section below on creosote-treated wood regulations.[26] However, state requirements for managing creosote-treated wood may be more stringent than federal requirements.

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. Reportable Quantities vary between 1 and 5000 pounds for the different PAH compounds, as seen in Table 37.

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[24] US EPA. Fossil Fuel Combustion Waste. Available at: http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ (accessed 10 June 2011)

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

[26] US EPA. Reregistration Eligibility Decision for Creosote (Case 0139). EPA 739-R-08-007. September 2008. Available at: http://www.epa.gov/oppsrrd1/REDs/creosote_red.pdf (accessed 10 June 2011).

Table 37 - CERCLA Reportable Quantity (RQ) for PAHs[27]

CAS	Name	CERCLA RQ (lbs)
50-32-8	benzo(a)pyrene	1
53-70-3	dibenzo(a,h)anthracene	1
56-49-5	3-methyl chlolanthrene	10
56-55-3	benzo(a)anthracene	10
57-97-6	7,12-dimethylbenz(a)anthracene	1
83-32-9	acenaphthene	100
85-01-8	phenanthrene	5000
86-73-7	fluorene	5000
91-20-3	naphthalene	100
120-12-7	anthracene	5000
129-00-0	pyrene	5000
189-55-9	benzo(r,s,t)pentaphene	10
191-24-2	benzo(g,h,i)perylene	5000
193-39-5	indeno(1,2,3-cd)pyrene	100
205-99-2	benzo(b)fluoranthene	1
206-44-0	fluoranthene	100
207-08-9	benzo(k)fluoranthene	5000
208-96-8	acenaphthylene	100
218-01-9	benzo(a)phenanthrene (chrysene)	100

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 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

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[27] 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 2011. Available at: www.epa.gov/ceppo/pubs/title3.pdf (accessed 10 June 2011).

year exceeds the reporting threshold. For most TRI chemicals, the thresholds are 25,000 pounds manufactured or 10,000 pounds otherwise used. However, for the category Polycyclic Aromatic Compounds (PACs) the reporting threshold is 100 lbs.[28] There are also a number of individual PAHs or PAH-containing substances that are reportable under the TRI. For more information on TRI chemicals and releases in Washington, see the discussion of Industrial Point Sources in the Production, Uses, and Releases chapter.

15 USC 2601 et seq., Toxic Substances Control Act

The Toxic Substances Control Act 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 (including those containing coal tar) and pesticides (including creosote products).

Because TSCA regulates uses of individual chemicals, not products or pollutants, TSCA does not have a large degree of significance in the overall picture of PAH regulations.

Creosote-Treated Wood Regulations

7 USC 136 et seq., Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

Under FIFRA, all pesticides must be licensed for use in the United States by EPA. In order for a EPA to license a pesticide, applicants must show that the use of the pesticide will not cause "unreasonable adverse effects on the environment."[29] Pesticides must also be properly labeled and packaged. Distributors cannot sell any pesticide to a user that is not registered in accordance with FIFRA. Applicators are required to take exams in order to obtain the necessary certification for the use of certain pesticides.

Creosote is the primary PAH-containing product that is regulated under FIFRA. Creosote is a restricted-use pesticide. Restricted use pesticides are pesticides that EPA licenses for use on specific pests under specific circumstances. In 1986, an EPA review of the pesticide registration for creosote resulted in requirements that workers use protection and protective clothing when applying creosote. The review also restricted creosote use to non-residential use sites. All uses of creosote besides pressure treatment of wood products were voluntarily cancelled by registrants under FIFRA in 2004. Creosote can now be applied as wood preservative only by certified

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[28] 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 2011. Available at: www.epa.gov/ceppo/pubs/title3.pdf (accessed 10 June 2011).

[29] US EPA. Summary of the Federal Insecticide, Fungicide, and Rodenticide Act. Available at: http://www.epa.gov/regulations/laws/fifra.html (accessed 10 June 2011).

applicators or someone under their direct supervision within strict guidelines. EPA's Reregistration Eligibility Decision (RED) for Creosote details these guidelines.[30]

According to the RED, there are no registered uses of creosote treated wood for residential purposes, but creosote treated wood (especially railroad ties) may be used in residential landscaping applications. EPA has indicated it believes exposure from these applications is minimal.

16 USC 1531-1544, Endangered Species Act (ESA)

Section 7 of the Endangered Species Act requires that any federal agency planning to fund, permit, or carry out activities that may affect an ESA-listed species must first consult on the effects of the action with the National Oceanic and Atmospheric Administration (NOAA)[31] Fisheries Service and/or the US Fish and Wildlife Service[32], depending on the species. Permit authority for the Corps of Engineers under the Section 10 of the Rivers and Harbors Act of 1899 and Section 404 of the Clean Water Act and the ESA-listed status of Puget Sound Chinook salmon, Puget Sound steelhead, Hood Canal Summer-Run chum salmon, and bull trout provide a Federal nexus for ESA consultation for nearly all projects pertaining to the use of treated wood in aquatic environments in the Puget Sound region. This includes construction, deconstruction, or rebuilding of small and large docks, bulkheads and overwater facilities.[33] ESA consultations in the Puget Sound region universally favor the use of these alternative preservatives or the use of steel over the installation of new creosote-treated wood into aquatic environments.

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).[34] For PAHs, the OSHA PEL in air is 0.2 milligrams/cubic meter (mg/m^3), measured as the benzene-soluble fraction of coal tar pitch volatiles. The National Institute for Occupational Safety and Health, which is charged with providing research, information, education, and

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[30] US EPA. Reregistration Eligibility Decision for Creosote (Case 0139). EPA 739-R-08-007. September 2008. Available at: http://www.epa.gov/oppsrrd1/REDs/creosote_red.pdf (accessed 10 June 2011).

[31] NOAA Fisheries Office of Protected Resources. Interagency Consultation (ESA Section 7). http://www.nmfs.noaa.gov/pr/consultation/ (accessed 10 June 2011).

[32] US Fish & Wildlife Service. Consultation. Available at: http://www.fws.gov/pacific/ecoservices/endangered/consultation/index.html (accessed 10 June 2011).

[33] US Army Corps of Engineers Regulatory Program. Private Docks. Available at: http://www.sac.usace.army.mil/assets/pdf/regulatory/Facts/Dock%20Permitting/DockFacts.pdf (accessed 10 June 2011).

[34] Occupational Safety and Health Administration. Permissible Exposure Limits (PELs). Available at: http://www.osha.gov/SLTC/pel/ (accessed 10 June 2011).

training in the field of occupational safety and health, has recommends a workplace air exposure limit of 0.1 mg/m^3.[35]

21 USC 301 et. seq., Federal Food, Drug, and Cosmetic Act (FDCA)

The Federal Food, Drug, and Cosmetic Act gives the Food and Drug Administration (FDA) the authority to regulate cosmetics. Under this authority, FDA has adopted regulations pertinent to certain semi-permanent and temporary hair dyes that contain coal tar. Dyes that contain coal tar ingredients must either seek listing and approval of these ingredients or include a caution statement on their label. Certain ingredients that have been found to cause cancer in laboratory animals must carry a caution statement specific to cancer.[36] FDA also regulates the use of coal tar in shampoos through the process for approval of over-the-counter (OTC) drugs. Coal tar is approved for treatment of dandruff, seborrheic dermatitis, or psoriasis at 0.5 to 5 percent. The concentration must be specified on the product label and certain warning phrases are required.[37]

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[35] Agency for Toxic Substances & Disease Registry. Case Studies in Environmental Medicine: Toxicity of Polycyclic Aromatic Hydrocarbons (PAHs). Available at: http://www.atsdr.cdc.gov/csem/pah/pah_standards-regulations.html (accessed 10 June 2011).

[36] US Food and Drug Administration. Hair Dye Products. November 1, 1997. Available at: http://www.fda.gov/cosmetics/productandingredientsafety/productinformation/ucm143066.htm (accessed 10 June 2011).

[37] US Food and Drug Administration. Final Monograph: Miscellaneous External Drug Products for Over-the-Counter Human Use: Dandruff, Seborrheic Dermatitis, and Psoriasis Drug Products. 21 CFR part 358 subpart H. Available at: http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=358&showFR=1&subpartNode=21:5.0.1.1.28.8 (accessed 10 June 2011).

Washington State Laws and Regulations

Water Regulations

Chapter 90.48 RCW Water Pollution Control

Relevant water quality standards for PAHs can be found in several Washington regulations:

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. This rule sets a groundwater quality criterion for PAH of 0.01 µg/dL.

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. For PAHs, this rule defers to EPA water quality criteria and the National Toxics Rule (see Federal Laws and Regulations).

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. WAC 246-290-72012 lists a MCLG for benzo(a)pyrene (PAHs) of 0, and a MCL of 0.002 mg/L, mirroring federal regulations.

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.[38]

The chapter sets criteria for individual PAHs as well as groups of PAHs, including:

- LPAH (low molecular weight polynuclear aromatic hydrocarbon) compounds: Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, and Anthracene.
- HPAH (high molecular weight polynuclear aromatic hydrocarbon) compounds: Fluoranthene, Pyrene, Benz(a)anthracene, Chrysene, Total Benzofluoranthenes,

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[38] 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).

Benzo(a)pyrene, Indeno(1,2,3,-c,d)pyrene, Dibenzo(a,h)anthracene, and Benzo(g,h,i)perylene.

Table 38- Sediment quality standards for PAHs

Chemical Parameter	mg/kg Organic Carbon (ppm Carbon)
LPAH	780
naphthalene	170
acenaphthylene	66
acenaphthene	57
fluorene	79
phenanthrene	480
anthracene	1200
2-methylnaphthalene	64
HPAH	5300
fluoranthene	1200
pyrene	1400
benz(a)anthracene	270
chrysene	460
total benzofluoranthenes	450
benzo(a)pyrene	210
indeno (1,2,3,-c,d) pyrene	88
dibenzo (a,h) anthracene	33
benzo(g,h,i)perylene	78

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 meet the federal air quality standards. Because PAHs are combustion byproducts, a number of regulations pertinent to burning and facility emissions are applicable.

Chapter 173-425 WAC Outdoor burning

The outdoor burning rule implements permitting and restrictions on non-agricultural and non-silvicultural outdoor burning. Certain materials are illegal to burn in any outdoor fire, including garbage, asphalt, petroleum products, and treated wood. Use of burn barrels is illegal. In addition, outdoor burning (residential and land clearing burning) is prohibited in all Urban

Growth Areas (UGAs) in Washington.[39] In areas where land clearing burning is allowed, a permit is required. Ecology actively promotes alternatives to yard waste burning, including chipping and composting.[40]

WAC 173-425-050 specifies that certain prohibited materials may be burned for firefighting instruction fires, subject to the requirements of Ecology or local air agencies. See Local Laws and Regulations for more information.

Chapter 173-430 WAC Agricultural burning

These rules establish a mandatory agricultural burning permit to do any agricultural burning in Washington. The rule also makes it illegal to allow smoke from an agricultural burn to impact others. Anyone conducting an agricultural burn must also submit required information on the burn after it is completed.[41]

Chapter 173-433 WAC Solid fuel burning devices

These regulations set strict standards for emissions of fine particles from solid fuel burning devices (such as wood stoves, pellet stoves, factory-built fireplaces, and masonry heaters). In order to be sold, offered for sale, advertised, given away, or installed in Washington, a solid fuel burning device must meet standards stricter than the EPA's standards. The regulations also set limits on the moisture content of wood that can be burned (no more than 20 percent) and smoke density of plumes (20 percent opacity). The rule also regulates the use of wood heating devices during burn bans enacted by local air quality agencies. Burn bans have two stages:

- Stage 1: The use of all uncertified wood heating devices is banned when pollution approaches unhealthful levels.
- Stage 2: All wood heating is banned when pollution reaches an even higher level.

Burn bans do not apply to homes with no other source of adequate heat.[42]

Chapter 173-434 WAC Solid waste incinerator facilities

These regulations establish emissions standards, design requirements, and performance standards for solid waste incinerator facilities. The definition of "solid waste" contains criteria for whether creosote treated wood is considered a solid waste for the purposes of these regulations.

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[39] Department of Ecology. Maps of Urban Growth Areas. Available at: http://www.ecy.wa.gov/programs/air/aginfo/ugamaps.htm (accessed 10 June 2011).

[40] Department of Ecology. Alternatives to Burning. Available at: http://www.ecy.wa.gov/programs/air/outdoor_woodsmoke/alternativestoburn.htm (accessed 10 June 2011).

[41] Department of Ecology. Agricultural Burning. Available at: http://www.ecy.wa.gov/programs/air/aginfo/agricultural_homepage.htm (accessed 10 June 2011).

[42] Department of Ecology. Wood Stoves, Fireplaces, and Pellet Stoves. Available at: http://www.ecy.wa.gov/programs/air/indoor_woodsmoke/wood_smoke_page.htm (accessed 10 June 2011).

Chapter 173-455 WAC Air quality fee regulation

This rule subjects sales of new and used solid fuel burning devices to a minimum $30 fee. This fee is deposited in a woodstove education and enforcement account, which funds enforcement and education programs at local air authorities and Ecology.

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. 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 civil penalties and/or criminal charges such as gross misdemeanor. A majority of the PAHs on the PBT list are also found on the list of toxic air pollutants in this rule (WAC 173-460-150), as seen in Table 39.

Table 39- PAHs on the PBT list that are Toxic Air Pollutants (WAC 173-460-150)[43]

CAS #	Toxic Air Pollutant
53-70-3	dibenzo(a,h)anthracene
56-49-5	3-methyl chlolanthrene
189-55-9	benzo(r,s,t)pentaphene
192-65-4	dibenzo(a,e)pyrene
193-39-5	indeno(1,2,3-cd)pyrene
194-59-2	7H-dibenzo(c,g)carazole
205-82-3	benzo(j)fluoranthene
205-99-2	benzo(b)fluoranthene
207-08-9	benzo(k)fluoranthene
218-01-9	benzo(a)phenanthrene (chrysene)
224-42-0	dibenzo(a,j)acridine
226-36-8	dibenzo(a,h)acridine

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[43] 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).

Chapter 332-24 WAC Forest protection

This rule establishes the conditions, permits, and fees associated with silvicultural burning in Washington on lands regulated by the Department of Natural Resources.[44]

Chapter 70.120 RCW Motor Vehicle Emission Control

Chapter 173-422 WAC Motor vehicle emission inspection

This regulation subjects vehicles that are registered in certain areas of Washington (including parts of Clark, King, Pierce, Snohomish, and Spokane counties) to vehicle emissions testing. This testing is intended to identify high polluting vehicles and vehicles with tampered or missing emission controls and to reduce their emissions, when such reduction can be accomplished at reasonable cost.

A new rule, chapter 173-422A WAC, Motor vehicle emission inspection, is being proposed and would apply to Washington's Motor Vehicle Emission Program beginning July 2012. The current rule, chapter 173-422, applies to Washington's Motor Vehicle Emission Program through June 2012. The proposed rule will facilitate the emission testing and repair by more businesses and reduce the impact of emission testing on the owners of older vehicles. Rule changes relevant to PAHs in the environment include:

- Requiring the same test standards for all 1995 model year and older gasoline vehicles.
- Exempting light-duty diesel vehicles from testing.
- Tightening the test standards for heavy-duty diesel vehicles.
- Exempting heavy-duty diesel vehicles with an engine meeting 2007 emission standards or equipped with an exhaust particle filter from testing.[45]

Chapter 70.120A RCW Motor Vehicle Emissions Standards

Chapter 173–423 WAC - Low Emission Vehicles

This law and regulation, also known as Washington's "Clean Car" law, adopts stricter emissions standards under the Clean Air Act for new cars, beginning with 2009 models. The law adopts California vehicle emissions standards for passenger cars, light duty trucks, and medium duty passenger vehicles, which are stricter than federal standards. The rule is updated periodically to maintain consistency with the standards set by the California Air Resources Board.

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[44] Washington State Department of Natural Resources. Fire Regulation, Silvicultural Burning and Fuel Management. Available at: http://www.dnr.wa.gov/RecreationEducation/Topics/FireBurningRegulations/Pages/rp_burn_fireburnfuelmgt.aspx (accessed 10 June 2011).

[45] Department of Ecology. Purpose of the Proposal and Its Anticipated Effects, Including Any Changes in Existing Rules. February 15th, 2011. Available at: http://www.ecy.wa.gov/laws-rules/activity/wac173422A.html (accessed 10 June 2011).

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. Wastes containing specific PAHs above set limits are regulated as persistent wastes. WAC 173-303-100 specifies that a waste that contains more than 1.0% PAHs qualifies as Extremely Hazardous Waste (EHW) and receives waste code WP03.[46] WAC 173-303-040 defines PAHs as "…those hydrocarbon molecules composed of two or more fused benzene rings". The definition also specifically enumerates the 20 PAHs covered by the regulation[47]. Ecology has provided additional guidance on PAHs in the document 'Chemical Test Methods for Designating Dangerous Waste'.[48]

PAHs must also be considered when designating waste for toxicity. 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, the toxicity of PAHs must be considered with other waste constituents to determine if the waste stream designates as a state-only toxic waste and assigned the waste codes of WT02 as dangerous waste or WT01 as EHW (extremely hazardous waste).

In addition to this specific designation code for PAHs, a number of specific codes are applicable to materials that may contain PAHs. The Washington dangerous waste regulations separate wastes into four categories:

- Characteristic wastes.
- Criteria wastes.
- Discarded chemical products.

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[46] Department of Ecology. Ten Designation Steps. Available at: http://www.ecy.wa.gov/programs/hwtr/demodebris/pages2/designat_steps.html (accessed 10 June 2011).

[47] WAC 173-303-040 Definitions, p. 32, http://www.ecy.wa.gov/pubs/wac173303.pdf (accessed 28 June 2011).

[48] Ecology Publication No. 97-407, Revised June 2009, http://www.ecy.wa.gov/pubs/97407.pdf (accessed 28 June 2011).

- 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. Coal tar creosote, Coal tar creosote, Coal tar creosote, as well as many PAH compounds, are included in the dangerous waste constituents list found in WAC 173-303-9905.[49]

Some materials are specifically excluded from the requirements of the dangerous waste regulations, including roofing tars and shingles and wood ash (including wood ash from wood treated only with creosote.)

Creosote treated wood is exempted under WAC 173-303-071(3)(g)(ii), provided it is managed according to the conditions of that exemption. Creosote treated wood must be:

- Disposed of in a solid waste landfill, provided it is not a listed or characteristic hazardous waste.
- Recycled at a facility that properly manages any hazardous residues.
- Sent to a permitted treatment, storage, and disposal (TSD) facility, which may include burning for energy recovery in an industrial furnace or boiler.

Ecology also currently encourages reuse of creosote treated wood in applications such as fence posts, retaining walls, landscaping, decks, and general construction.[50]

Lastly, PAHs are often found in used oil which 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. WAC 173-303-515 contains management standards for used oil.

Chapter 70.95I RCW Used oil recycling

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 1000 gallons of lubricating oil to consumers (500 gallons in a city with an approved used oil recycling element in their hazardous waste plan).

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[49] WAC 173-303-9905. Dangerous Waste Constituents List. Available at: http://apps.leg.wa.gov/wac/default.aspx?cite=173-303-9905 (accessed 16 June 2011).

[50] Department of Ecology. Treated Wood Exclusion. January 2003. Available at: http://www.ecy.wa.gov/biblio/0304038.html (accessed 16 June 2011).

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. The regulatory definition for PAHs in MTCA aligns with the 16 PAHs found in Clean Water Act standards. The regulation further defines carcinogenic PAHs (cPAHs) as those identified as A (known human) or B (probable human) carcinogens by the United States Environmental Protection Agency, including benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene. The mixture is considered a single hazardous substance, and benzo(a)pyrene equivalent is used as a reference chemical for the purpose of cleanup and remediation levels.

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. For PAHs, the Method A cleanup levels for groundwater and soil (expressed as benzo(a)pyrene equivalents) are found in Table 40:

Table 40- MTCA Method A Cleanup Levels

Medium	Table	Level
Groundwater	720-1	0.1 µg/liter
Unrestricted Land Uses	740-1	0.1 mg/kg
Industrial Properties	745-1	2 mg/kg

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. The Department of Ecology (Ecology) uses the toxicity equivalency factor (TEF) methodology, developed by the U.S. EPA, to evaluate the toxicity and assess the risks for environmental mixtures of carcinogenic PAHs.[51]

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.

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[51] 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 leaky 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 shall be immediately reported to Ecology and appropriate cleanup and containment measure must be taken. Under most circumstances, MTCA cleanup standards apply to the remediation of releases from leaky underground storage tanks. This chapter was adopted in 1990 and violators face fines of up to $5,000 dollars per day per violation.

Creosote-Treated Wood Regulations

Multiple Statutes – Chapter 19.29A, 19.280, 19.285, 43.52, 80.50, 79.02, 82.29A, 84.36 RCW

Multiple Regulations –173-407, 480-109 WAC

Each of the listed statutes and regulations contain language intended to exclude the burning of creosote-treated wood under various programs intended to promote alternative energy sources. Creosote-treated wood is excluded from the definition of materials which can be considered biomass fuel.

Chapter 43.20 RCW State Board of Health

WAC 246-366A, Environmental Health and Safety Standards for Primary and Secondary Schools

This regulation prohibits the use of creosote treated wood to construct, install, or maintain playground equipment, landscape structures, or other structures on which students may play.

Chapter 70.95 RCW Solid Waste Management — Reduction and Recycling

Chapter 173-350, Solid Waste Handling Standards

This regulation establishes standards for handling solid wastes to assure the efficient use of resources. Facilities that engage in solid waste handling activities (disposal, storage, treatment etc.) must obtain a permit, unless the facility fits the categorical requirements for an exemption stated in the regulation. Permits are not required for facilities that demonstrate the beneficial use of the solid wastes generated or accumulated.

The regulation excludes creosote-treated wood from the definition of "wood waste." However, it specifically defines "wood derived fuel" to include wood pieces or particles that contain creosote. The combustion of wood waste or wood derived fuel is exempt from solid waste permitting.

Title 75 RCW Food Fish and Shellfish

WAC 220-110, Hydraulic Code Rules

This regulation provides for the protection of fish life by setting standards for hydraulic projects. The regulation specifies that all piling, lumber, or other materials treated with preservatives shall be sufficiently cured to minimize leaching into the water or bed. The use of wood treated with creosote or pentachlorophenol is not allowed in lakes in Washington.

Worker & Product Safety Regulations

Chapter 49.17 RCW Washington Industrial Safety and Health Act

Chapter 296-62 WAC General Occupational Health Standards

This chapter defines coal tar pitch volatiles and specifies that employers must reduce employee exposures to coal tar pitch volatiles in coke oven emissions.

Chapter 296-155 WAC Safety Standards for Construction Work

WAC 296-155-620, applicable to pile driving equipment, specifies that protective equipment must be used when working with creosote timbers. Protective creams must be used on exposed skin surfaces and gloves and eye protection worn, especially when driving piles.

WAC 296-155-755 contains regulations for handling hot tar & open tar heating pots.

Chapter 296-841 WAC Airborne Contaminants

This chapter specifies Permissible Exposure Limits (PELs) of 0.2 mg/m^3 for PAHs (coal tar pitch volatiles) that mirror the federal OSHA requirements (see Federal Regulations). They also specify Short-Term Exposure Limits (STEL) of 0.6 mg/m^3.

Chapter 69.04 RCW Intrastate Commerce in Food, Drugs, and Cosmetics

This statute mirrors the federal Food, Drug, and Cosmetic Act in adopting a labeling requirement for coal tar hair dyes. The statute requires that these products be labeled with the following warning:

"Caution -- This product contains ingredients which may cause skin irritation on certain individuals and a preliminary test according to accompanying direction should first be made. This product must not be used for dyeing the eyelashes or eyebrows; to do so may cause blindness."

Chapter 70.160 RCW Smoking in public places (formerly Washington clean indoor air act)

This state law specifies that no person may smoke in a public place or in any place of employment in Washington.

Chapter 70.295 RCW Storm Water Pollution – Coal Tar

This law prohibits the sale and application of coal tar pavement sealants in Washington State. A retailer may not sell coal tar pavement products after January 1, 2012, and no person may apply a coal tar pavement product on a driveway or parking area after July 1, 2013.

Taxes

Chapter 82.21 RCW Hazardous substance tax – model toxics control act

Chapter 458-20-252 WAC Hazardous substance tax and petroleum product 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 and manage solid and hazardous waste in the state of Washington.[52]

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.

Specific PAH-containing substances that are subject to the Hazardous Substance Tax include coal tar creosote, creosote oil, individual PAHs, and groupings of PAHs such as Polycyclic Organic Matter (POM) and Polynuclear Aromatic Hydrocarbons (PNAs).

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

Local Laws and Regulations

Air Regulations

Air quality in most areas of Washington State is protected by local clean air agencies, including[53]:

- Benton Clean Air Agency - Benton County
- Northwest Clean Air Agency - Whatcom, Island, & Skagit counties
- Olympic Region Clean Air Agency - Thurston, Mason, Pacific, Grays Harbor, Jefferson, & Clallam counties
- Puget Sound Clean Air Agency - King, Snohomish, Pierce, & Kitsap counties
- Southwest Clean Air Agency - Lewis, Skamania, Clark, Cowlitz, & Wahkiakum counties
- Spokane Regional Clean Air Agency - Spokane County
- Yakima Regional Clean Air Agency - Yakima County

Individual clean air agencies adopt their own regulations.

Several local air agencies specify removal of certain materials that would release PAHs when burned from structures before fire fighting training exercises, including composition roofing, asphalt roofing shingles, asphalt siding materials, miscellaneous debris from inside the structure, carpet, linoleum, and floor tile.[54]

Select Regulations in Other US Jurisdictions

State of New Jersey: Chapter 113 (§§1-7-C.13:1K-36 to 13:1K-42)

This law bans the sale and use of creosote as of Jan. 1, 2007, but allows continued use of existing creosote treated wood. The law bans the burning of creosote-treated wood and requires that it be disposed of in a properly lined landfill. Railroad and utility companies are exempted from the requirements of the bill.[55]

State of New York: Article 27, Title 25 (27-2501 to 27-2513)

This law, similar to the New Jersey law, bans the manufacture, sale and use of creosote as of Jan. 1, 2008, but allows continued use of existing creosote treated wood. The law also requires creosote treated wood to be disposed of in an approved, lined facility to prevent groundwater contamination, and bans the burning of creosote treated wood except in permitted facilities.

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[53] Department of Ecology. Local Clean Air Agencies. Available at: http://www.ecy.wa.gov/programs/air/local.html (accessed 16 June 2011).

[54] e.g. Puget Sound Clean Air Agency. Fire Department Training Exercises. Regulation 1, Section 8.08. Available at: http://www.pscleanair.org/regulated/businesses/regulations.aspx (accessed 16 June 2011).

[55] State of New Jersey. An Act Concerning the Sale, Use, and Burning of Creosote or Creosote-Treated Wood, and Supplementing Title 13 of the Revised Statutes. Chapter 113, §§1-7-C.13:1K-36 to 13:1K-42. Available at: ftp://www.njleg.state.nj.us/20062007/PL07/113_.HTM (accessed 16 June 2011).

Railroads, electric corporations, telephone, and other utilities are exempt from the ban. Existing marinas were also exempted Until Jan. 1, 2010.[56]

Various Counties & Municipalities (Austin, TX[57]; White Bear Lake, MN[58]; Maplewood, MN[59]; Suffolk County, NY[60]; Dane County, WI[61]; District of Columbia[62])

Each of the municipalities listed has enacted restrictions on the sale or use of coal tar sealants on pavement within their jurisdictions.

City of Berkeley: Res. No. 62,693-N.S. Environmentally Preferable Purchasing Policy

The city's environmentally preferable purchasing policy, enacted in 2004, contains a prohibition on the purchase of all creosote treated wood.[63]

Various States and Municipalities

The American Transportation Research Institute maintains a compendium of anti-idling regulations in various jurisdictions.[64]

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[56] New York Department of Environmental Conservation. Creosote: Article 27, Title 25 (27-2501 through 27-2513) PHASE OUT OF CREOSOTE. Available at: http://www.dec.ny.gov/chemical/42394.html (accessed 16 June 2011).

[57] City of Austin. Coal Tar Sealant Ban: Pavement Sealants and PAH Contamination. Available at: http://www.ci.austin.tx.us/watershed/coaltar_main.htm (accessed 16 June 2011).

[58] City of White Bear Lake. Coal Tar Sealant Ban. Available at: http://www.whitebearlake.org/index.asp?Type=B_BASIC&SEC=%7BEE7E830B-377D-4161-BB4B-1B91DA39F7CE%7D (accessed 16 June 2011)

[59] City of Maplewood. Stormwater Ordinance and Standards. Available at: http://www.ci.maplewood.mn.us/index.aspx?NID=719 (accessed 16 June 2011).

[60] Jennifer Gustavson, North Shore Sun. New Law Bans Coal Tar Sealers in Suffolk County. Available at: http://northshoresun.timesreview.com/2011/06/12304/new-law-bans-coal-tar-sealers-in-suffolk-county/

[61] Dane County Office of Lakes and Watersheds. Ordinance on Coal Tar Sealants. Available at: http://www.danewaters.com/business/coalTar.aspx (accessed 16 June 2011).

[62] District of Columbia. Coal Tar Ban in the District of Columbia. Available at: http://ddoe.dc.gov/ddoe/cwp/view,a,1209,q,500531.asp (accessed 16 June 2011).

[63] City of Berkeley. Resolution No. 65,693-N.S. Adopting an Environmentally Preferable Purchasing Policy (EPP). Available at: http://www.ci.berkeley.ca.us/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/Environmental%20Preferable%20Puchasing%20Resolution.pdf (accessed 16 June 2011).

[64] American Transportation Research Institute. Idling Regulations Compendium, updated January 2012. Available at: http://atri-online.org/2012/01/01/idling-regulations-compendium/ (accessed 17 May 2012).

Select International Regulations

Germany – Proposed Restriction of PAHs in Consumer Products

In June 2010, Germany submitted a dossier to the European Commission seeking to implement legal limits on PAHs in consumer products under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) program or other regulatory authorities. Germany is proposing a suggested limit of 0.2 mg PAH/kg for 8 PAHs in articles. (Under REACH, an "article" refers to an object or a product, as opposed to a chemical substance.) The 8 PAHs include benzo(a)pyrene, benzo(e)pyrene, benzo(a)anthracene, dibenzo(a,h)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, and chrysene.[65]

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[65] Bureau Veritas. Germany Proposed Restriction of Polycyclic Aromatic Hydrocarbons (PAH). June 2010. Available at: http://bureauveritas.com/wps/wcm/connect/bv_com/group/home/about-us/our-business/our-business-consumer-products/news+and+events/regulatory+bulletins/germany_proposes_pah_restriction (accessed 16 June 2011).

Economic Analyses

Evaluation of PAH-Reduction Costs and Current Costs of Exposure

Introduction

As part of the process to construct a Chemical Action Plan for PAHs, Ecology evaluated a variety of alternative measures to reduce PAH emissions in Washington State. Ecology also attempted to estimate and illustrate within a high degree of confidence the existing environmental and health impacts of PAH exposure.

Evaluated Requirements

Many measures for reducing PAH exposure fall under similar behavioral requirement categories (for example, education and informational campaigns may apply to woodstoves, diesel engines, and gardening equipment), so Ecology estimated the costs associated with the following required action categories (with their represented PAH reduction measures listed).

- Wood smoke
- Creosote treated wood
- Diesel engines
- Gardening equipment
- Education and information campaigns
- Wood stove incentive programs

Status Quo

These options were evaluated relative to the status quo, which already serves to limit other types of PAH exposure in the population and environment. The status quo includes:

- Ecology and local air agencies continue existing programs to reduce wood smoke.
- Washington State already requires cleaner burning new stoves, which includes prohibiting resale of non-certified used stoves.
- New creosote treated marine pilings not generally used.
- Utilities have already voluntarily stopped using creosote treated utility poles.
- Washington State has adopted California’s emission standards in our Clean Car law.
- Emphasis on reducing car trips.
- New federal standards for diesel engines and fuel.
- Regional port program on reducing emissions from several sources.

Summary of Estimated Losses due to Fine Particulate Exposure and Costs of PAH Reductions

Losses due to Fine Particulate Exposure

Ecology estimated the 20 year value of respiratory health impacts associated with fine particulates from combustion sources at over $2.5 billion. In addition, the 20 year value of mortality from exposure to particulate matter is $59-163 billion.

Costs of PAH Reduction Measures

Wood Smoke

Ecology estimated that switching uncertified wood stoves to certified wood stoves by 2022 would cost $59-206 million, and switching uncertified stoves to non-wood heat would cost $263-307 million. All the costs were slightly lower for switching by 2032.

Wood Stove Incentive Programs

Ecology estimated the annual cost of an incentive program at $7.2 million, to incentivize change out of all uncertified stoves by 2022, with lower annual costs for a 20 year incentive program lasting until 2032.

Creosote-Treated Wood

Ecology estimated the maximum value of replacements for re-used creosote treated wood over 20 years at $454 million in today's dollars.

Ecology also estimated the average annual cost of removal and replacement of marine pilings at $4.4 million.

Diesel Engines - Retrofits

Ecology estimated the 20-year discounted cost of retrofitting all diesel engines to be approximately $3.3 billion, though this cost falls to $792 million to $949 million when limited to the most likely effective diesel retrofit vehicles, excluding newer models and models likely better to be replaced, but adding locomotives in use in Washington State.

Ecology also estimated the average cost of a large shore power project to be $3.7 million in infrastructure and capital improvements, plus $0.5 million per ship in conversion costs.

Diesel Engines – Anti-idling technology

Ecology estimated the costs of anti-idling technology for large hauling trucks over 20-years as between $70 thousand and $5.5 million per parking lot installing technology, accounting for infractructure costs. This is the equivalent of a 20-year present value per anti-idling space of $7 thousand to $108 thousand. With the same use, these technologies could create a cost savings for diesel use and truck maintenance between $300 thousand and $11 million per lot using them over 20 years, or $30 thousand to $239 thousand per space.

For trucks staying 8 hours in a parking lot (overnight), the savings in diesel use and truck maintenance exceed costs, regardless of whether lots install basic plug-ins, electricity with heating and cooling, or also provide telecommunications services.

For 1-hour stays in a parking lot, trucks save more in diesel use and truck maintenance than it costs to provide combined electricity, heat, and cooling (i.e., if just electricity, or a package of electricity, heating/cooling, and communications is provided, the cost is higher than what is saved in fuel use and maintenance).

Emergency Vehicle Idling

Auxiliary power units (APUs) on long-idling vehicles such as ambulances and fire trucks pay for themselves in the first year. Ecology estimated that, if installed on all emergency fire and medical vehicles in Washington State, APUs would cost approximately $8 million in the first year, but generate a savings in fuel and maintenance costs of nearly $11 million each year (over $185 million saved in present value over 20 years). Most of this savings would go to local fire and medical service providers.

Gardening Equipment

Ecology found that most electric or manual gardening equipment does not cost more than gasoline gardening equipment. However, Ecology also estimated that a requirement to use only electric equipment could result in an additional $25 million in annual employment costs.

Education and Information Campaigns

Ecology found a range of costs for education campaigns, with an average cost of $6.8 million for a mid-sized campaign.

Benefits of PAH Reduction: Estimated Losses Due to Existing PAH Exposure

Morbidity and Mortality due to Fine Particulate Exposure

In 2009 Ecology used a mapping procedure developed by the Environmental Protection Agency (BenMAP) to estimate the values of respiratory health impacts associated with exposure to fine particulates from combustion sources in the state. Ecology used this analysis as an estimate of existing PAH-related health costs because it was the best approximation of these health costs available. There is no analysis currently equivalent to this analysis, specifically about PAH health costs in Washington State.

Ecology's BenMAP analysis estimated the following annual respiratory health impacts and values. These value losses and impacts on quality of life of over $2.5 billion dollars in the next 20 years could be mitigated or avoided with reductions in fine particulate emissions such as those that would be reduced with the PAH-reduction methods listed above in this analysis.

In addition, the same analysis estimated approximately 1,100 people in Washington State die annually from disorders associated with particulate matter exposure. Ecology estimates the value of mortality using the value of statistical life (VSL) – a value of a willingness to pay for reducing risk of death by 100 percent that is extrapolated from willingness to pay for smaller reductions in mortality risk. There is wide variance in the literature estimates of the value of statistical life, and Ecology uses the primary range of these estimates, between $4 million and $11 million per life lost.

Using the range of values for VSL, the annual losses in Washington State is estimated to be between $4.4 billion and $12.1 billion each year. The 20-year discounted present value of this range is $59.2 billion to $162.9 billion in willingness to pay to reduce mortality risk.

Table 41 Value of Time and Quality of Life Lost Annually to Fine Particulate Exposure

Disease	Median Incidence	Estimated Cost (millions)
Heart Attack (nonfatal)	1,500	$70
All Cardiovascular (less heart attack)	450	$17
Chronic Lung Disease	100	$2
Pneumonia	250	$5
Acute Bronchitis	1,900	$0.85
Asthma	100	$1.2
Asthma, Emergency Room Visits	400	$0.15
Work Loss Days	174,000	$31
Minor Restricted Activity Days	1,000,000	$64
	TOTAL ANNUAL COST	$190
	DISCOUNTED 20-YEAR PRESENT VALUE OF ILLNESS COST	**$2.6 billion**
Mortality – Low VSL	1,100	$4,400
Mortality – High VSL	1,100	$12,100
	DISCOUNTED 20-YEAR PRESENT VALUE OF MORTALITY COST	**$59.2 – 162.9 billion**

Estimated Costs – Wood Smoke

Ecology estimated the costs associated with replacing uncertified woodstoves with either certified woodstoves or a non-wood heating method, as would exist under a phase-out on use of uncertified woodstoves or both certified and uncertified wood stoves for heat.

Ecology developed two scenarios for deadlines under a ban on use of uncertified woodstoves: Ban starting in ten years (2022) and ban starting in twenty years (2032). These are functionally equivalent to phasing out the use of uncertified stoves over ten or twenty years. Ecology also analyzed costs associated with switching to a non-wood source of heat overall in these time periods. Ecology assumed that use of fireplaces was primarily aesthetic, as compared to the use of woodstoves for heat. This is consistent with findings in counties surveyed in Washington State by Puget Sound Clean Air Agency from which Ecology extrapolated multipliers for statewide use. Fireplaces without inserts were the most likely to be used for aesthetic purposes, while those with inserts were more likely to be used to supplement heating. Ecology notes that the costs estimated in this section would be higher if they included woodstoves with inserts.

While there would be large variance in when people chose to replace their uncertified woodstoves – likely with highest numbers right before the deadline or ban – ecology chose to estimate conservatively high costs based on smooth annual reductions in the number of uncertified woodstoves in use.

Ecology also analyzed the intersecting scenarios of uncertified stoves being replaced with either certified stoves or a non-wood heat source. Ecology assumed that natural gas heat would be the non-wood heating option chosen, as it has the lowest installed cost compared to other central-heating options such as heat pumps.

Ecology acknowledges that households ceasing use of their uncertified woodstove would also have the option of room-based heat such as using space heaters and installing baseboard heaters, household electric heat such as heat pumps, and electric or gas furnaces. If the uncertified woodstove option is taken away, people who are using woodstoves for heat will likely revert to an existing heat source (and incur the initial and ongoing costs of that source; so baseboard heaters would create a lower installation cost, but have higher fuel costs than low-cost wood), or install a certified stove or non-wood heat source (and continue to have low wood fuel costs, or pay the necessary electricity or natural gas costs of a non-wood heat source).

Ecology wanted to reflect comparable heating and fuel attributes in this analysis, and so assumed for one part of its analysis that households switching from using uncertified woodstoves would install a certified stove (higher initial costs), rather than use electric or gas heat (higher long-run fuel costs that were the likely reason they were using wood for heat in the first place).

For the other part of this analysis, Ecology assumed that households switching from uncertified woodstoves could switch to non-wood heat sources. This part would represent the outcome if households chose to incur the higher installation costs and ongoing fuel costs associated with non-wood heat sources. Ecology did not expect most people switching away from woodstoves to use this option, as it is more expensive in both installation and fuel costs, and the results below support this expectation by illustrating the higher installation costs of non-wood heat sources.

To maintain conservative estimates, Ecology assumed everyone switching away from an uncertified woodstove would need to install some sort of new heat source (wood or non-wood). Actual costs would likely be lower or at most as estimated, because many households would be able to use an existing non-wood heat source if they chose to incur the fuel costs, or otherwise have to install a certified woodstove.

In order to perform the necessary woodstove calculations, Ecology first estimated the number of Washington households using woodstoves each year, based on a forecast of state population, and a typical household size. Ecology used US Census data on Washington State population to determine that the average population growth rate since 1982 is 1.66 percent. Based on this value, Ecology estimated each year’s state population between 2012 and 2032.

According to the US Census Bureau, the typical household in Washington State has 2.63 members. Assuming state household size will not change over time, Ecology forecast the number of households each year between 2012 and 2032. Assigning the average 13.86 percent of households as surveyed by PSCAA that have woodstoves is applicable to the whole state, Ecology also calculated the number of households forecasted to use woodstoves in each of those years, as well as the numbers of uncertified versus certified woodstoves in each year, based on average percentages calculated for PSCAA counties.

Table 42 shows what could happen to the total number of stoves each year, by type, if there was no additional regulation of uncertified woodstoves. It fixes the number of uncertified woodstoves at the 2012 value of 56,741 – reflecting the existing ban on uncertified woodstoves – and shows two scenarios: one in which people purchasing heat sources will purchase certified woodstoves, and the other in which people will purchase wood or non-wood heat sources. Since no one can purchase an uncertified woodstove, the number of uncertified woodstoves stays constant. This table illustrates the difference in growth of certified woodstoves versus non-wood heat sources under the status quo.

Table 42 Woodstove Forecast with Existing Regulation

Woodstove Forecast with Existing Regulation (total number of stoves or heat sources in each year)						
Year	Uncertified Woodstoves	Growth Occurs Only in Certified Woodstoves		Growth Occurs in both Certified Woodstoves and Other (non-wood) Heat Sources		
		Certified Catalytic Woodstoves	Certified Non-Catalytic Woodstoves	Certified Catalytic Woodstoves	Certified Non-Catalytic Woodstoves	Non-Wood Heat Sources
2012	56,741	238,853	73,557	238,853	73,557	
2013	56,741	243,533	74,998	242,814	74,777	941
2014	56,741	248,290	76,463	246,841	76,017	1,897
2015	56,741	253,126	77,953	250,934	77,278	2,870
2016	56,741	258,042	79,467	255,095	78,559	3,858
2017	56,741	263,040	81,006	259,325	79,862	4,863
2018	56,741	268,121	82,570	263,626	81,186	5,885
2019	56,741	273,286	84,161	267,997	82,532	6,923
2020	56,741	278,536	85,778	272,442	83,901	7,979
2021	56,741	283,874	87,422	276,960	85,292	9,053
2022	56,741	289,300	89,093	281,552	86,707	10,144
2023	56,741	294,816	90,791	286,221	88,145	11,253
2024	56,741	300,424	92,518	290,968	89,606	12,380
2025	56,741	306,125	94,274	295,793	91,092	13,527
2026	56,741	311,920	96,058	300,698	92,603	14,692
2027	56,741	317,811	97,873	305,685	94,139	15,876
2028	56,741	323,800	99,717	310,754	95,700	17,081
2029	56,741	329,888	101,592	315,907	97,287	18,305
2030	56,741	336,077	103,498	321,146	98,900	19,549

2031	56,741	342,369	105,436	326,471	100,540	20,814
2032	56,741	348,765	107,405	331,885	102,207	22,100

Phase-Out by 2022

Based on these forecasts of woodstove number and type, Ecology analyzed costs associated with:

- Phasing out uncertified woodstove use by 2022:
    - Requiring switching from uncertified wood stoves to at least a certified woodstove.
    - Requiring switching from uncertified wood stoves to a non-wood heat source.
    - Requiring switching uncertified and certified wood stoves to non-wood heat sources by 2022.

Table 43 Discounted Costs and Present Value of Woodstove Replacement (2022 deadline)

Year	TOTAL COST SWITCH TO CATALYTIC (range; millions)		TOTAL COST SWITCH TO NONCATALYTIC (range; millions)		TOTAL COST SWITCH TO NON-WOOD HEAT (range; millions)		TOTAL COST SWITCH TO NON-WOOD HEAT UNDER BAN (range; millions)	
	min	max	min	max	min	max	min	max
2012	$5.57	$19.40	$1.72	$5.97	$32.42	$37.83	$210.94	$246.10
2013	$5.31	$18.48	$1.63	$5.69	$30.88	$36.03	$200.90	$234.38
2014	$5.05	$17.60	$1.56	$5.42	$29.41	$34.31	$191.33	$223.22
2015	$4.81	$16.76	$1.48	$5.16	$28.01	$32.68	$182.22	$212.59
2016	$4.58	$15.96	$1.41	$4.91	$26.68	$31.12	$173.54	$202.47
2017	$4.37	$15.20	$1.34	$4.68	$25.40	$29.64	$165.28	$192.83
2018	$4.16	$14.48	$1.28	$4.46	$24.20	$28.23	$157.41	$183.64
2019	$3.96	$13.79	$1.22	$4.25	$23.04	$26.88	$149.91	$174.90
2020	$3.77	$13.13	$1.16	$4.04	$21.95	$25.60	$142.78	$166.57
2021	$3.59	$12.51	$1.11	$3.85	$20.90	$24.38	$135.98	$158.64
2022	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2023	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2024	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2025	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2026	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2027	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2028	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2029	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2030	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2031	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
TOTAL	$45.18	$157.29	$13.91	$48.43	$262.89	$306.70	$1,710.29	$1,995.34

Ecology used a social discount rate of 1.5 percent. This is the average of 12 years of bi-annual real (inflation-adjusted) rates of return on US Treasury I-Bonds. This rate reflects the short-term, risk-free, inflation-adjusted rate of return available to the general public.

Phase-Out by 2032

Based on these forecasts of woodstove number and type, Ecology analyzed costs associated with:

- Phasing out uncertified woodstove use by 2032:
  - Requiring switching from uncertified wood stoves to at least a certified woodstove.
  - Requiring switching from uncertified wood stoves to a non-wood heat source.
  - Requiring switching uncertified and certified wood stoves to non-wood heat sources by 2032.

Table 44 Discounted Costs of Woodstove Replacement (2032 deadline)

YEAR	TOTAL COST SWITCH TO CATALYTIC (range; millions)		TOTAL COST SWITCH TO NONCATALYTIC (range; millions)		TOTAL COST SWITCH TO NON-WOOD HEAT (range; millions)		TOTAL COST SWITCH TO NON-WOOD HEAT UNDER BAN (range; millions)	
	min	max	min	max	min	Max	min	max
2012	$2.79	$9.70	$0.86	$2.99	$16.21	$18.91	$105.47	$123.05
2013	$2.65	$9.24	$0.82	$2.84	$15.44	$18.01	$100.45	$117.19
2014	$2.53	$8.80	$0.78	$2.71	$14.70	$17.16	$95.67	$111.61
2015	$2.41	$8.38	$0.74	$2.58	$14.00	$16.34	$91.11	$106.30
2016	$2.29	$7.98	$0.71	$2.46	$13.34	$15.56	$86.77	$101.23
2017	$2.18	$7.60	$0.67	$2.34	$12.70	$14.82	$82.64	$96.41
2018	$2.08	$7.24	$0.64	$2.23	$12.10	$14.11	$78.70	$91.82
2019	$1.98	$6.89	$0.61	$2.12	$11.52	$13.44	$74.96	$87.45
2020	$1.89	$6.57	$0.58	$2.02	$10.97	$12.80	$71.39	$83.29
2021	$1.80	$6.25	$0.55	$1.93	$10.45	$12.19	$67.99	$79.32
2022	$1.71	$5.95	$0.53	$1.83	$9.95	$11.61	$64.75	$75.54
2023	$1.63	$5.67	$0.50	$1.75	$9.48	$11.06	$61.67	$71.95
2024	$1.55	$5.40	$0.48	$1.66	$9.03	$10.53	$58.73	$68.52
2025	$1.48	$5.14	$0.45	$1.58	$8.60	$10.03	$55.93	$65.26
2026	$1.41	$4.90	$0.43	$1.51	$8.19	$9.55	$53.27	$62.15
2027	$1.34	$4.67	$0.41	$1.44	$7.80	$9.10	$50.73	$59.19
2028	$1.28	$4.44	$0.39	$1.37	$7.43	$8.66	$48.32	$56.37
2029	$1.22	$4.23	$0.37	$1.30	$7.07	$8.25	$46.02	$53.69
2030	$1.16	$4.03	$0.36	$1.24	$6.74	$7.86	$43.83	$51.13
2031	$1.10	$3.84	$0.34	$1.18	$6.42	$7.48	$41.74	$48.70
TOTAL	$36.46	$126.92	$11.23	$39.08	$212.14	$247.49	$1,380.13	$1,610.16

Ecology used a social discount rate of 1.5 percent. This is the average of 12 years of bi-annual real (inflation-adjusted) rates of return on US Treasury I-Bonds. This rate reflects the short-term, risk-free, inflation-adjusted rate of return available to the general public.

Summary

Table 45 summarizes the ranges of costs associated with the woodsmoke-reduction programs analyzed.

Table 45 Total Discounted Present Value Costs of Woodstove Reduction Programs

Total Discounted Present Value Costs of Woodstove Reduction Programs		
Reduction Program	Minimum	Maximum
Replacement of uncertified wood stoves with certified stoves by 2022	$59 million	$206 million
Replacement of uncertified wood stoves with non-wood heat by 2022	$263 million	$307 million
Replacement of certified and uncertified woodstoves with non-wood heat by 2022	*$1.7 billion*	*$2.0 billion*
Replacement of uncertified wood stoves with certified stoves by 2032	$48 million	$166 million
Replacement of uncertified wood stoves with non-wood by 2032	$212 million	$247 million
Replacement of certified and uncertified wood stoves with non-wood heat by 2032	*$1.4 billion*	*$1.6 billion*

Estimated Costs – Incentive Programs

Ecology surveyed woodstove change-out incentives in nine states (of which Washington and California had existing, funded incentive programs), and found that existing incentives range between $75 and $5000 (from seven available quantitative ranges of incentive payment), with an average of $1255 per qualifying change out. These programs subsidize private funds being spent on woodstove changeout, as discussed above under various phase-out and deadline ban scenarios.

In the case of encouraging switching to certified wood stoves or non-wood heat statewide by 2022, this would entail (at the average surveyed incentive payment) an annual subsidization for replacing 5,700 uncertified woodstoves. This would be an annual total incentive payment of $7.2 million in government spending for ten years, displacing private spending on woodstove replacement discussed above, and likely incentivizing sooner woodstove replacement than the smooth rate over time assumed in this analysis.

For the same scenarios by 2032, this would entail subsidization of 2,800 woodstoves each year for 20 years. This would be an annual total incentive payment of $3.5 million in government spending for 20 years, displacing private spending on woodstove replacement discussed above, and likely incentivizing sooner woodstove replacement than the smooth rate over time assumed in this analysis.

In the absence of a ban on uncertified or general wood burning in selected areas or the state as a whole, it is unclear how many new woodstove changeouts an incentive payment would prompt. This would depend on the size of the payment and how long it was offered.

If it is the case that the average payment of $407.50 per changeout is sufficient to incentivize all of the changeouts assumed above to be prompted by an eventual ban, then the costs would be as above in this section, amounting to $20 million in incentives to replace all uncertified stoves by 2022, or to $22 million in incentives to replace all uncertified stoves by 2032. These are the total present values of all annual incentive payments in these scenarios.

Table 46 Incentive Programs

Incentive Programs		
Location	Low Incentive	High Incentive
California -- Bay Area	$300	$600
California -- Sacramento	$75	$500
California -- Shasta	$200	$500
Washington State -- Spokane	$400	$550
Washington State -- Pierce County and Marysville	$200	$750
Washington State – Puget Sound Clean Air Agency	$1,500	$3,000
Washington State – City of Tacoma	$4,000	$5,000

Estimated Costs – Creosote-Treated Wood

Ecology estimated the costs associated with two types of bans reducing or limiting exposure to PAHs in creosote-treated wood:

- Ban re-use of creosote-treated wood for certain applications.
- Require removal or replacement of creosote-treated wood in aquatic areas.

Banning re-use of creosote-treated wood for certain applications

A ban on the re-use of creosote-treated wood would entail banning multiple residential and commercial uses of railway ties, including landscaping and farm (fence post, e.g.) uses. The EPA has recommendations on safer ways to use railway ties in these applications, but has not approved the uses as it has certain types of permitted landfilling, gasification, and cogeneration.

According to the Railway Tie Association's (RTA) "Wood Crossties 2008 Benchmark Tie Disposal Survey," as well as RTA and Association of American Railroads data, each year in Washington State:

- Nearly 68 thousand creosote-treated railroad ties are re-used in commercial landscaping.
- Over 24 thousand ties are re-used in farm applications.
- Over 67 thousand ties are re-used in residential landscaping.

Ecology developed the above estimates by converting Washington State rail miles to numbers of ties, and applying RTA percentages of 2.5 – 3 percent of ties removed and replaced (for reuse or disposal) each year.

A ban of these uses for used railway ties would necessitate landscapers (residential and commercial) and farms to find alternate products to substitute for the ties. At the standard size of ties (7 inches by 9 inches by 9 feet), these applications re-use the equivalent of the volumes of wood listed in Table 47.

Table 47 Quantity and Volume of Railway Ties Annually Re-Used

Quantity and Volume of Railway Ties Annually Re-Used						
Application	Annual Ties Re-Used	Width (inches)	Depth (inches)	Length (inches)	Total Volume of Ties Re-Used (cubic inches)	Total Volume of Ties Re-Used (cubic feet)
Commercial Landscaping	67,625	7	9	108	460,120,500	3,195,281
Farm	24,279	7	9	108	165,194,316	1,147,183
Residential Landscaping	67,437	7	9	108	458,841,348	3,186,398

Alternatives to railway ties in landscaping and farm applications include lowest-cost naturally rot-resistant and insect-resistant woods such as redwoods and cedars. Ecology surveyed prices for these woods, and has presented them in Table 48, below.

Table 48 Prices of Various Timber Dimensions of Cedar and Redwood

Prices of Various Timber Dimensions of Cedar and Redwood							
Type of Wood	Width (inches)	Depth (inches)	Length (inches)	Volume (cubic inches)	Volume (cubic feet)	Price	Price per Cubic Foot
Cedar	8	8	12	768	5.33	$4.00	$0.75
Cedar	4	4	12	192	1.33	$2.79	$2.09
Cedar	6	6	96	3456	24.00	$28.80	$1.20
Cedar	1	6	12	72	0.50	$2.24	$4.48
Cedar	6	6	96	3456	24.00	$70.64	$2.94
Redwood	2	8	12	192	1.33	$3.49	$2.62
Redwood	8	8	12	768	5.33	$6.00	$1.13
Cedar	4	8	12	384	2.67	$2.50	$0.94
AVERAGE PRICE PER CUBIC FOOT							$2.02
Minimum Price per Cubic Foot							$0.75
Maximum Price per Cubic Foot							$4.48

The Rail Tie Association cites the price of a new, treated tie as $95. Used ties may sometimes be provided for free by railroads or yards, but Ecology surveyed possible prices for used ties ranging up to $56 (longer switch ties carried the highest prices). The costs of using cedar or redwood timbers would be mitigated by any expenditure a landscaper would make on railroad ties. For inexpensive or free ties (which Ecology could not determine the extent of), a landscaper would incur up to the full cost of banning the reuse of rail ties. In the case of the most expensive used railway ties, Ecology believes landscapers would choose the lower cost equivalent of another type of timber in the first place, in which case a ban on re-use would have little or no cost impact.

At the minimum, average, and maximum prices per cubic foot, Ecology estimated the annual costs for replacing railway ties used in landscaping and farm applications. Ecology used volume to reflect that in applications such as soil retention and fence posts, it is not just the length of timbers that matters in long-run durability and strength. These total values are presented below in Table 49.

Table 49 Total Annual Cost Range for Use of Alternatives to Railway Ties

Total Annual Cost Range for Use of Alternatives to Railway Ties					
Application	Annual Ties Re-Used	Annual Volume of Ties Re-Used (cubic feet)	Annual Value at Minimum Price (millions)	Annual Value at Average Price (millions)	Annual Value at Maximum Price (millions)
Commercial Landscaping	67,625	3,195,281	$2.40	$6.45	$14.31
Farm	24,279	1,147,183	$0.86	$2.32	$5.14
Residential Landscaping	67,437	3,186,398	$2.39	$6.43	$14.28
TOTAL	159,341	7,528,862	$5.65	$15.19	$33.73

Ecology could not confidently estimate the number of existing landscaping and farm-use creosote-treated railway ties, and so could not additionally estimate the total cost of replacing existing ties in use in these applications.

Over 20 years, the discounted present values of these replacement costs sum, at the maximum price, to $454 million in the equivalent of today's dollars.

Requiring removal or replacement of creosote-treated marine pilings

Ecology estimated the cost of removing or replacing creosote-treated marine pilings. The Washington State Department of Natural Resources (DNR) reported, for 2005 – 2007, its cost of projects removing both creosote pilings and rogue beach logs, across various locations. The average cost per ton removed was $643. This cost reflects removal (and occasional replacement) of pilings and structures, and restoration of beaches performed by DNR. More complicated projects might involve replacement of large quantities of creosote-treated wood, as performed in the San Francisco Bay area, for which $300 – $1,100 per piling for demolition, removal, and possible replacement of larger pier projects was reported. Taking the ratio of tons of project to pilings from the DNR projects of 1.17 tons per piling, this Bay Area estimate would range between $256 and $939 per ton.

At this time, Ecology could not reliably inventory the number of tons of creosote-treated pilings in Washington State. Even where listed by various organizations, the most precise description of the number of total pilings and constructions is, "hundreds of thousands." Instead of choosing a specific number of tons to be removed or replaced, Ecology analyzed total present-value costs for various rates of removal or replacement. Table 50 summarizes the annual costs under various combinations of per-ton price and annual removal rate.

Table 50 Annual Piling Removal and Replacement Costs Under Various Scenarios

Annual Piling Removal and Replacement Costs Under Various Scenarios			
Cost per Ton	Removal Rate		
	100 tons/year	500 tons/year	1000 tons/year
$256	$25,600	$128,000	$256,000
$643	$64,300	$321,500	$643,000
$939	$93,900	$469,500	$939,000

Table 51 summarizes the discounted 20-year present value cost of marine piling removal and replacement at the minimum, median, average, and maximum annual costs.

Table 51 Discounted Annual and Total 20-Year Present Value Costs of Piling Removal

Discounted Annual and Total 20-Year Present Value Costs of Piling Removal and Replacement				
Year	Minimum Annual Cost	Median Annual Cost	Average Annual Cost	Maximum Annual Cost
2012	$25,600	$256,000	$326,756	$939,000
2013	$24,381	$243,810	$311,196	$894,286
2014	$23,220	$232,200	$296,377	$851,701
2015	$22,114	$221,142	$282,264	$811,144
2016	$21,061	$210,612	$268,823	$772,518
2017	$20,058	$200,583	$256,022	$735,731
2018	$19,103	$191,031	$243,830	$700,696
2019	$18,193	$181,934	$232,219	$667,330
2020	$17,327	$173,271	$221,161	$635,552
2021	$16,502	$165,020	$210,630	$605,288
2022	$15,716	$157,162	$200,600	$576,465
2023	$14,968	$149,678	$191,047	$549,014
2024	$14,255	$142,550	$181,950	$522,870
2025	$13,576	$135,762	$173,285	$497,972
2026	$12,930	$129,297	$165,034	$474,259
2027	$12,314	$123,140	$157,175	$451,675
2028	$11,728	$117,277	$149,690	$430,167
2029	$11,169	$111,692	$142,562	$409,683
2030	$10,637	$106,373	$135,774	$390,174
2031	$10,131	$101,308	$129,308	$371,594
2032	$9,648	$96,484	$123,151	$353,899
Total Present-Value Cost	$344,633	$3,446,326	$4,398,852	$12,641,016

At the average annual combination of per-ton cost and annual replacement rate, the present value of costs is nearly $4.4 million. At the upper end of annual costs estimated, the present value costs could reach over $12.6 million. Ecology could not determine the rate of replacement that would be required under any considered PAH-reduction action or regulation, or precisely the number of existing pilings in Washington State, but has presented a range of possible total costs based on rates of removal/replacement and demonstrated per-ton costs.

Estimated Costs – Diesel Engines

In addressing possible courses of action to reduce PAH emissions from equipment, Ecology considered the following actions.

- Retrofit diesel vehicles.
- Provide shore-power at ports.
- Anti-idling technology.
- Limit allowable/salable gardening equipment.

Retrofitting diesel tractors, loaders, backhoes, generator sets, cranes and trucks

Ecology based its cost estimation of diesel vehicles in part on the EPA's "Diesel Retrofit Technology: An Analysis of the Cost-Effectiveness of Reducing Particulate Matter and Nitrogen Oxides Emissions from Heavy-Duty Nonroad Diesel Engines Through Retrofits." The analysis estimates typical costs of reducing particulate matter (a component of which is PAHs) through diesel retrofits. Ecology began this analysis by estimating the per-vehicle (or per-generator or engine) costs of retrofit with either a diesel oxidation catalyst (DOC) or catalyzed diesel particulate filter (CDPF), across multiple equipment ages and lifespans.

Table 52 Discounted Lifetime Retrofit Costs per Unit of Equipment

Discounted Lifetime Retrofit Costs per Unit of Equipment

Off-Road Vehicle or Engine Type	Average Lifespan (years)	Retrofit Technology	Discounted Lifetime Retrofit Cost	
			Minimum	Maximum
Tractors, Loaders, and Backhoes	16	DOC	$4,980	$5,011
		CDPF	$5,540	$5,573
Generator Sets	16	DOC	$4,979	$5,023
		CDPF	$5,540	$5,580
Cranes	10	DOC	$4,980	$5,022
		CDPF	$5,534	$5,575
Trucks	10	DOC	$4,964	$5,012
		CDPF	$5,519	$5,568

Ecology then estimated the number of each type of equipment in Washington State over twenty years. Many of these equipment types are not required to be licensed in all cases, but those requiring licenses are primarily of significant size and reflecting the higher PAH emissions this analysis is concerned with.

For tractors, loaders, and backhoes, Ecology did not have reliable data on loaders and backhoes, but did have additional information on self-propelled farm equipment in addition to tractors, including balers, combines, and forage harvesters. In the US Department of Agriculture's 2007 survey, there were nearly 83,000 pieces of this equipment in use in Washington State.

For generator sets, Ecology used indirect estimates from a US EPA survey of nonroad engines in the United States, as cited by an analysis of national diesel exhaust performed by the Renewable Energy Policy Project. Ecology weighted the national estimate of nearly 630 thousand diesel generators nationally by the relative population of Washington state, estimating nearly 14,000 generator sets of any size in existence in the state. This is a likely overestimate for use in retrofitting technology estimates, as it includes the smallest consumer diesel generators, as well as the largest industrial diesel generators.

For cranes, Ecology used a minimum estimate of 22,000 individual employers or lessees of cranes as discussed in the Washington State Labor and Industries analysis of the Phase 2 Construction Crane rule. Ecology assumed this number of cranes (of various ages) would be in use in any given year. Lacking data on how many cranes were owned or operated by each employer, Ecology conservatively assumed at least one crane per owner.

For trucks, Ecology estimated the number of existing trucks in any given year based on the Department of Licensing's database of 2001 new title transactions for Other Trucks. Since the subset of on-road versus off-road vehicles could not be identified, Ecology estimated a maximum of all commercial off-road and on-road "other" trucks. In this dataset, "other" distinguishes these classes from gasoline vehicles. The estimated annual number of vehicles newly titled was 7,270. Given a ten-year equipment lifespan, and acknowledging that this is not the first year for diesel off-highway trucks in Washington state, Ecology assumed that in any given year there are approximately 73,000 diesel off-road trucks in operation.

Based on the average lifespan of each type of equipment, and the estimated number of each type of equipment in the state, Ecology estimated the 20-year discounted present value of costs associated with diesel retrofits to be approximately $3.3 billion dollars to retrofit ALL equipment in use over the next 20 years.

As a more reasonable estimate of the costs of retrofitting only suitable diesel engines in Washington State, Ecology estimated costs based on information in its 2006 Diesel Particulate Emission Reduction Strategy. That document asserts that of the 180,000 estimated legacy diesel vehicles on the road, 62,441 are suitable for diesel-control retrofitting. Similarly, of non-road mobile vehicles, 24,443 are assumed to be suitable for control technology. In addition, the Reduction Strategy estimates 894 locomotive engines operating in Washington State.

Using the approximate lifetime costs of retrofit technologies in Table 52 of $5 thousand to $6 thousand, Ecology estimated present values costs for just those on-road and non-road (including locomotives) vehicles suitable for diesel retrofits as $972 million to $1.2 billion in present value over 20 years. In this calculation, Ecology assumed that the population of suitable legacy diesel vehicles had a ten-year lifespan, and were uniformly retrofitted over the 20 years. If suitable vehicles were retrofitted immediately after a 10-year lifespan, these costs would be $792 million to $949 billion over 20 years.

Table 53 Discounted Lifetime Retrofit Costs

TABLE 53: Discounted Lifetime Retrofit Costs

Retrofitting All Off-Road and Truck Diesel Engines

Off-Road Vehicle or Engine Type	Retrofit Technology	Units	Units in 20-year time-span by same Operator	Age-adjusted unit equivalent over 20 years	Minimum Total Present Value Cost (millions)	Maximum Total Present Value Cost (millions)
Tractors, Loaders, and Backhoes	DOC	82,739	1.25	103,424	$515	$518
	CDPF	82,739	1.25	103,424	$573	$576
Generator Sets	DOC	13,733	1.25	17,166	$85	$86
	CDPF	13,733	1.25	17,166	$95	$96
Cranes	DOC	22,000	2	44,000	$219	$221
	CDPF	22,000	2	44,000	$244	$245
Trucks	DOC	72,700	2	145,400	$722	$729
	CDPF	72,700	2	145,400	$802	$810
Total 20-Year Present Value Cost of All Diesel Retrofit					$3,255	$3,281

Retrofitting Only Suitable Diesel Engines (subset of all diesel)

Vehicle Type	Units	Units in 20-year time-span by same Operator	Age-adjusted unit equivalent over 20 years	Minimum Total Present Value Cost (millions)	Maximum Total Present Value Cost (millions)
On-Road Mobile Sources	62,441	2	124,882	$624	$749
Off-Road Mobile Sources	24,443	2	48,886	$244	$293
Locomotives	894	2	1,788	$9	$11
Total 20-Year Present Value Cost of Suitable Diesel Retrofit (subset of retrofitting all diesel)				$792	$949

Provide shore power at ports

Ecology researched the costs of providing shore power to various vessels in port, based largely on a white paper from the American Association of Port Authorities. In San Diego, a project to provide shore power to cruise ships in terminal is estimated to cost $7 million ($2 million for 12 megawatt service; $3 million for equipment; $2 million for infrastructure), plus $250,000 annually in operating and maintenance costs.

Shore power conversion for Princess Cruises in Juneau, AK in 2005 is reported to have cost $4.5 million, including $2.5 million in construction and equipment, and $500,000 to convert each ship to use shore power. In current dollars, this is equivalent to $5.2 million.

The 2005 Port of Los Angeles Alternative Marine Power (AMP) program constructed for China Shipping is reported to have cost $7.8 million for construction and an AMP barge, plus $320,000 for each large vessel conversion to accept shore power.

Two additional projects at the Port of Los Angeles are expected to carry much lower costs, due to their use of existing space conduits and infrastructure. They carry expected costs of $1.2 million and $1.7 million, which are equivalent to $1.38 million and $1.96 million, respectively, in current dollars. At these costs, the Port expects to have AMP systems at 15 berths, serving cruise and large cargo vessels.

Other ports have evaluated the viability and cost-effectiveness of shore power estimating the following costs of retrofitting and accommodating existing port infrastructure.

- Port of Houston: $25 million for capital investment and land-side infrastructure.
- San Francisco cruise terminal: $1.5 – 3 million for infrastructure, plus $500,000-700,000 per retrofit of each existing cruise ship.

In addition, here in Washington State:

- Port of Tacoma spent $2.7 million on shore power infrastructure and retrofitting two cargo ships. At least $1.5 million of this was on the land-side infrastructure.
- Port of Seattle installed $3.2 million in infrastructure for shore power for Princess and Holland America cruise lines. The costs of vessel modifications were $0.5 - $1.1 million.

On average, Ecology assumes a large (cruise ship, container, or solid or liquid cargo vessel) shore power project could cost $3.7 million in infrastructure and capital improvements, plus $0.5 million per ship in conversion costs. Ecology excluded the outlying value of the Houston shore power project, as it was out of the overall range of the remaining estimates.

Ecology also noted that there are economies of scale in ship retrofits, as a retrofitted ship can use shore power at any available port connection. For example, a retrofitted Princess cruise ship can use shore power in both Seattle and Juneau. As more ports install shore power, the per-port cost of ship retrofits will decrease (as in the Princess example, $500 thousand to retrofit one ship is the equivalent of only $250 thousand in cost per shore-power-enabled port of call).

Anti-Idling Technology – Truck Parking

Ecology evaluated the costs and cost-mitigation associated with anti-idling technology for on-road hauling trucks, based on estimated costs of providing trucks electricity access (what the EPA calls truck "Shorepower") and more comprehensive delivery of heat, air-conditioning, electricity, and communications systems. For three types of anti-idling technology, the EPA commissioned an analysis of associated costs and other factors. The minimum unit costs are listed in Table 54, below.

Table 54 Summary of Minimum TSE Technology Costs

Summary of Minimum TSE Technology Costs			
	IdleAire	CabAire	Electricity Access
Per space installation cost	$16,000 for a 50-space minimum	$10,000 for a 10-20 space minimum	$4,500 for a 10-space minimum
On-board truck technology cost	$10 window adapter	$0	$200
Fee for service	$1 per hour	$1 per hour	$0.75 per hour

Source: Ross & Associates, 2009. Truck Stop Electrification and Anti-Idling as a Diesel Emissions Reduction Strategy at US-Mexico Ports of Entry. Analysis Performed for US EPA, http://www.epa.gov/Border2012/docs/reports/OtayTruckStopElectrificationReport2009.pdf

Ecology estimated total costs associated with both short truck stays (1 hour) and long "hotelling" stays (8 hours or more). Ecology also assumed that lots were full at their minimum size (as listed in Table 54), and operated year-round. Actual costs at lots larger than the minimum size would likely be lower per-truck, due to economies of scale in infrastructure, and possible fee reductions, but Ecology felt this estimation maintained conservatively high unit cost estimates. Ecology also assumed that once a truck had on-board technology to receive plug-in electric power, it could use it at multiple truck stops, or over multiple years.

Table 55 summarizes the total costs to lot and truck operators for various example technologies. Each cost accounts for initial installation costs (at minimum lot size), plus 20 years of ongoing operations costs (on-board truck technology and service fees) multiplied by the minimum number of trucks making either 1-hour or 8-hour stays in any given day. These costs are shared between the lot operator and truck operator. Lot operators may choose to pass on installation costs to truck operators, but Ecology did not estimate the degree of this wealth transfer, as both lot and truck operator costs are reflected in the total.

Table 55 Total Present Value Cost per Lot over 20-years

Total Present Value Cost per Lot (and per Space) over 20-years			
	IdleAire	CabAire	Electricity Access
PV Cost (1-hour stays)	$3.2 million ($66 thousand)	$0.1 million ($7 thousand)	$0.8 million ($78 thousand)
PV Cost (8-hour stays)	$5.4 million ($109 thousand)	$0.5 million ($49 thousand)	$1.1 million ($110 thousand)

Anti-idling technologies also create a cost savings, in reduced fuel consumption during periods when a truck would otherwise have been idling. Ecology used the EPA's assumption that each hour a truck idles, it uses a gallon of diesel fuel, and creates 50 – 95 cents in maintenance costs. This means – at the current Washington State average diesel gas price of $4.457 – one hour of avoided idling saves a truck at least $4.96, and an 8-hour stay avoiding idling saves a truck $39.66. For comparable minimum lot sizes to the cost calculation above, Ecology estimated the 20-year savings on fuel and maintenance under different anti-idling technology lots. Table 56 summarizes these cost savings, and shows the ratio of benefits to costs for each technology and length of per-truck stay.

Table 56 Total Present Value Cost Savings per Lot over 20 years

Total Present Value Cost Savings per Lot (and per Space) over 20 years			
	IdleAire	CabAire	Electricity Access
PV Cost Savings (1-hour stays)	$1.5 million ($30 thousand)	$0.3 million ($30 thousand)	$0.3 million ($30 thousand)
Ratio of Benefits to Costs (1-hour stays)	0.45	4.25	0.38
PV Cost Savings (8-hour stays)	$12.0 million ($239 thousand)	$2.4 million ($239 thousand)	$2.4 million ($239 thousand)
Ratio of Benefits to Costs (8-hour stays)	2.20	4.86	2.18

In Table 56, Ecology noted that cost savings (benefits) were larger than costs for all three technologies, for trucks staying 8 hours. Benefits also exceeded costs for 1-hour stay lots for CabAire technology, providing electricity, heat, and cooling.

Ecology did not account for multiple stays in a given space each day (i.e., a space would have a 1-hour truck stay on any day, but not 24 separate trucks rotating through; a space would have an 8-hour truck stay on any day, but not 3 separate trucks rotating through), but including multiple trucks per space in any given day would proportionally increase both costs and cost savings, leaving conclusions unaffected.

Ecology's analysis also assumes that any given lot will stay in operation for 20 years. If lots exit and enter the market, then they will experience repeated initial costs of installation for idling-reduction equipment. If, however, the operators of lots change, but the equipment stays in use at the same locations, the costs will be the same.

Anti-Idling Technology – Emergency Vehicles

Ecology evaluated the costs and cost-mitigation (benefits of fuel and maintenance savings) associated with anti-idling technology that could be installed on fire response and emergency medical response vehicles. These diesel vehicles idle for longer periods of time to support emergency activities. Ecology evaluated costs and benefits of auxiliary power unit (APU) technology, based on its assessment of installation cost and cost-savings in its Diesel Reduction Strategy.

Ecology multiplied initial APU costs of $7 thousand by the number of fire protection locations and licensed emergency service agencies in the state. Ecology conservatively assumed that there was one vehicle per location or agency (though, for example, large providers like the Seattle Fire department have one response truck per location, plus additional shared ladder trucks, smaller vehicles, and emergency medical response vehicles), and that these costs would be paid up front, in full.

To estimate cost-savings for fuel use and maintenance, ecology multiplied estimated annual fuel and maintenance savings (adjusted to current $4.457 diesel price per gallon) by the number of fire protection locations and licensed emergency service agencies in the state. Ecology then calculated the 20-year present value of this benefit. Table 57 summarizes the costs and benefits of APU technology if installed on all fire and medical emergency vehicles in Washington State. Total cost-savings in the first year would likely exceed the installation costs of APU technology.

Table 57 Installation Costs and Fuel/Maintenance Savings of Auxiliary Power Units for Emergency Vehicles (millions)

Installation Cost and Fuel/Maintenance Savings of Auxiliary Power Units for Emergency Vehicles (millions)

Emergency Vehicle Type	Initial Cost	Annual Savings	20-year Present Value Savings
Fire Protection	$4.2	$5.9	$100.8
Medical	$3.5	$5.0	$84.6
TOTAL	$7.7	$10.9	$185.4

Estimated Costs for Gardening Equipment

In estimating the costs associated with limiting high-PAH emitting gardening equipment, Ecology considered two things: the differential cost of equipment that performed the same task (e.g., electric versus gasoline powered mowers), and the differential amount of work (in time or quantity of effort) and its value. Table 58 summarizes the average price differentials of gardening equipment, by type.

Table 58 Differential Costs of Gardening Equipment

Differential Costs of Gardening Equipment			
PAH-Emitting Equipment	Mean Retail Price	Price Differential	Compared To
Gas vs. Electric			
Two-cycle leaf blower	$209	$136	Electric leaf blower
Gas lawn mower	$435	$70	Electric lawn mower
Two-cycle chainsaw	$264	$164	Electric chainsaw
Two-cycle hedge trimmer	$272	$181	Electric hedge trimmer
Gas vs. Manual			
Two-cycle leaf blower	$209	$187	Rake
Gas lawn mower	$435	$295	Hand-push lawn mower
Two-cycle chainsaw	$264	$223	Axe
Two-cycle hedge trimmer	$272	$226	Hand hedge trimmer

Ecology needed to reflect the differences in effort (the legitimate value of exercise notwithstanding; rather in regard to productivity) across gasoline and electric equipment (we could not confidently estimate differences in effort for gasoline versus manual equipment) to achieve the same task. Ecology based these estimates on the attributes of the gasoline versus electric equipment, especially as pertains to effectiveness and portability.

Ecology surveyed available gardening equipment at retail prices, conservatively limiting the survey to equipment with the highest ratings in Bing searches, and noting both the highest and lowest prices if equipment was available at multiple stores. Where possible, Ecology gathered data not only on price, but also on equipment attributes, such as cutting edge and air volume. Ecology found that on average:

- Gasoline leaf blowers put out air at 1.19 times the speed of cordless electric blowers. (Ecology accounted only for the cordless electric blowers, since they were comparably portable to gas blowers.)
- Gas-powered blowers put out over 5.1 times the volume of air that cordless electric blowers do. Ecology conservatively assumed that moving the same amount of air (and, presumably, the same amount of leaves) would take five times as long with the electric blower.
- Gasoline-powered lawnmowers have a 5-percent wider cutting area than electric lawnmowers.

- Gas-powered chainsaws have a cutting edge 21 percent longer than electric chainsaws.
- Gas-powered hedge trimmers have a cutting edge 9 percent longer than electric trimmers.

Ecology calculated the weighted average difference in price between gas-powered and electric garden equipment by category. The weighted average accounts for the larger effort or time a user would spend using equipment that moved less air, or cut less in one stroke. Ecology assumed a linear relationship between air moved and effort, and between cutting edge size and effort, and weighted prices for equipment with lower cutting edge or air volume by the ratio of additional effort required to use it. Table 59 summarizes the price differentials weighted by equipment attribute differential.

Table 59 Differential Costs of Gardening Equipment

Differential Costs of Gardening Equipment				
PAH-Emitting Equipment	Mean	Differential	Weighted Differential	Compared To
Two-cycle leaf blower	$209	$136	$164	Electric leaf blower
Gas lawn mower	$435	$70	-$52	Electric lawn mower
Two-cycle chainsaw	$264	$164	-$143	Electric chainsaw
Two-cycle hedge trimmer	$272	$181	-$172	Electric hedge trimmer

Accounting for both price and attribute, Ecology found that attribute-adjusted electric leaf blowers are an average of $164 more expensive to use than gas-powered blowers, but electric lawnmowers, chainsaws, and hedge trimmers are still less expensive to use than their gas-powered equivalents.

Ecology also accounted for the possibility that these differences in attributes would translate into additional worker time costs in the case of businesses and agencies employing gardeners. According to the Bureau of Labor Statistics, the prevailing wage for landscaper and groundskeeper workers in Washington State is $13.84 per hour. Working between 5 percent and 510 percent more would result in additional employment expenditures of $0.69 and $70.58 per worker, per activity. For the reported 16,270 such workers in the state, a requirement to use only electric equipment would result in at least $24.68 million in annual employment costs.

Estimated Costs – Education and Information Campaigns

Ecology surveyed costs for various kinds of informational and educational campaigns. The results are summarized in Table 60, below. As the table indicates, there is a wide variety of informational campaigns, in size, media, and scope of reach. Without specific programmatic information on an informational campaign’s attributes, Ecology chose to be comprehensive in its description of these campaigns, and its average of $6.8 million for a midsize campaign.

Table 60 Costs of Informational and Educational Campaigns

Costs of Informational and Educational Campaigns				
Who	What	Population	Method	Cost
Cities of Phoenix, Mesa, Scottsdale, AZ (breakdown:	Water-Use It Wisely	2,191,654 breakdown: Phoenix 1,512,986, Mesa 447,541, Scottsdale 231,127	Radio and TV ads, website, partnered with Lowes (in-store signage, and workshops), radio, aggressive public relations, inserts, workshops, movie theater cups and popcorn bags, baseball game jumbotron ads, billboard, transit signs, airport and magazine ads, earth day events, brochures, 16 foot pyramid made of one gallon milk containers	$12,100
				$28,867
Ottawa, Canada	Ottawa's Commuter Challenge	812,129	Newspaper articles and ads, brochures, newsletter, radio and TV, web site.	$32,500
				$32,500
Toronto, Ontario, Canada	The Roach Coach Project	2,631,725	Letters to property managers and tenants, on-site workshops	$42,000
Ontario, Canada	Switch out mercury recovery campaign	11,410,046	Methods of outreach included engaging Ontario’s auto recycling industry by showcasing the program at trade shows and by contacting Trevor Pettit, the Executive Director of the Ontario Automotive Recyclers Association (OARA). Mr. Pettit sent out a letter to each of OARA’s members, urging their participation.	$50,000

Calgary, Canada	Calgary Commuter Challenge	900,000	Posters, newspaper ads, employers, radio	$50,000
Kamloops, BC, Canada	WaterSmart	69,200	College student bicycle patrols ($20,000), and information booths, radio and TV ads, newspaper (advertising $11,000), appearances at public events	$82,000
State of Vermont	Child sexual abuse prevention, Stop It Now! Vermont	630,337	Radio and TV public service announcements, bus transportation signs, posters, op-ed pieces, feature stories, and letter-to-the-editor campaigns	$180,000
Greater Cincinnati area	Do Your Share for Cleaner Air	2,130,151	Radio, TV, newspapers, employers, fax, web site, buses, billboards	$236,836
Metropolitan Portland, OR	Oregon's Air Quality Public Education and Incentive Program	1,000,000	Partnerships with businesses, posting announcements in stores, radio spots, cable TV, Portland Business Journal, inserts in electricity bills, posters	$250,000
King County/Western WA	Get in the Loop -- Buy Recycled	1,000,000	In-store promotional materials, print and radio advertising, shelf talker, self-stick door decals, posters, buttons	$275,000
Okotoks, Canada	Sustainable Okotoks, Alberta	17,145	Newspaper, brochures, conservation guide	$485,000
States of Virginia and Maryland	Chesapeake Bay pollution campaign	13,827,665 (breakdown: Maryland 5,789,929, Virginia 8,037,736)	Advertising and website, media stories, posters, brochures, decals, door hangers and lawn signs, restaurant coasters	$550,000
Canada (NRC/Natural Resources Canada)	Auto$mart Program for Canada's novice drivers	270,000 students	Student driver kits, video, CD-ROM	$820,000

Seattle, WA	Bert the Salmon: Promoting Natural Lawn Care	608,660	TV and radio, promotional events, habit change kits, brochures, promotional video, home and garden show	$853,000
San Francisco Bay Area	Spare the Air	6,100,000	Radio, TV, newspapers, employers, phone, fax, e-mail, free carpool parking, guaranteed rides home	$1,044,415
				$1,044,415
Oshawa, Ontario	The Residential Conservation Assistance Program (ReCAP)	131,000	Home visits, tax and utility bill inserts, word of mouth, fact sheets, low interest financing, media	$1,200,000
Go Boulder (Colorado)	Reduce traffic congestion and air pollution	294,567	Transit bus passes, community and school-based events, media coverage	$2,900,000
City of Ashland, OR	Resource Conservation	17,500	Inserts in electricity bills, newspaper ad, radio ads, presentations to local groups, community access TV, booth at the county homebuilders show	$5,120,626
University of Washington	U-PASS	50,000 breakdown 33,000 students, 17,000 faculty and staff	Posters, brochures, and campus newspaper advertising	$17,471,000
British Columbia, Canada	BC21 PowerSmart	4,563,296	Home audit teams, bus ads, utility bill inserts, shopping mall booths	$20,000,000
State of California	Flex Your Power	37,253,956	TV, radio, outdoor, online and print media	$111,400,000

Economic Analyses References

Buffalo Lumber February 2012 price sheet.

Dunn Lumber February 2012 price sheet.

East West Cedar February 2012 price sheet.

Eastern Red Cedar February 2012 price sheet.

Lumber Out West February 2012 price sheet.

Old Growth Timbers February 2012 price sheet.

Puget Sound Clean Air Agency. 2008. “2005 Air Emission Inventory.” March.

Railway Tie Association. Frequently Asked Questions. http://www.rta.org/Default.aspx?tabid=70. Accessed February 2012.

Redwood Lumber February 2012 price sheet.

Tacoma-Pierce County Clean Air Taskforce. 2011. “Report and Recommendations to Puget Sound Clean Air Agency.” December.

US Department of Agriculture, National Agricultural Statistics Service. 2008. 2007 Census of Agriculture. Report for Washington State.

US Environmental Protection Agency, Office of Transportation and Air Quality. 2007. “Diesel Retrofit Technology: An Analysis of the Cost-effectiveness of Reducing Particulate Matter and Nitrogen Oxides Emissions from Heavy-Duty Nonroad Diesel Engines Through Retrofits.” May.

Washington State Department of Ecology, Air Quality Program. 2006. “Diesel Particulate Reduction Strategy for Washington State.” Publication number 06-02-022.

Washington State Department of Ecology, Air Quality Program. 2009. “Health Effects and Economic Impacts of Fine Particle Pollution in Washington.” Publication number 09-02-021.

Washington State Department of Labor and Industries. 2011. “Small Business Economic Impact Statement for the Crane Rule (Phase 2).” June. http://www.lni.wa.gov/rules/AO08/32/0832SBEIS.pdf

Washington State Department of Licensing. 2012. Report of Vehicle Transactions by Class. 2011 calendar year.

General References

Achazzi RK and CAM Van Gestel (2003) Uptake and Accumulation of PAHs by Terrestrial Invertebrates. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Albers PH and TR Loughlin (2003) Effects of PAHs on Marine Birds, Mammals, and Reptiles. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Altenburger R, HSegner, and R Van Der Oost (2003) Biomarkers and PAHs-Prospects for the Assessment of Exposure and Effects in Aquatic Systems. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Ankley GT, LP Burkard, PM Cook, SA Diamond, RJ Erickson and DR Mount (2003) Assessing Risks from Photoactivated Toxicity of PAHs to Aquatic Organisms. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Asphalt Institute. Asphalt Maintenance and Rehabilitation FAQs. http://www.asphaltinstitute.org/public/engineering/maintenance_rehab/maint_rehab_faqs.asp (accessed 2/16/11).

Atkinson, Roger, Sara Hoover, Janet Arey & Kim Preston (2006) Atmospheric Chemistry of Gasoline-Related Emissions: Formation of Pollutants of Potential Concern, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, 262 pages.

Battelle Memorial Institute (2003) Guidance for Environmental Background Analysis Volume II: Sediment, 243 pages. http://web.ead.anl.gov/ecorisk/related/documents/Final_BG_Sediment_Guidance.pdf

Blake, A (2007) Active Railroads. Washington State Department of Transportation, GIS Cartography, Olympia, WA.

Brenner, RC, VS Magar, JA Ickes, JE Abbott, SA Stout, EA Crecelius, and LS Bingler (2002) Characterization and FATE of PAH-Contaminated Sediments at the Wyckoff/Eagle Harbor Superfund Site. Environ. Sci. Tech. 26, 2605-2613.

Britt, Phillip F., A. C. Buchanan, III and Clyde V. Owens, Jr. (2004) Mechanistic Investigation into the Formation of Polycyclic Aromatic Hydrocarbons From the Pyrolysis of Terpenes, Prepr. Pap.-Am. Chem. Soc., Div. Fuel Chem., 49(2), 868.

Burgess, Robert M. (2009) Evaluating Ecological Risk to Invertebrate Receptors from PAHs in Sediments at Hazardous Waste Sites, US Environmental Protection Agency Ecological Risk Assessment Support Center Office of Research and Development, Cincinnati, OH, 23 pages. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=214715

Bureau Veritas (2010) Germany Proposed Restriction of Polycyclic Aromatic Hydrocarbons (PAH). Bulletin.

Carls MG, L Holland, M Larsen, TK Collier, NL Scholz, and JP Incardona (2008) Fish embryos are damaged by dissolved PAHs, not oil particles. Aquatic Toxicology 88. 121-127

Centers for Disease Control and Prevention (CDC), 2005. Cigarette Smoking Among Adults-United States (2004) Centers for Disease Control and Prevention MMWR Weekly 54(44):1121-1124.

City of Austin (2005) Draft. PAHs in Austin Texas Sediments and Coal-Tar Based Pavement Sealants Polycyclic Aromatic Hydrocarbons. City of Austin, Watershed Protection and Development Review Department, Environmental Resources Management Division.

Cooper, David L, Joseph Gerratt & Mario Raimondi (1986) The Electronic Structure of the Benzene Molecule. Nature 323, p. 699-701. http://www.nature.com/nature/journal/v323/n6090/abs/323699a0.html

Crane, Judy L., Kim Grosenheider & C. Bruce Wilson (2010) Contamination of stormwater Pond Sediments by Polycyclic Aromatic Hydrocarbons (PAHs) in Minnesota: The Role of Coal Tar-based Sealcoat Products as a Source of PAHs, Minnesota Pollution Control Agency, 133 pages. http://www.leg.state.mn.us/docs/2010/other/100587.pdf

Danish Ministry of the Environment (2011) PAHs in toys and childcare articles. Survey of Chemical Substances in Consumer Products No. 114. 41 pages.

den Besten PJ, D ten Hulscher and B van Hattum (2003) Bioavailability, Uptake and Effects of PAHs in Aquatic Invertebrates in Field Studies. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Dickey Philip (2003) Guidelines for Selecting Wood Preservatives. For the San Francisco Department of the Environment. 56 pages.

Douben, Peter E. T. (2003) PAHs: An Ecotoxicological Perspective, Wiley, 377 pages.

Dutch Competent Authorities (2008) Creosote and possible alternatives: a comparison. 10 pages.

Ecology, Washington State Department of Ecology (1989) Concentrations of Polycyclic Aromatic Hydrocarbons in Sediment and Ground Water Near the Wyckoff Wood Treatment Facility, West Seattle, Washington. Publication 89-e03. 30 pages. http://www.ecy.wa.gov/biblio/89e03.html

Ecology. Washington State Department of Ecology (2000a) Proposed Strategy to Continually Reduce Persistent Bioaccumulative Toxics (PBTs) in Washington State. Publication 00-03-054. 72 pages.

Ecology. Washington State Department of Ecology (2000b) Washington State Litter Study. Volume II- Litter Generation & Composition Report. Publication 00-07-023. 110 pages.

Ecology. Washington State Department of Ecology (2003), Sediment Toxicity Near Gas Works Park, Lake Union, Seattle, Publication No. WA-03-03-014, 37 pages.

Ecology. Washington State Department of Ecology (2005a) Study of Unauthorized Tire Piles (ESHB 2085). Publication 05-07-043. 327 pages.

Ecology. Washington State Department of Ecology (2005b) Temporal Monitoring of Puget Sound Sediments: Results of the Puget Sound Ambient Monitoring Program, 1989-2000. Publication 05-03-016. 267 pages. http://www.ecy.wa.gov/biblio/0503016.html

Ecology. Washington State Department of Ecology (2009a) Determination of PBT Chemical Trends in Selected Washington Lakes Using Age-Dated Sediment Cores, 2008 Sampling Results. Publication 09-03-030. 57 pages.

Ecology. Washington State Department of Ecology (2009b) Urban Waters Initiative, 2007. Sediment Quality in Elliott Bay. Publication 09-03-014. 166 pages

Ecology. Washington State Department of Ecology (2010a) Washington State Toxics Monitoring Program: Trend Monitoring for Chlorinated Pesticides, PCBs, PAHs, and PBDEs in Washington Rivers and Lakes, 2008. Publication 10-03-027. 166 pages. Trend Monitoring for Chlorinated Pesticides, PCBs, PAHs, and PBDEs in Washington Rivers and Lakes, 2008

Ecology. Washington State Department of Ecology (2010b) Determination of PBT Chemical Trends in Selected Washington Lakes Using Age-Dated Sediment Cores, 2009 Sampling Results. Publication 10-03-035. 57 pages.

Ecology, Washington State Department of Ecology (2010c) Control of Toxic Chemicals in Puget Sound, Phase 3: Study of Atmospheric Deposition of Air Toxics to the Surface of Puget Sound. Publication 10-02-012. 54 pages. http://www.ecy.wa.gov/biblio/1002012.html

Ecology. Washington State Department of Ecology (2011a) Washington State Toxics Monitoring Program: Monitoring with SPMDs for PBTs in Washington Waters in 2009. Publication 11-03-029. 146 pages

Ecology. Washington State Department of Ecology (2011b) Control of Toxic Chemicals in Puget Sound: Assessment of Selected Toxic Chemicals in the Puget Sound Basin, 2007-2011. Publication 11-03-055. 295 pages

Ecology. Washington State Department of Ecology (2011c) Toxic Chemicals in the Puget Sound Basin: Phase 3:Primary Sources of Selected Toxic Chemicals and Quantities Released in the Puget Sound Basin. Publication 11-03-024. 297 pages.

Eisler R (1987) Polycyclic aromatic hydrocarbon hazards to fish, wildlife, and invertebrates: a synoptic review. US Fish and Wildlife Service Biological Report 85(1.11). 55 p.

Environment Canada (1994) Canadian Environmental Protect Act Priority substances List Assessment Report Polycyclic Aromatic Hydrocarbons, 86 pages.

European Commission (2003) Opinion of the Scientific Committee on Toxicity, Ecotoxicity and the environment (CSTEE) on “Questions to the CSTEE relating to scientific evidence of risk to health and the environment from polycyclic aromatic hydrocarbons in extender oils and tyres”. 11 pages

Feldman and Shistar (1997) Poison Poles- A report About Their Toxic Trail and Safer Alternatives. http://www.beyondpesticides.org/wood/pubs/poisonpoles/index.html

Greenberg BM (2003) PAH Interactions with Plants: Uptake, Toxicity and Phytoremediation. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Hafner, WD, DL Carlson, and RA Hites (2005) Influence of Local Human Population on Atmospheric Polycyclic Aromatic Hydrocarbon Concentrations. Environ. Sci. and Techn. 39(19) 7374-7379.

Hazardous Substance Data Bank (2010) National Library of Medicine, National Toxicology Program (via TOXNET), Bethesda, MD.

Hicken, CE. TL Linbo, DH Baldwin, ML Willis, MS Meyers, L Holland, M Larsen, MS Stekoll, SD Rice, TK Collier, NL Scholz, and JP Incardona (2011) Sublethal exposure to crude oil during embryonic development alters cardiac morphology and reduces aerobic capacity in adult fish. PNAS.

Howard, PH, RS Boethling, WF Jarvis, WM Meylan, and EM Michalenko (1991) Handbook of Environmental Degradation Rates. Lewis Publishers, Michigan.

Ilnitsky, AP, VS Mischenko, and LM Shabad (1977) New data on volcanoes as natural sources of carcinogenic substances. Cancer Letters vol. 3, p. 227.

Incardona JP, TK Collier, and NL Scholz (2004) Defects in cardiac function precede morphological abnormalities in fish embryos exposed to PAHs. Toxicology and Applied Pharmacology. 196 (2). 191-205

Kidder, Michelle K., Phillip F. Britt and A. C. Buchanan, III (2001) Flash Vacuum Pyrolysis of Plant Steroids: The Impact of Steroid Structure on the Formation of Polycyclic Aromatic Hydrocarbons, Fuel Chemistry Division Preprints, 46(1), 7 pages.

Kimbrough, K.L., Lauenstein, G.G., Christensen, J.D., and Apeti, D.A. (2008) An assessment of two decades of contaminant monitoring in the Nation’s Coastal Zone. National Oceanic and

Atmospheric Administration/National Center for Ocean Science Technical Memorandum, Silver Spring, MD. 118 pages.

Kuo, L-J, P Louchouarn, BE Herbert, JM Brandenberger, TL Wade, and E Crecelius (2011) Combustion-derived substances in deep basins of Puget Sound: Historical inputs from fossil fuel and biomass combustion. Environmental Pollution 159. 983-990.

Landahl JT, BB McCain, MS Myers, LD Rhodes, and DW Brown (1990) Consistent associations between hepatic lesions in English sole and PAHs in bottom sediment. Environmental Health Perspectives. Vol. 89. 195-203

Latimer JS and J Zeng (2003) The Sources, Transport and Fate in the Marine Environment. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Lefkovitz LF, VI Cullinan, and EA Crecelius (1997) Historical Trends in the Accumulation of Chemicals in Puget Sound. NOAA Technical Memorandum NOS ORCA 111. 159 pages.

Li A, J-K Jang, and PA Scheff (2003) Application of EPA CMB8.2 Model for Source Apportionment of Sediment PAHs in Lake Calumet, Chicago. Environ. Sci. and Tech. Vol. 37. 2958-2965.

Lindstedt, R. P. and V. Markaki (2009) Detailed and Simplified Chemical Kinetics of Aviation Fuels and Surrogates, Imperial College, London, Submitted to the European Office of Aerospace Research and Development, 88 pages.

Mackay, D., W.Y. Shiu and K.C. Ma. (1992) Illustrated Handbook of Physical Chemical Properties and Environmental Fate for Organic Chemicals. Volume II: Polynuclear Aromatic Hydrocarbons, Polychlorinated Dioxins, and Dibenzofurans. Lewis Publishers, New York NY.

Mahler, B., P. Van Metre, T. Bashara, J. Wilson, and D. Johns (2005) Parking Lot Sealcoat: An unrecognized source of polycyclic aromatic hydrocarbons. Environmental Science and Technology, 39: 5560-5566.

Mahler B, PC Van Metre, JT Wilson, and M Musgrove (2010) Coal-Tar-Based Parking Lot Sealcoat: An Unrecognized Source of PAH to Settled House Dust. Environmental Science and Technology, 44: 894-900.

Malcolm HM and RF Shore (2003). Effects of PAHs on Terrestrial and Freshwater Birds, Mammals and Amphibians. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

McCormick, RL (2007) The Impact of Biodiesel on Pollutant Emissions and Public Health. Inhalation Toxicology 19 (12) 1033-1039.

Meador J (2003) Bioaccumulation of PAHs in Marine Invertebrates. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Meador JP, FC Sommers, GM Ylitalo, and CA Sloan (2006) Altered growth and related physiological responses in juvenile Chinook salmon (Oncorhynchus tshawytscha) from dietary exposure to PAHs. Canadian Journal of Fisheries and Aquatic Sciences. 63(10). 2364-2376

Moriwaki, H, S Kitajima, and K Katahira (2009) Waste on the roadside, 'poi-sute' waste: It's distribution and elution potential of pollutants into the environment. Waste Management 29. 1192-1197.

Mount D, CG Ingersoll and JA McGrath (2003) Approaches to Developing Sediment Quality Guidelines for PAHs. In Douben PET (eds), PAHs: An Ecotoxicological Perspective. J. Wiley & Sons, Ltd., England.

Myers MS, BF Anulaciaon, BL French, WL Reichert, CA Laetz, J Buzitis, OP Olson, S Sol, and TC Collier (2008) Improved flatfish health following remediation of a PAH-contaminated site in Eagle Harbor, Washington. Aquatic Toxicology 88(4). 277-288

National Interagency Fire Center. http://www.nifc.gov/fireInfo/fireInfo_statistics.html

National Park Services (1997) Environmental Contaminants Encyclopedia PAHS Entry, Roy J. Irwin, editor, Water Resources Divisions, Water Operations Branch, 176 pages.

Otterson, S (2007) Washington State Base Year 2005 County Inventories.

Parametrix (2011) Creosote Release from Cut/Broken Piles, Asarco Smelter Site. Prepared for Washington Department of Natural Resources, 47 pages

Parker, Sybil P. (editor in Chief) (1993) McGraw-Hill Encyclopedia of Chemistry, Second Edition.

Payne JF, A Mathieu, and TK Collier (2003) Ecoltoxicological Studies Focusing on Marine and Freshwater Fish. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Richter, Henning, Timothy G. Benish, Oleg A Mazyar, William H. Green and Jack B. Howard (2000a) *Formation of Polycyclic Aromatic Hydrocarbons and Their Radicals in Nearly Sooting Premixed Benzene Flame*, Proceedings of the combustion Institute, Volume 24, pp. 2609-2618.

Richter, Henning, Timoth G. Benish, Francisco Ayala and Jack B. Howard (2000b) *Kinetic Modeling of the Formation of Polycyclic Aromatic Hydrocarbons*, ACS Fuel Chem. Div. Preprints 45(2), 273-277.

Roush, James A. & David M. Mauro (2009) Site Assessment for Proposed Coke Point Dredged Material Containment Facility at Sparrows Point, Baltimore County, Maryland, Maryland Port Administration, 491 pages. http://textonly.mde.state.md.us/programs/Land/HazardousWaste/HazardousWasteHome/Documents/www.mde.state.md.us/assets/document/10%20Attachment%20IV%20forensic%20reports.pdf

Refining Process Services, Inc. (2001) Introduction to Petroleum Refining Processing Training, September 11-13, 2001, Houston, Texas.

RTA, 2010. Internet Home Page, Railway Tie Association**.** http://www.rta.org/. Accessed July 20, 2010.

The Scientific Committee on Toxicity, Ecotoxicity and the Environment (2003) Questions to the CSTEE Relating to Scientific Evidence of Risk to Health and the Environment from Polycyclic Aromatic Hydrocarbons in Extender Oils and Tyres. European Commission. http://www.ec.europa.eu/health/ph_risk/committees/sct/documents/out206_en.pdf

Sherrod, DR, WE Scott, PH Stauffer, eds. (2008) A volcano rekindled: the renewed eruption of Mount St. Helens, 2004-2006. U.S. Geological Survey professional paper, 1750, 856 p.

Simpson, AT, and PA Ellwood (1996) Polycyclic Aromatic Hydrocarbons in Quench Oils. Ann. Occup. Hyg. 40(5), 531-537

Slavinskaya, N. A, M. Wacker and M Aigner (2009) Kinetic Modeling of Cyclohexane Oxidation with PAH Formation, Proceedings of the European Combustion Meeting, 6 pages. http://www.combustion.org.uk/ECM_2009/P811395.pdf

Smith, ST (2007). A cost-benefit analysis of creosote-treated wood vs. non-treated wood materials. Taken from the website of the Creosote Council. http://creosotecouncil.org/pdf/CCIII_Cost-BenefitAnalysis.pdf

Stout, SA and TP Graan (2010) Quantitative Source Apportionment of PAHs in Sediments of Little Menomonee River, Wisconsin: Weathered Creosote versus Urban Background. Environ. Sci. and Tech. Vol 44. 2932-2939.

Stracquadanio, M, E Dinelli, and C Trombini (2003) Role of volcanic dust in the atmospheric transport and deposition of polycyclic aromatic hydrocarbons and mercury. J. Environ. Monit. 5, 984-988.

Stratus Consulting (2006) Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations. Prepared for NOAA Fisheries, 106 pages.

US Department of Health & Human Services Agency for Toxic Substances and Disease Registry (ASTDR) (1995) Toxicological Profile for Polycyclic Aromatic Hydrocarbons, 487 pages.

US Department of Health & Human Services Agency for Toxic Substances and Disease Registry (ASTDR) (2002) Toxicological Profile for Wood Creosote, Coal Tar Creosote, Coal Tar, Coal Tar Pitch, and Coal Tar Pitch Volatiles, 394 pages.

U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program (NTP) (2005) Report on Carcinogens, Eleventh Edition, http://ntp.niehs.nih.gov/?objectid=035E5806-F735-FE81-FF769DFE5509AF0A

US Department of Health & Human Services Agency for Toxic Substances and Disease Registry (ASTDR) (2008) Proposed Substances To Be Evaluated for Set 23 Toxicological Profiles, Federal Register, Pages 73329-73332, http://www.federalregister.gov/articles/2008/12/02/E8-28551/proposed-substances-to-be-evaluated-for-set-23-toxicological-profiles, accessed 1/26/2011.

U.S. DOT (2002) Omnibus Household Survey. U.S. Department of Transportation, Bureau of Transportation Statistics. 125 pages. www.bts.gov/programs/omnibus_surveys/household_survey/2002/january/.

US Environmental Protection Agency (EPA) (1979) *Water-Related Environmental Fate of 129 Priority Pollutants, Volume II*, EPA-440 4-79-029b, 667 pages.

USEPA Emission Inventory Improvement Program (2001) Open Burning. Volume III: Chapter 16. 72 pages.

USEPA (2004) CMB8.2 Users Manual. http://www.epa.gov/ttn/scram/receptor_cmb.htm

USEPA (2007) Second five-year review report for the Wyckoff/Eagle Harbor Superfund site Bainbridge Island, Washington. 338 p.

http://yosemite.epa.gov/r10/cleanup.nsf/b0067394308bf1a2882568ab007ca6d7/bbda6f55e18fbb9e882570dd005a0fa9!OpenDocument

USEPA (2010) National Priority Chemicals Trends Report (2005-2007). EPA530-R-10-011. 7 pages.

US National Institute of Health Hazardous Substances Database (HSDB), accessed 12/1/2010, http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~w672PB:1.

Van Brummelen TC, B van Hattum, T Crommentuijn, and DE Kalf (1998) Bioavailability and Ecotoxicology of PAHs. In Neilson AH (ed), *PAHs and Related Compounds Biology*. Springer, Berlin, Germany.

Van Metre PC, BJ Mahler, and ET Furlong (2000) Urban Sprawl Leaves Its PAH Signature. Environmental Science and Technology, 34: 4064-4070.

Van Metre, P., J. Wilson, C. Fuller, E. Callender, and B. Mahler, (2004). Collection, Analysis and Age-Dating of Sediment Cores From 56 U.S. Lakes and Reservoirs Sampled by the U.S. Geological Survey, 1992–2001. United States Geological Survey. http://pubs.usgs.gov/sir/2004/5184/

Van Metre, P., B. Mahler, and J. Wilson, (2008) PAHs underfoot: Contaminated dust from coal-tar sealcoated pavement is widespread in the United States. Environmental Science and Technology, 39: 23-25.

Van Metre, P., and B. Mahler (2010) Contribution of PAHs from coal-tar pavement sealcoat and other sources to 40 U.S. lakes. Science of the Total Environment, 409: 334-344.

Vines CA, T Robbins, FJ Griffin, and GN Cherr (2000) The effects of diffusible creosote-derived compounds on development in Pacific herring (*Clupea pallasi*). Aquatic Toxicology 51(2). 225-239

Volkering F and AM Breure. (2003) Biodegradation and General Aspects of Bioavailability. In Douben PET (eds), *PAHs: An Ecotoxicological Perspective*. J. Wiley & Sons, Ltd., England.

Wang, Jun, Henning Richter, Jack B. Howard, Yiannis A. Levendis and Joel Carlson (2002). Polynuclear Aromatic Hydrocarbon and Particulate Emissions from Two-State Combustion of Polystyrene: The Effects of the Secondary Furnace (Afterburner) Temperature and Soot Filtration, Environ. Sci. Technol., 36, 797-808.

WDOH (2010) Tobacco Prevention and Control Program Data and Reports. Washington State Department of Health**.** www.doh.wa.gov/tobacco/news/facts.htm. Accessed April 10, 2010.

WDNR. Washington State Department of Natural Resources (2009). Character and Extent of the 2008 Fire Season. 17 pages.

WDOR (2007) Per capita Cigarette Consumption Down 29 percent Over past Decade. Washington State Department of Revenue News Release. www.dor.wa.gov/docs/pubs/news/2007/nr_cigaretteconsumptiondownl.pdf. Accessed September 1, 2010.

Washington State Department of Transportation (WSDOT) (2007) Pavement Sealer Applications. Materials Laboratory tech notes.

WSDOT (2010) Washington State Department of Transportation, Creosote Removal Initiative. www.wsdot.wa.gov/ferries/your_wsf/corporate_communications/creosote. Accessed July 21, 2010.

Werme C, J Hunt, E Beller, K Cayce, M Klatt, A Melwani, E Polson, and R Grossinger (2010) Removal of Creosote-Treated Pilings and Structures from San Francisco Bay. Prepared for the California State Coastal Conservancy. Contribution No. 605. San Francisco Estuary Institute, Oakland, California.

Westbrook, C. K., W. J. Pitz, O. Herbinet, E. J. Silke and H. J. Curran (2007) A Detailed Chemical Kinetic Reaction Mechanism for n-Alkane Hydrocarbons from n-Octane to n-Hexadecane, Lawrence Livermore National Laboratory, publication UCRL-CONF-234947, 69 pages.

World Health Organization International Agency for Research on Cancer (IARC) (1998) IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 32, Polynuclear Aromatic Compounds, Part 1, Chemical, Environmental and Experimental Data, 54 pages, http://monographs.iarc.fr/ENG/Monographs/vol32/volume32.pdf, accessed 1/25/2011.

World Health Organization (2004) Coal Tar Creosote. Concise International Chemical Assessment Document 62, 149 pages.

World Health Organization International Agency for Research on Cancer (IARC) (2010) IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 22, Some Non-heterocyclic Polycyclic Aromatic Hydrocarbons and Some Related Exposures, 853 pages, http://monographs.iarc.fr/ENG/Monographs/vol92/index.php, accessed 1/25/2011.

Appendix A Comparative lists of PAHs

CAS	Name	Washington PBT list	US EPA TRI	1977 Clean Water Act Priority	ATSDR Tox Profile	ATSDR additional PAHs for future	HSDB PAHs	NTP 2005 anticipated carcinogens	IARC carcinogens	EPA IRIS carcinogens	California Prop 65 carcinogens	EPA Master List of Compounds Emitted	CERCLA reportable substances	WA dangerous waste regulations	WA Sediment Quality Standards	WA Toxic Air Pollutants	OR final prioroity persistent pollutants
11057-45-7	benzoperylene					x											
120-12-7	anthracene		x	x	x		x					x	x	x	x		x
129-00-0	pyrene			x	x		x					x	x		x		x
15679-24-0	2,7-dimethylpyrene						x										
189-55-9	benzo(r,s,t)pentaphene	x	x				x	x	2B		x	x	x			x	
189-64-0	dibenzo(a,h)pyrene	x	x				x	x	2B		x			x			
191-24-2	benzo(g,h,i)perylene	x	x	x	x		x		3	D		x	x	x	x		x
191-30-0	dibenzo(a,l)pyrene		x				x	x	2A		x	x					
192-65-4	dibenzo(a,e)pyrene	x	x				x	x	3		x	x		x		x	
192-97-2	benzo(e)pyrene				x		x										
193-39-5	indeno(1,2,3-cd)pyrene	x	x	x	x		x	x	2B	B2	x	x	x	x	x	x	x
194-59-2	7H-dibenzo(c,g)carazole	x	x					x	2B		x					x	
194-69-4	benzo(c)chrysene						x										
196-78-1	benzo(g)chrysene						x										
198-55-0	perylene	x							3			x					
203-12-3	benzo(g,h,i)fluoranthene					x											

203-33-8	benzo(a)fluoranthene					x								x			
205-82-3	benzo(j)fluoranthene	x	x		x		x	x	2B		x	x		x	x	x	
205-99-2	benzo(b)fluoranthene	x	x	x	x		x	x	2B	B2	x	x	x	x	x	x	x
206-44-0	fluoranthene	x	x	x	x		x		3	D		x	x	x	x		x
207-08-9	benzo(k)fluoranthene	x	x	x	x		x	x	2B	B2	x	x	x		x	x	x
208-96-8	acenaphthylene			x	x		x					x	x	x	x		
217-54-9	dibenzo(b,k)chrysene						x							x			
218-01-9	benzo(a)phenanthrene (chrysene)	x	x	x	x		x		2B	B2	x	x	x		x	x	x
224-41-9	dibenz(a,j)anthracene					x											
224-42-0	dibenzo(a,j)acridine	x	x				x	x	2B		x					x	
225-51-4	benz(c)acridine						x										
226-36-8	dibenzo(a,h)acridine	x	x				x	x	2B		x					x	
2381-15-9	10-methylbenz(a)anthracene						x										
2381-16-0	9-methylbenz(a)anthracene						x										
2381-21-7	methylpyrene					x	x										x
2381-31-9	8-methylbenz(a)anthracene						x										
2422-79-9	12-methylbenz(a)anthracene						x										
2541-69-7	7-methylbenz(a)anthracene						x										
3442-78-2	2-methylpyrene						x										
3697-24-3	5-methyl chrysene		x				x	x	2B		x	x		x			
479-23-2	cholanthrene						x							x			
50-32-8	benzo(a)pyrene		x	x	x		x	x	1	B2	x	x	x		x		x
53-70-3	dibenzo(a,h)anthracene	x	x	x	x		x	x	2A	B2	x	x	x		x	x	x
5385-75-1	dibenzo(a,e)fluoranthene		x				x							x			
5522-43-0	1- nitropyrene		x						2B		x	x					
56-49-5	3-methyl cholanthrene	x	x				x				x	x	x			x	
56-55-3	benzo(a)anthracene		x	x	x		x	x	2B	B2	x	x			x		x

56832-73-6	benzofluoranthene					x											
57-97-6	7,12-dimethylbenz(a)anthracene		x				x				x		x				
73467-76-2	benzopyrene					x											
781-43-1	9,10-dimethylanthracene						x							x			
8001-58-9	creosote		x						2A	B1	x			x			
8007-45-2	coal tar						x	known	1					x			
83-32-9	acenaphthene			x	x		x					x	x		x		
85-01-8	phenanthrene		x	x	x		x					x	x		x		x
86-73-7	fluorene			x	x		x					x	x		x		
86-74-8	carbazole						x				x						
91-20-3	naphthalene		x	x					2B		x	x	x		x		
92-24-0	benzo(b)anthracene					x											

Appendix B Puget Sound Hazard Evaluation Figures

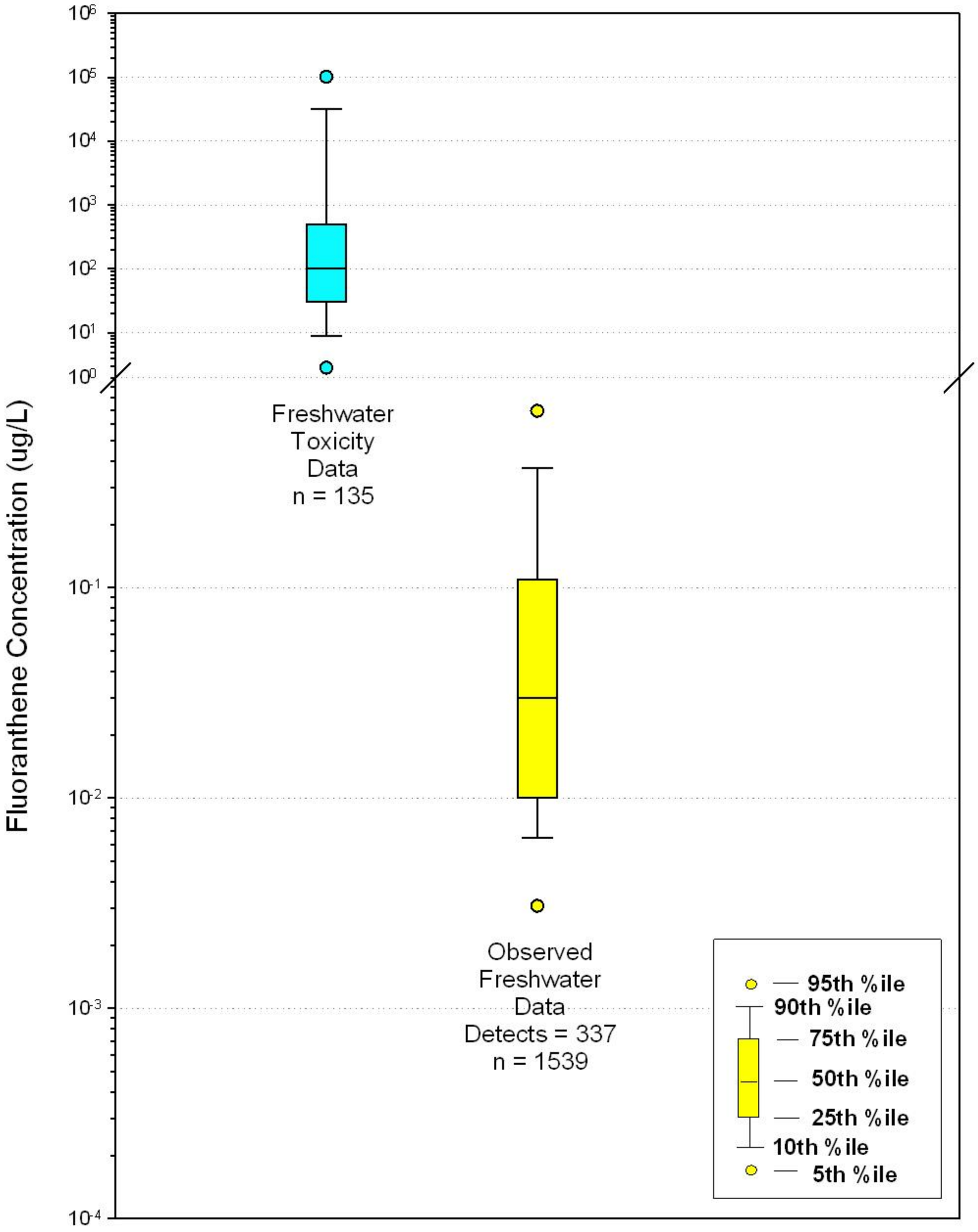

Figure B1 Fluoranthene in freshwater. Box plot of observed environmental concentrations (yellow) in surface water plotted against box plot of available effects concentrations (blue). All concentrations are presented on a log scale; note scale shift on Y axis. N represents the number of available measurements. N represents the number of available measurements.

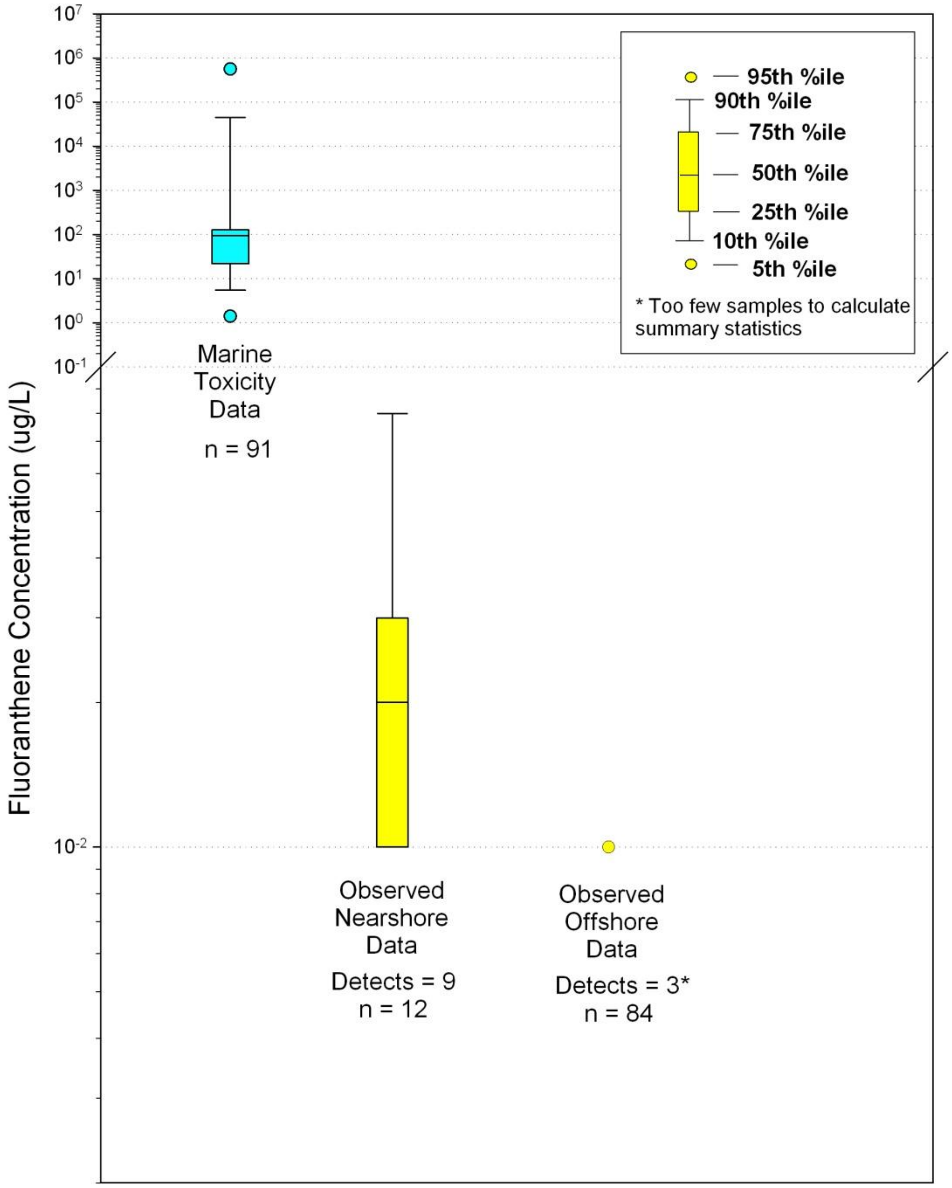

Figure B2 Fluoranthene in marine water. Box plot and/or data points of observed environmental concentrations (yellow) in surface water plotted against box plot of available effects concentrations (blue). All concentrations are presented on a log scale; note scale shift on Y axis. N represents the number of available observed measurements. N represents the number of available measurements.

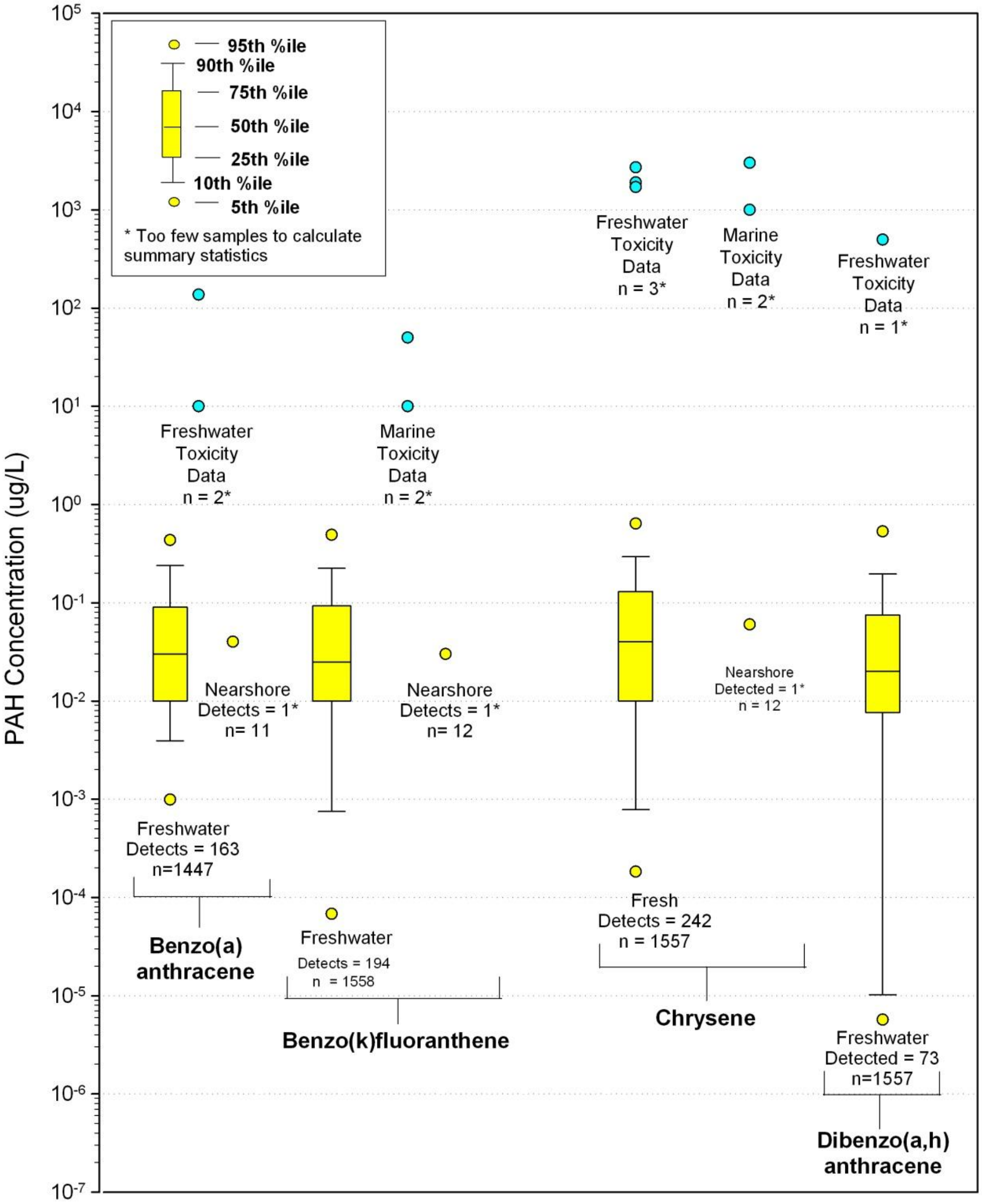

Figure B3 Small dataset PAHs in fresh and marine water. Box plots and/or data points of observed environmental concentrations (yellow or green) in surface water plotted against box plot of available effects concentrations (yellow). All concentrations are presented on a log scale; note scale shift on Y axis. N represents the number of available measurements.

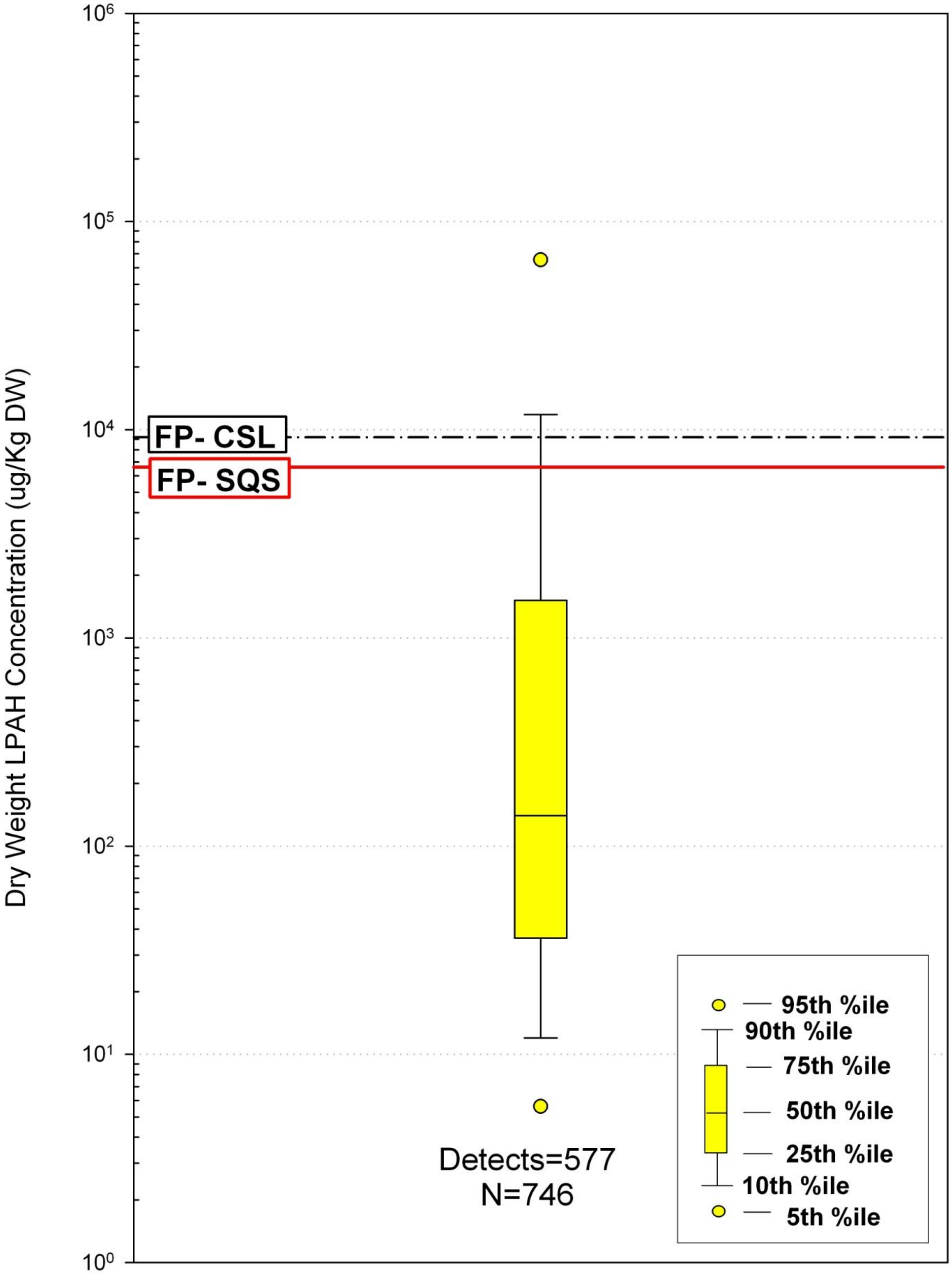

Figure B4 LPAH in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL- Floating Percentile Cleanup Screening Level. All concentrations are presented on a log scale.

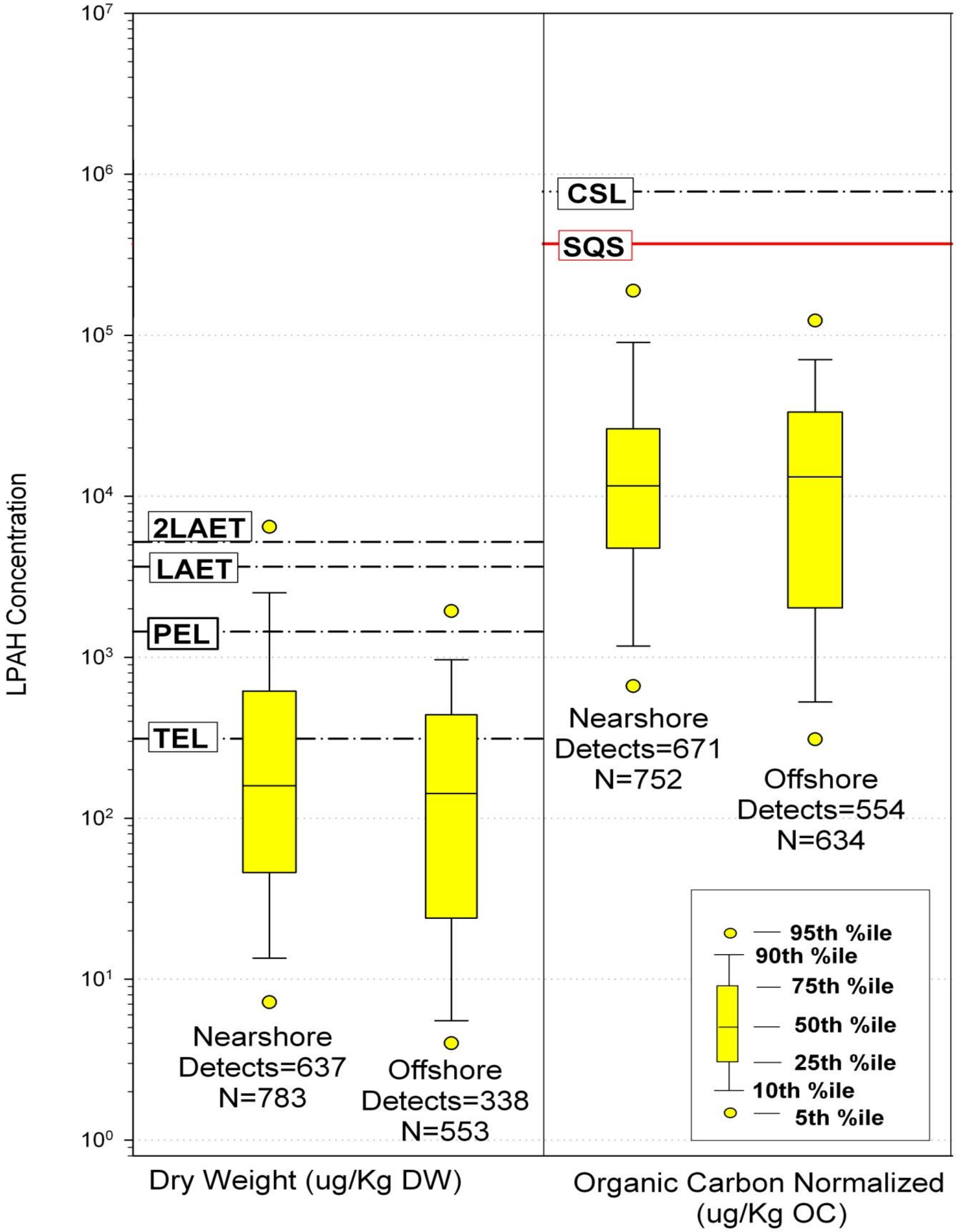

Figure B5 LPAH in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. TEL – Threshold Effect Level, PEL – Probable Effects Level; LAET – Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold; SQS – Sediment Quality Standard, CSL- Cleanup Screening Level. All concentrations are presented on a log scale.

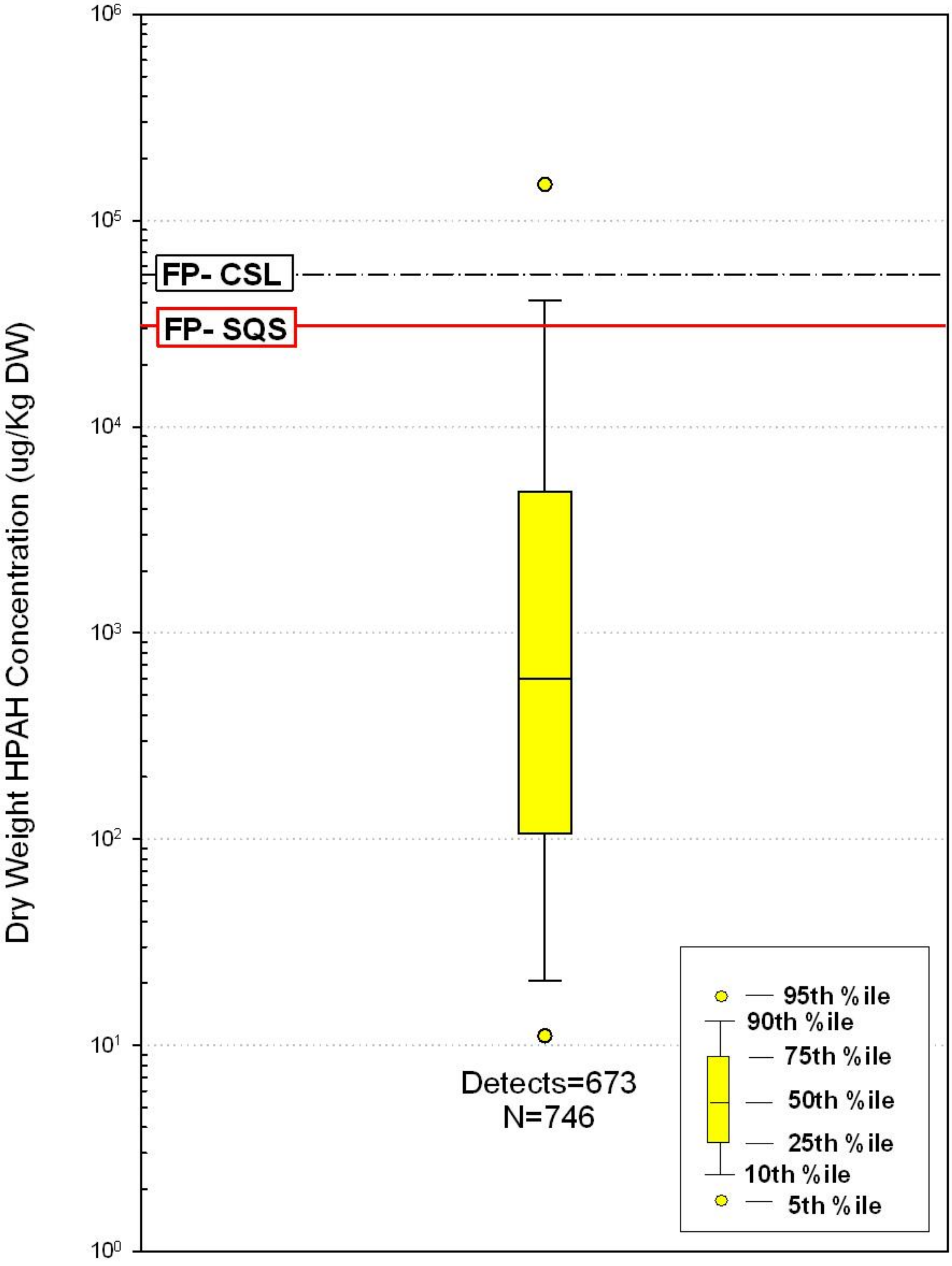

Figure B6 HPAHs in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL-Floating Percentile Cleanup Screening Level. All concentrations are presented on a log scale.

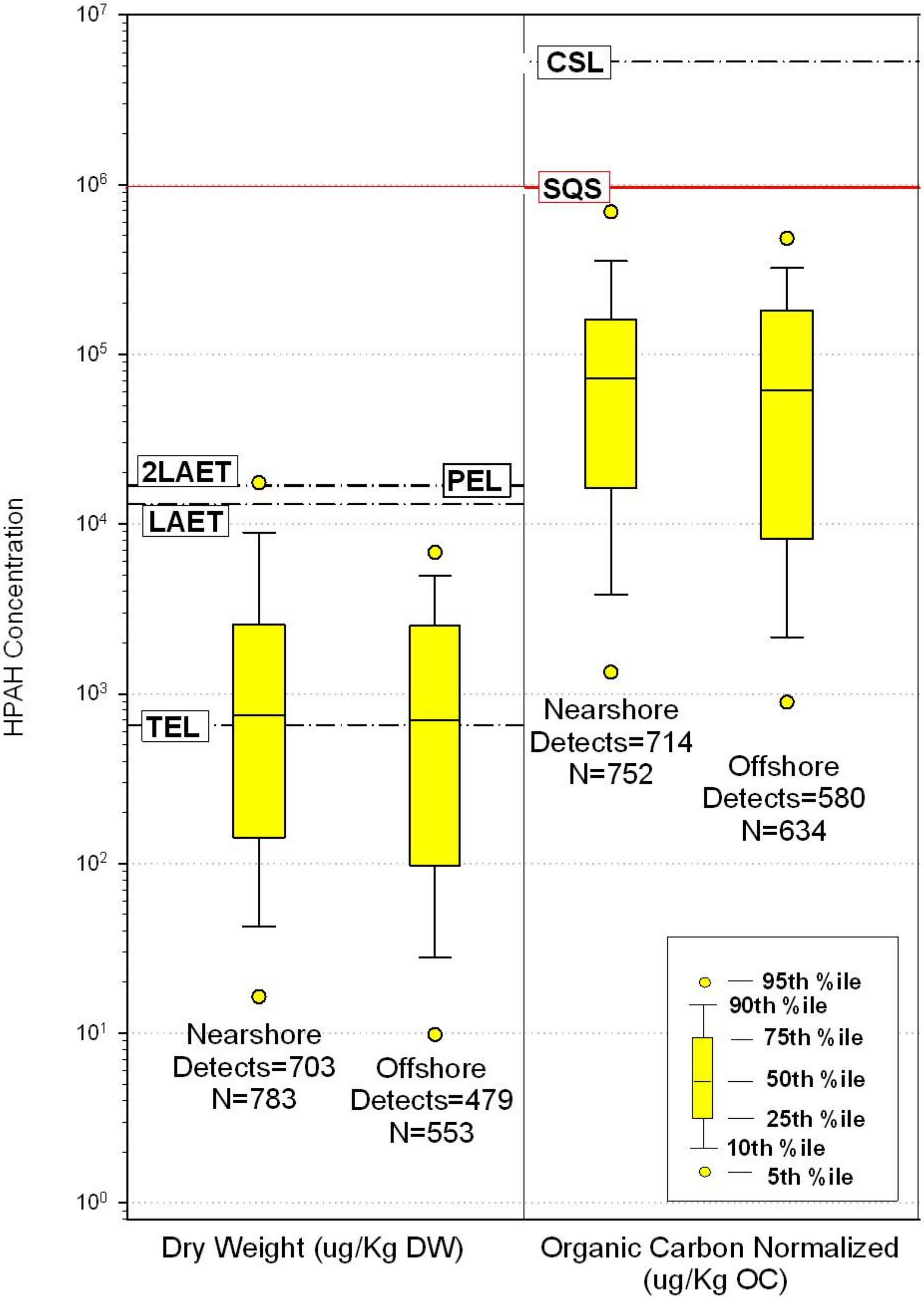

Figure B7 HPAHs in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. TEL – Threshold Effect Level, PEL – Probable Effects Level; LAET – Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold; SQS – Sediment Quality Standard, CSL- Cleanup Screening Level. All concentrations are presented on a log scale.

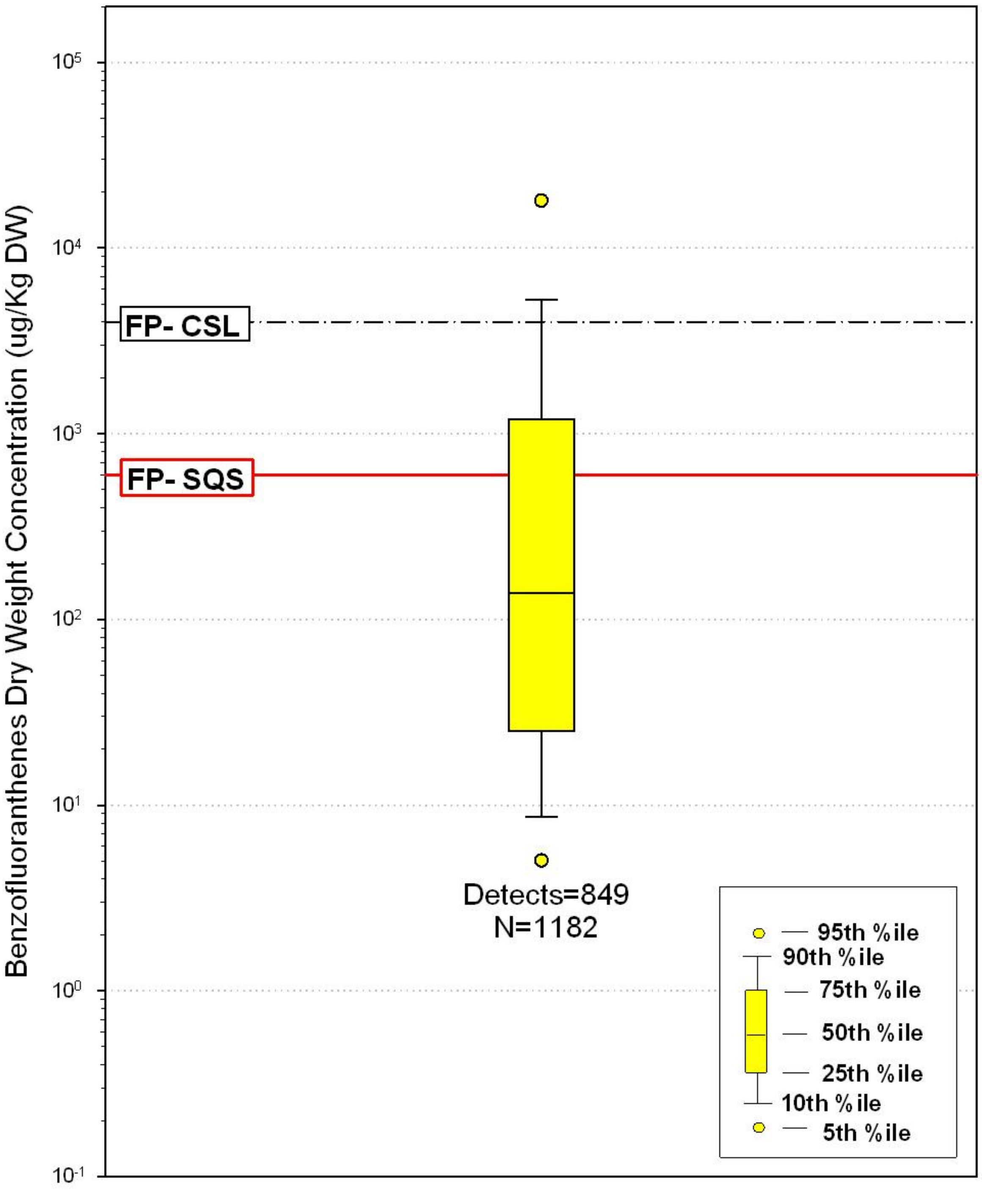

Figure B8 Benzofluoranthenes in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL- Floating Percentile Cleanup Screening Level. All concentrations are presented on a log scale.

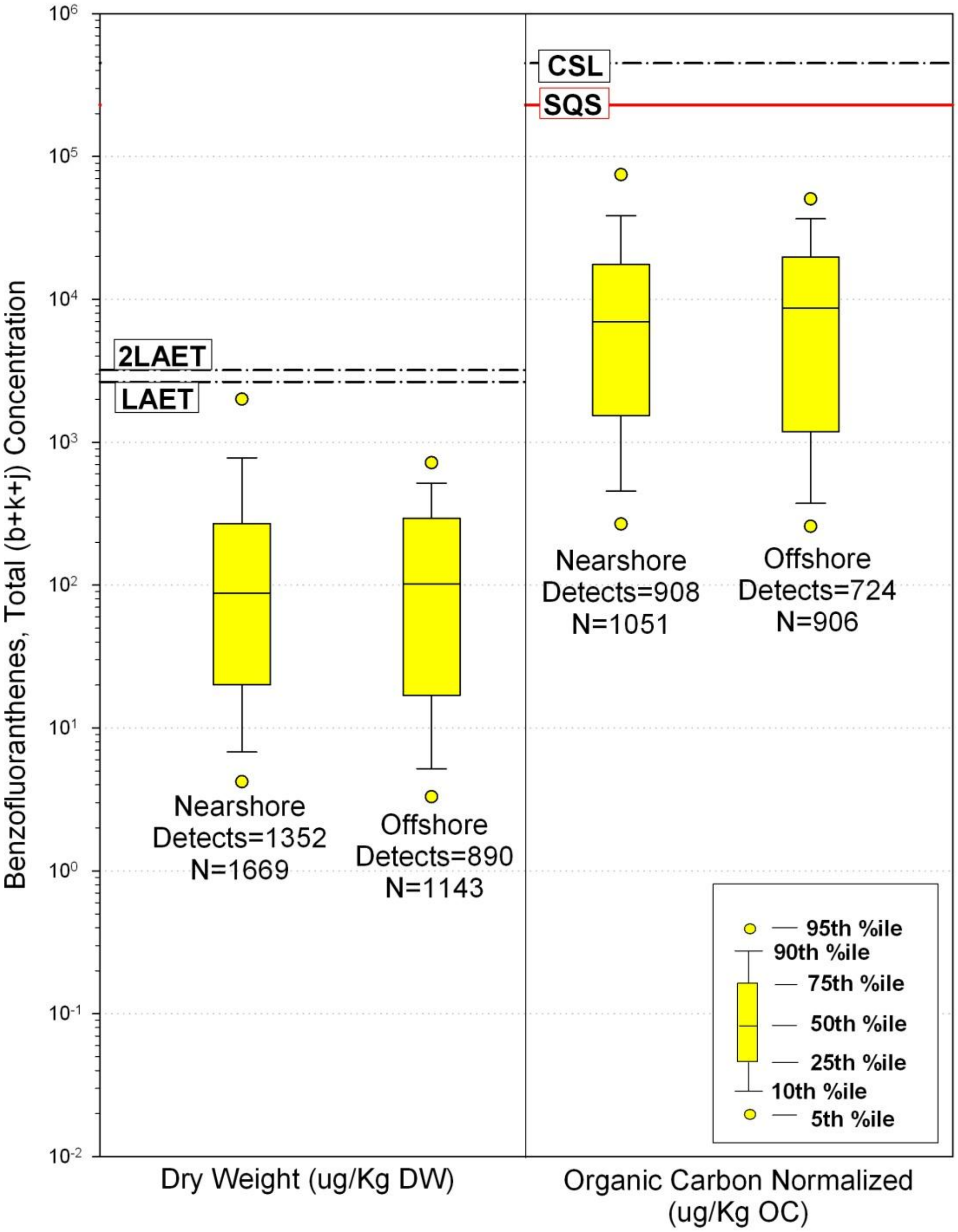

Figure B9 Benzofluoranthenes in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. Probable Effects Level; LAET – Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold; SQS – Sediment Quality Standard, CSL- Cleanup Screening Level. All concentrations are presented on a log scale.

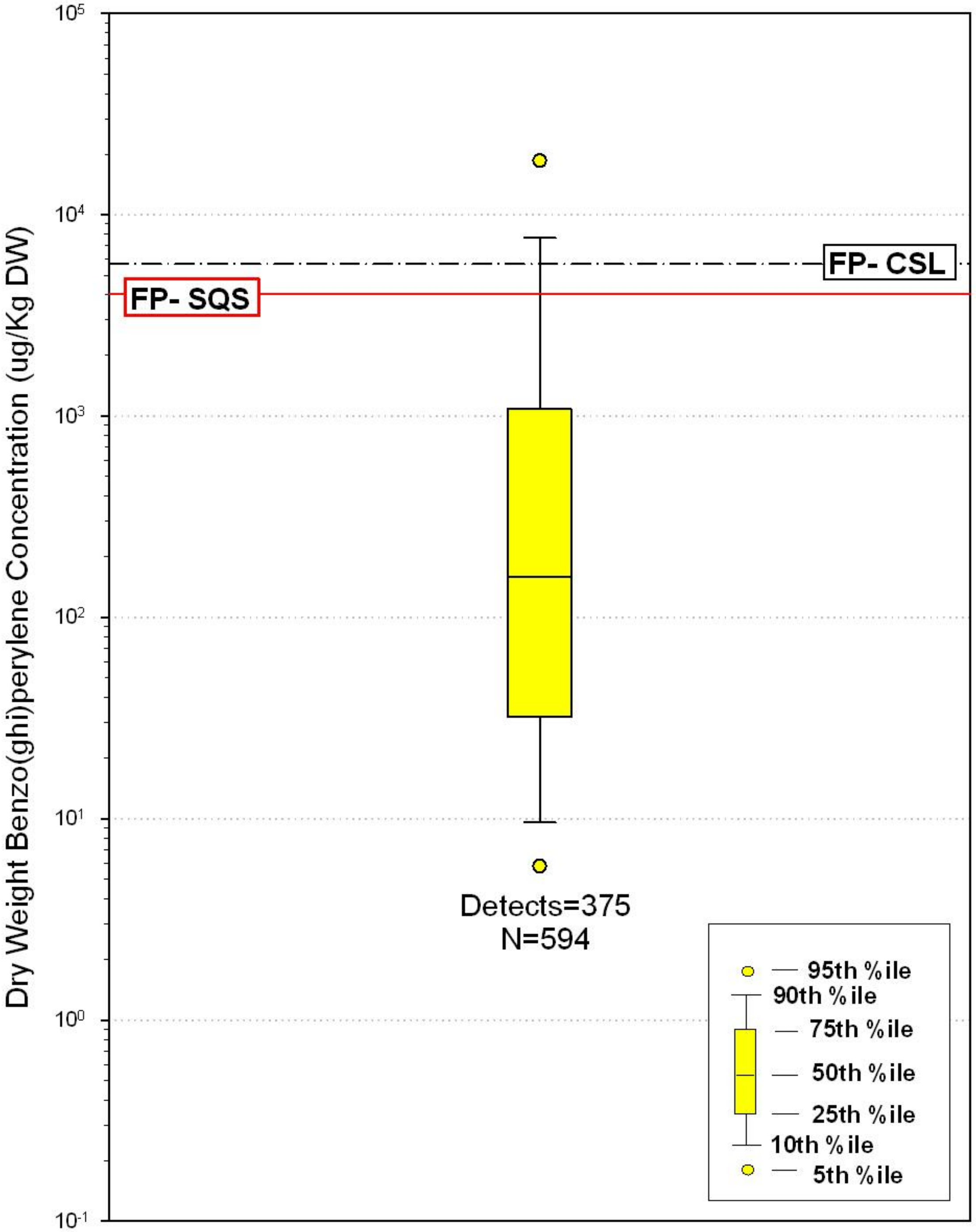

Figure B10 Benzo(ghi)perylene in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL- Floating Percentile Cleanup Screening Level. All concentrations are presented on a log scale.

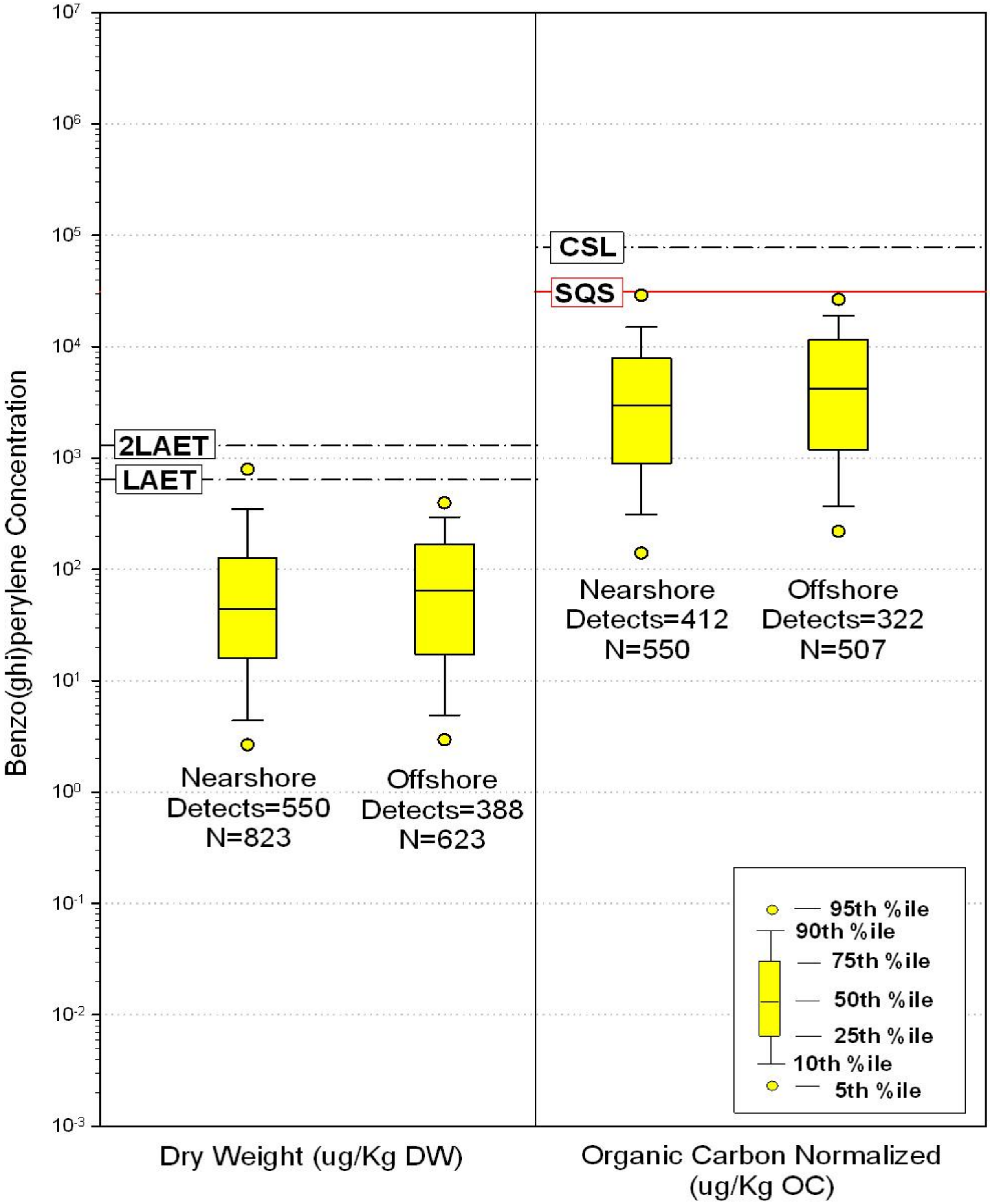

Figure B11 Benzo(ghi)perylene in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold; SQS – Sediment Quality Standard, CSL- Cleanup Screening Level. All concentrations are presented on a log scale.

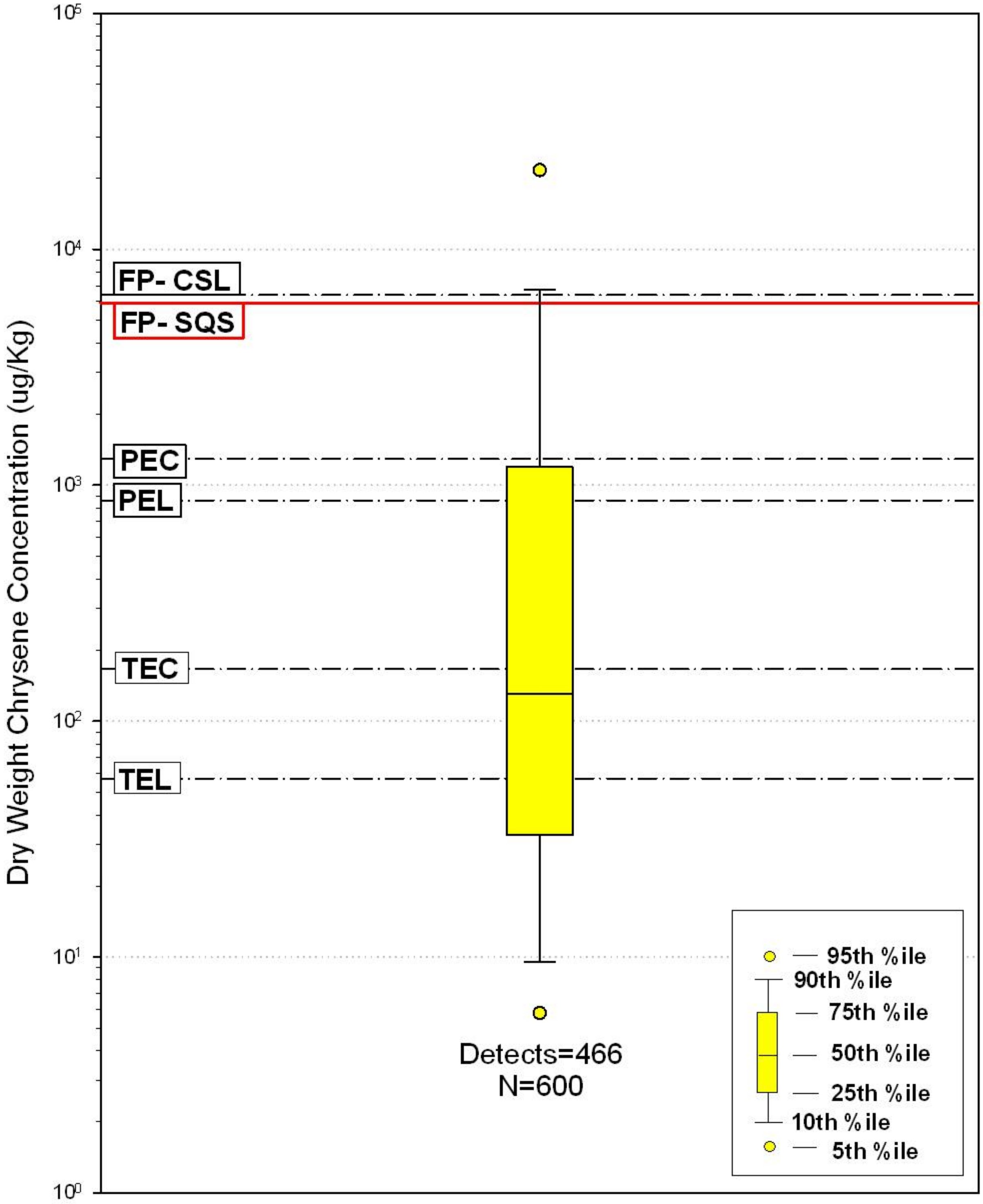

Figure B12 Chrysene in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL- Floating Percentile Cleanup Screening Level; TEL – Threshold Effect Level, PEL – Probable Effects Level; TEC – Threshold Effects Concentration, PEC – Probable Effect Concentration. All concentrations are presented on a log scale.

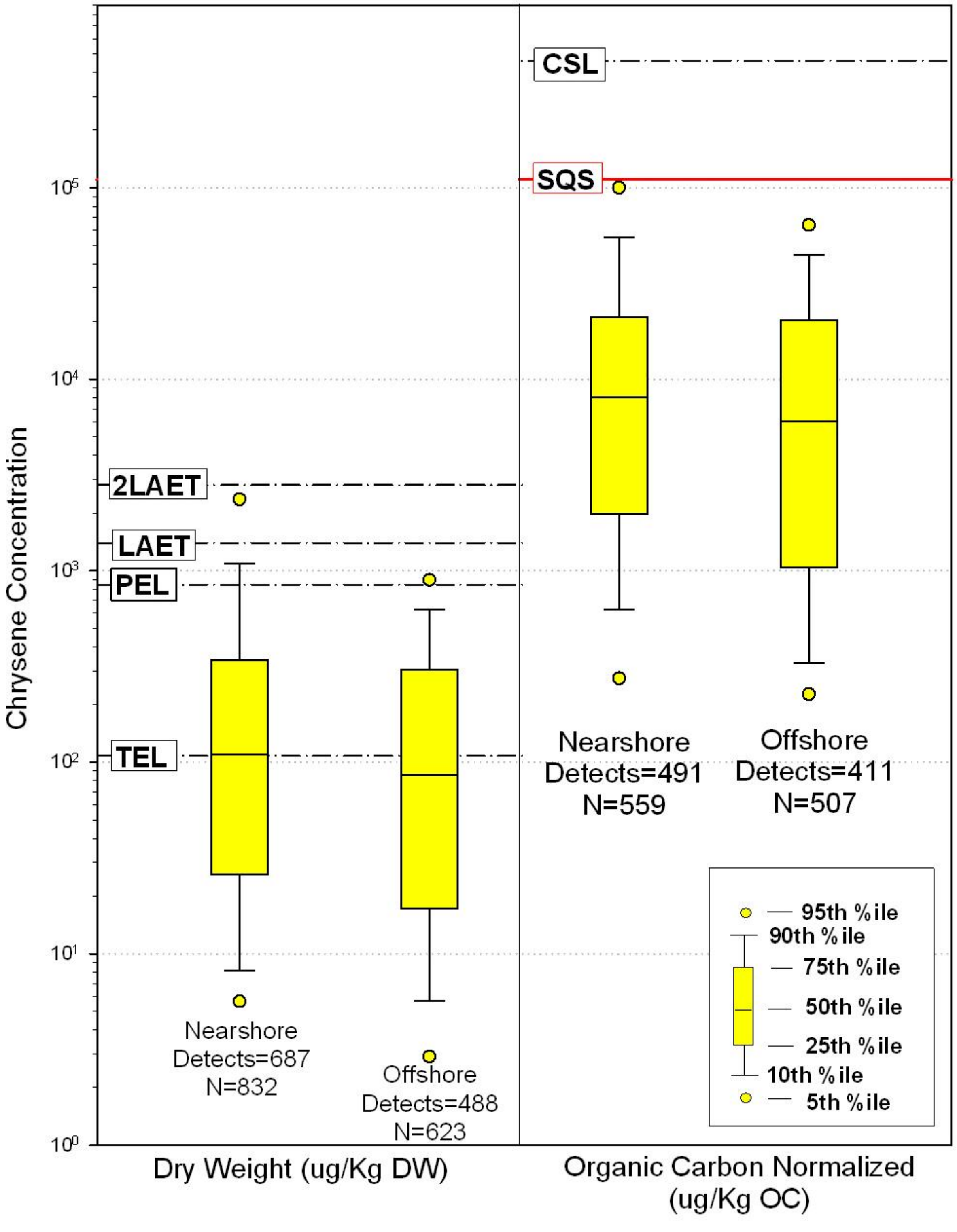

Figure B13 Chrysene in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. TEL – Threshold Effect Level, PEL – Probable Effects Level; LAET – Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold; SQS – Sediment Quality Standard, CSL- Cleanup Screening Level. All concentrations are presented on a log scale.

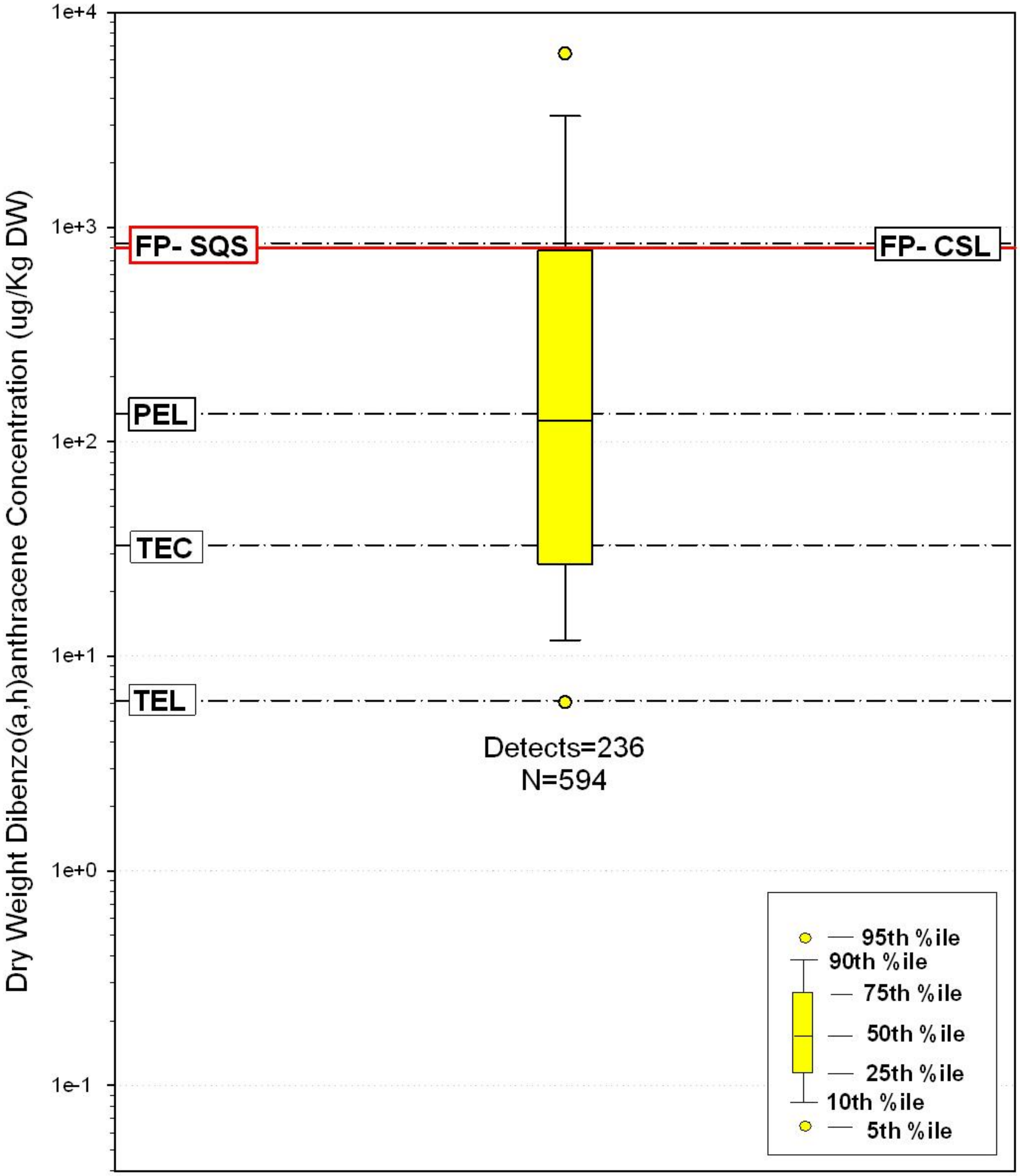

Figure B14 Dibenzo(a,h)anthracene in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL- Floating Percentile Cleanup Screening Level; TEL – Threshold Effect Level, PEL – Probable Effects Level; TEC – Threshold Effects Concentration, PEC – Probable Effect Concentration. All concentrations are presented on a log scale.

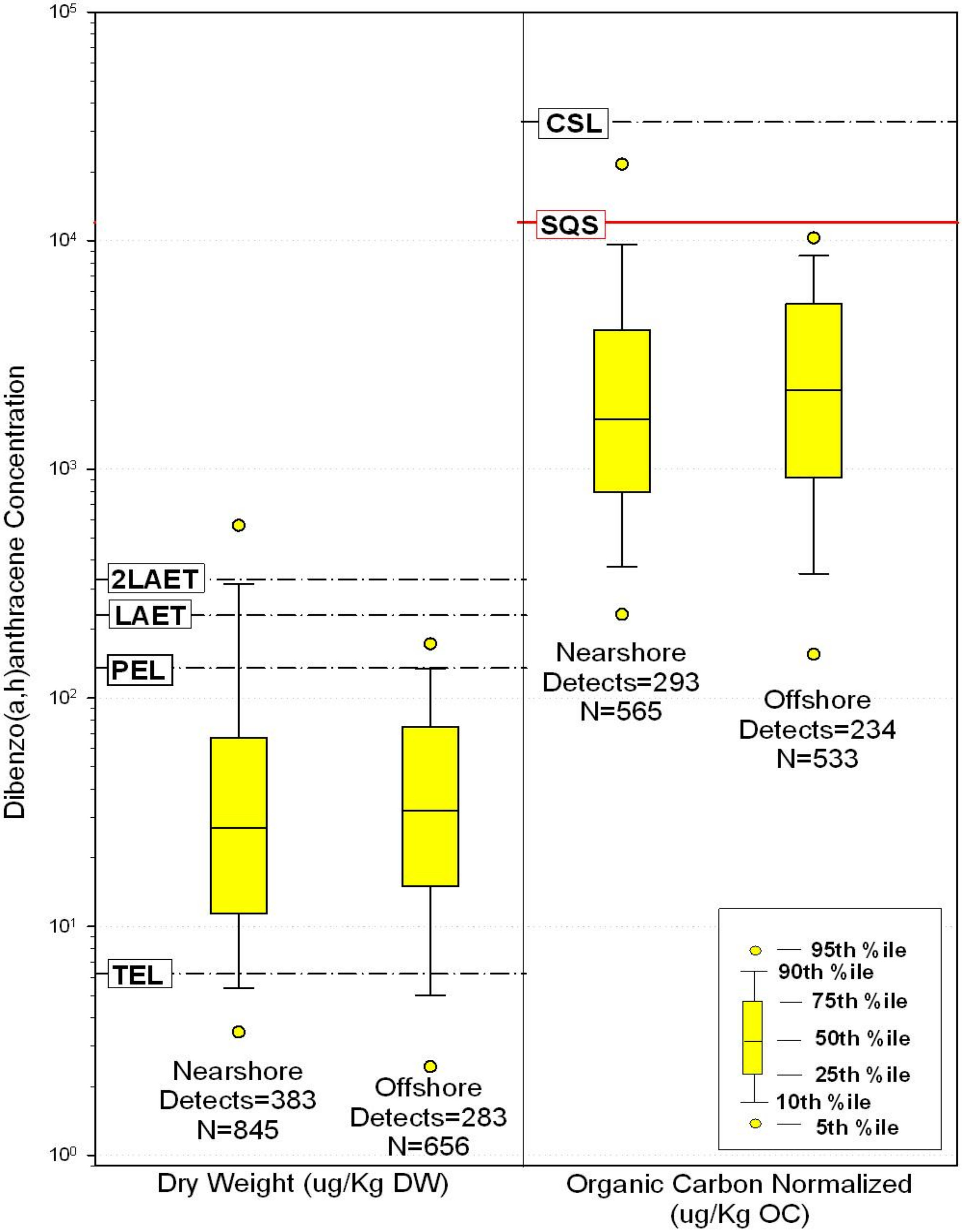

Figure B15 Dibenzo(a,h)anthracene in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. TEL – Threshold Effect Level, PEL – Probable Effects Level; LAET – Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold; SQS – Sediment Quality Standard, CSL- Cleanup Screening Level. All concentrations are presented on a log scale.

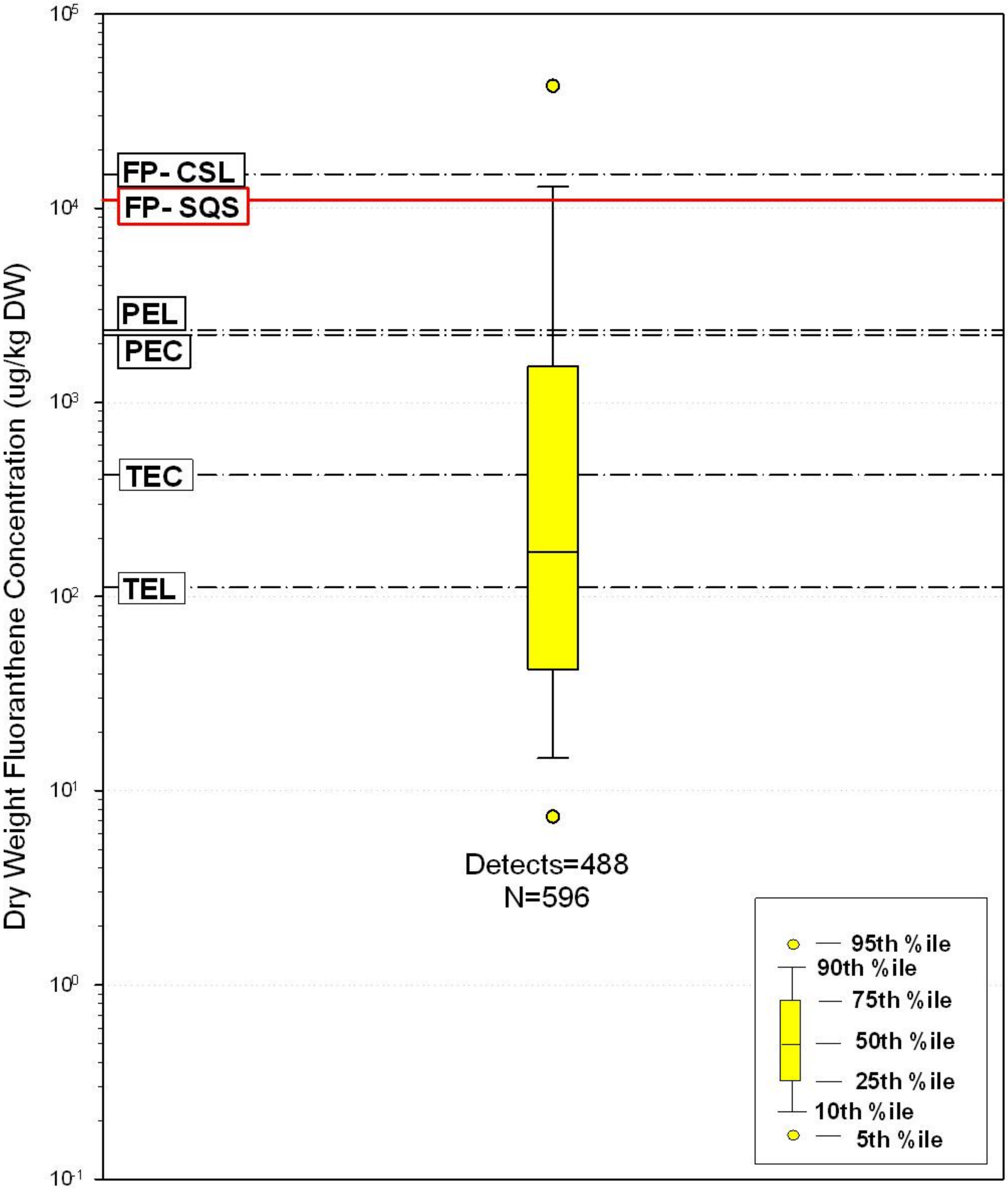

Figure B16 Fluoranthene in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL- Floating Percentile Cleanup Screening Level; TEL – Threshold Effect Level, PEL – Probable Effects Level; TEC – Threshold Effects Concentration, PEC – Probable Effect Concentration. All concentrations are presented on a log scale.

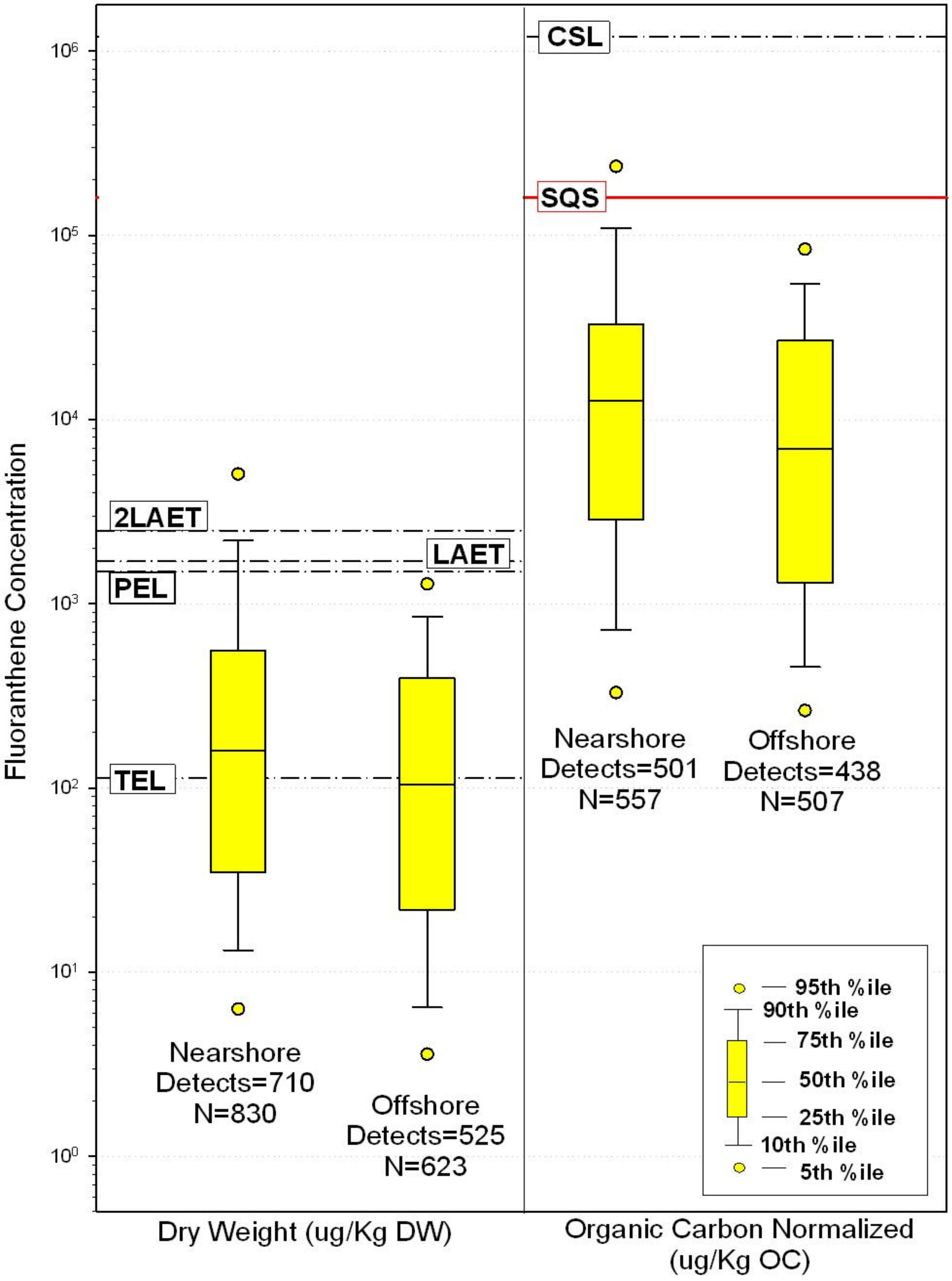

Figure B17 Fluoranthene in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. TEL – Threshold Effect Level, PEL – Probable Effects Level; LAET – Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold; SQS – Sediment Quality Standard, CSL- Cleanup Screening Level. All concentrations are presented on a log scale.

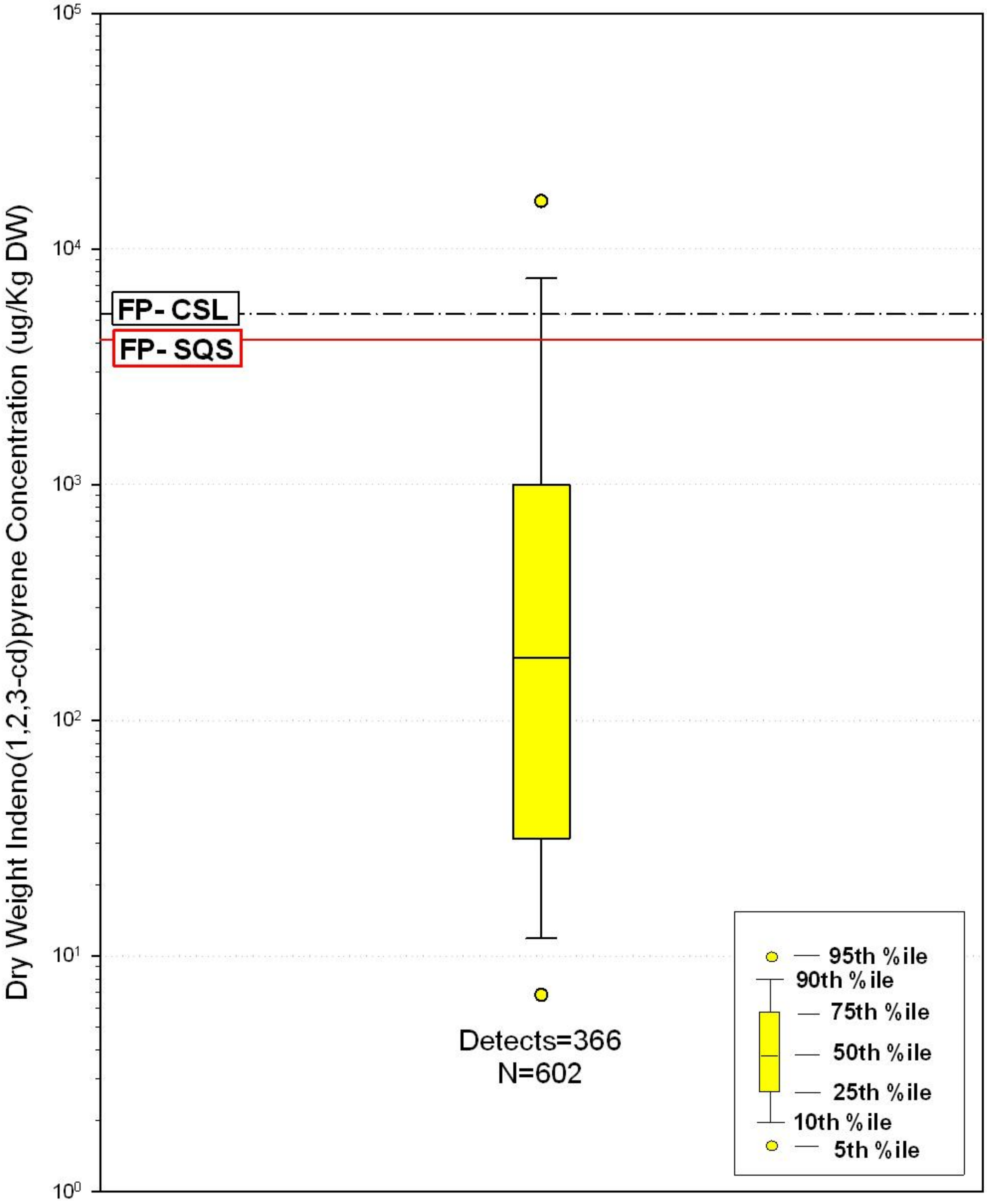

Figure B18 Indeno(1,2,3)pyrene in freshwater sediment. Box plot of observed environmental concentrations in surface sediments plotted against sediment thresholds. FP-SQS – Floating Percentile Sediment Quality Standard, FP-CSL- Floating Percentile Cleanup Screening Level. All concentrations are presented on a log scale.

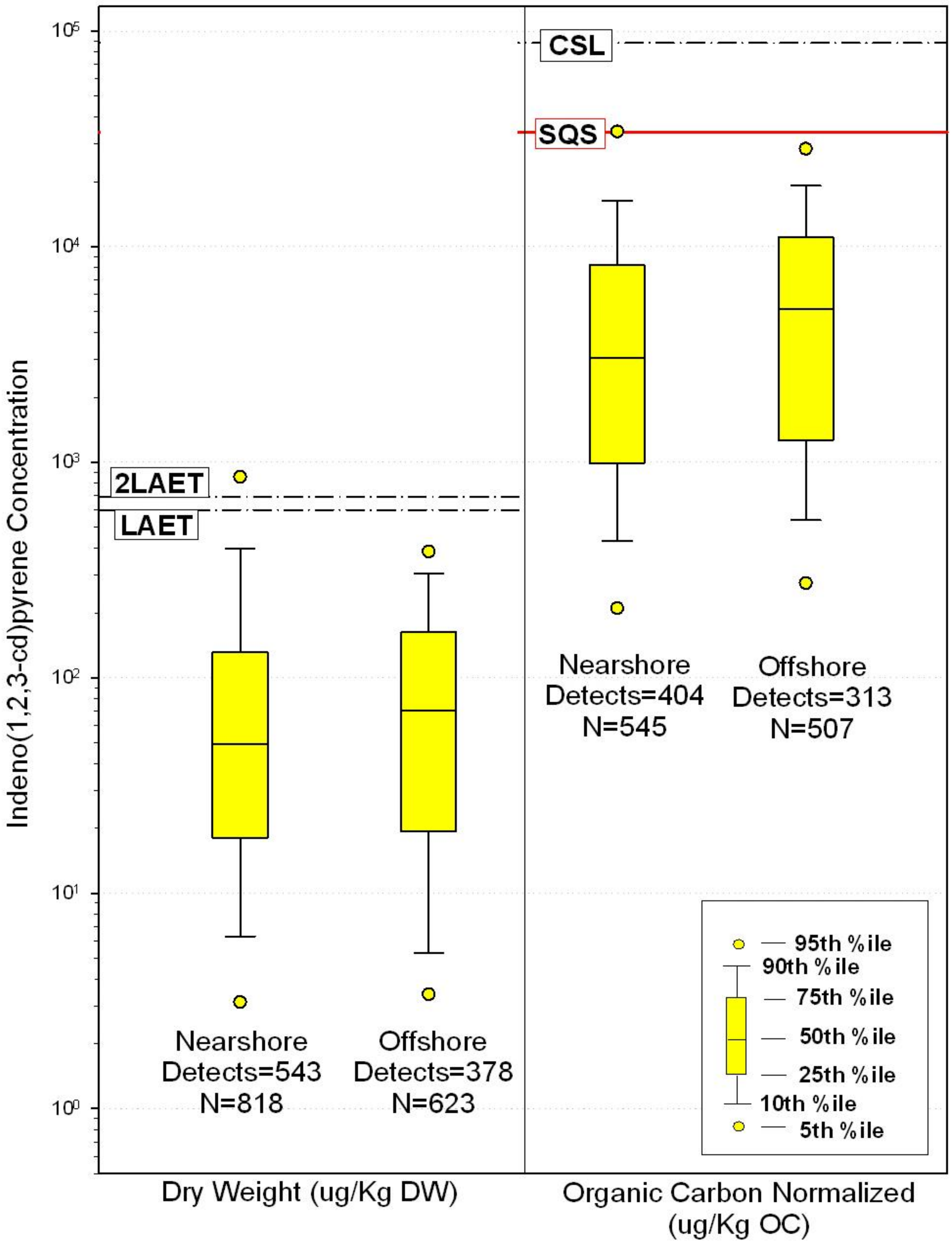

Figure B19 Indeno(1,2,3)pyrene in marine sediment. Box plots of observed environmental concentrations in surface sediments plotted against sediment thresholds. TEL – Threshold Effect Level, PEL – Probable Effects Level; LAET – Lowest Apparent Effects Threshold, 2-LAET – Second Lowest Apparent Effects Threshold. All concentrations are presented on a log scale.

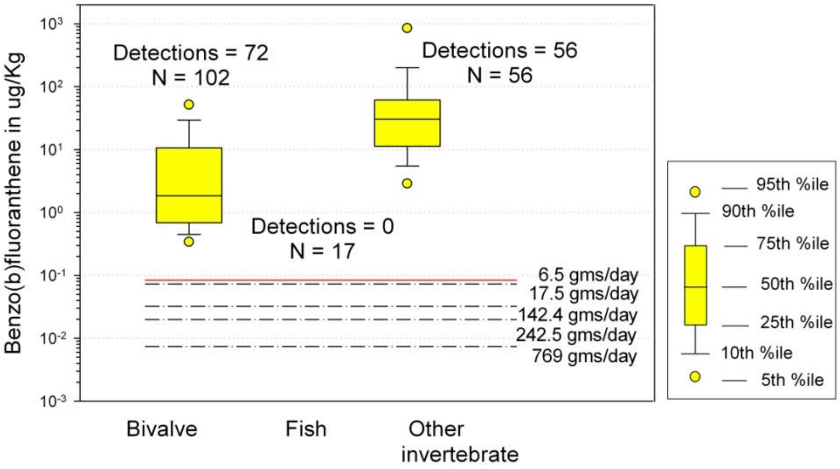

Figure B20 Benzo(b)fluoranthene in freshwater bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

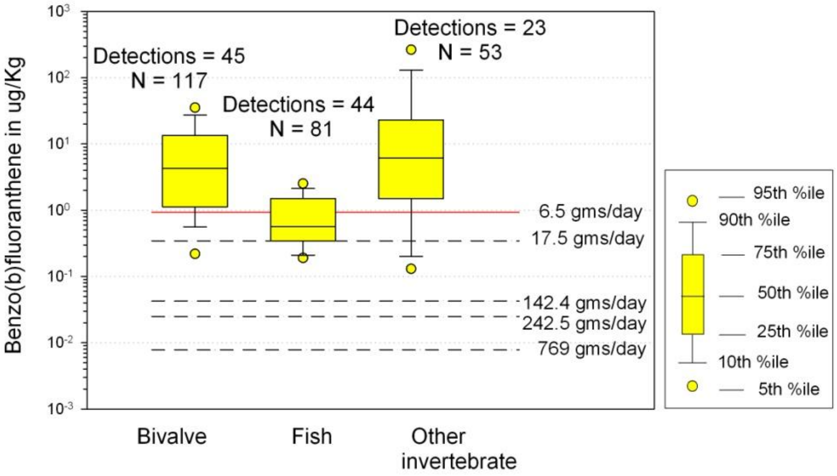

Figure B21 Benzo(b)fluoranthene in nearshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

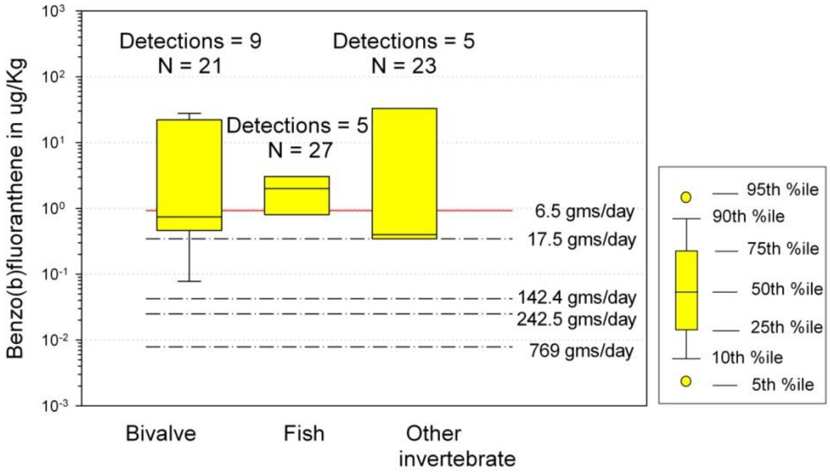

Figure B22 Benzo(b)fluoranthene in offshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

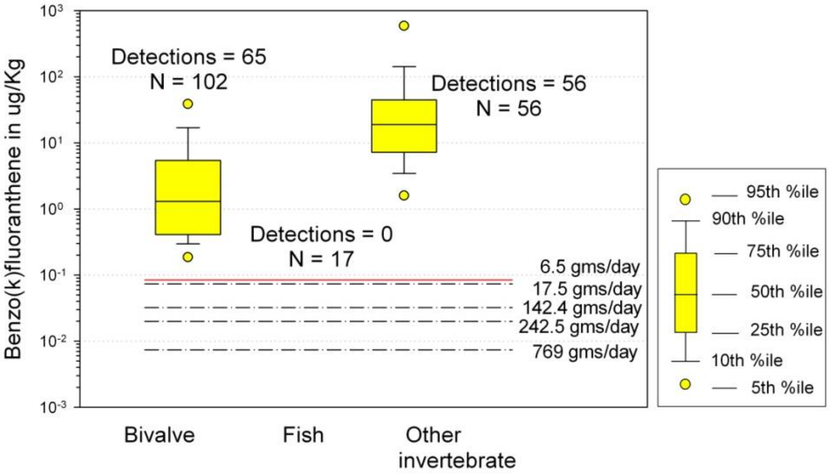

Figure B23 Benzo(k)fluoranthene in freshwater bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

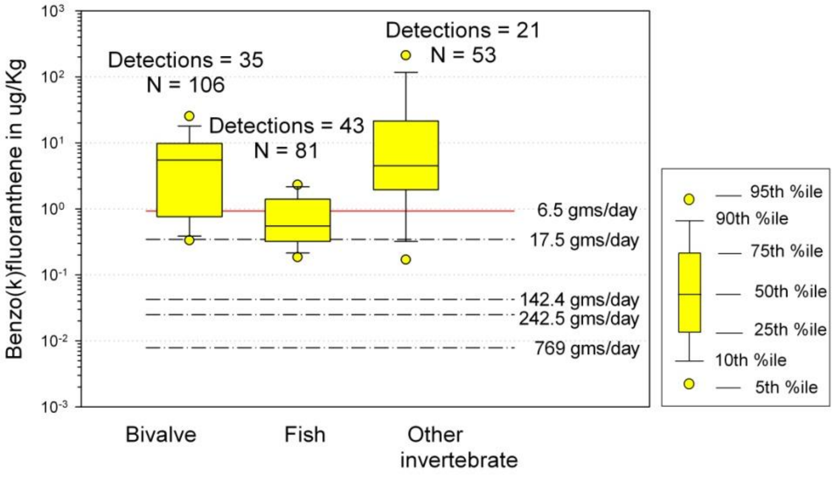

Figure B24 Benzo(k)fluoranthene in freshwater bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

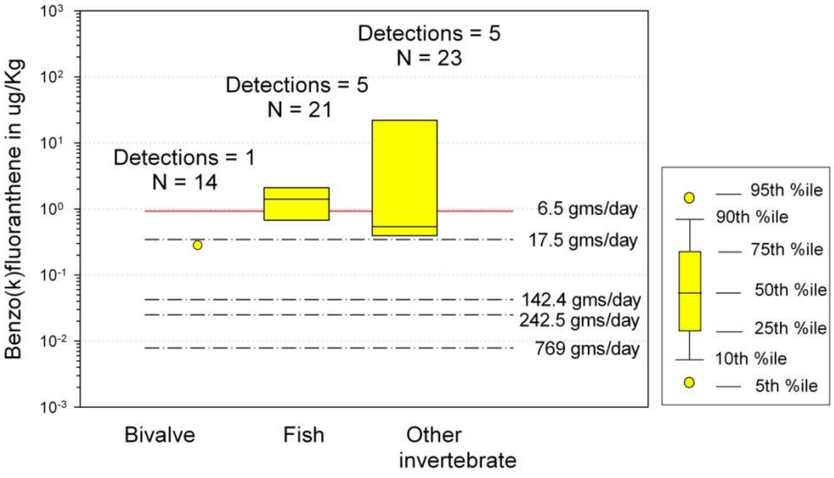

Figure B25 Benzo(k)fluoranthene in offshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

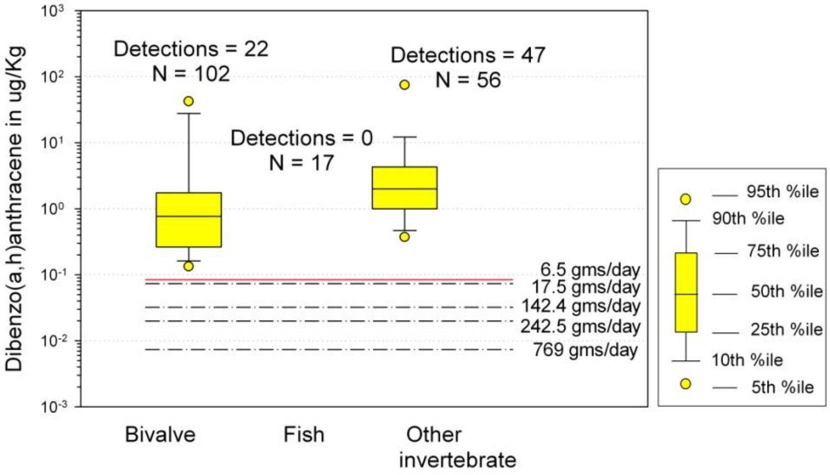

Figure B26 Dibenzo(a,h)anthracene in freshwater bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

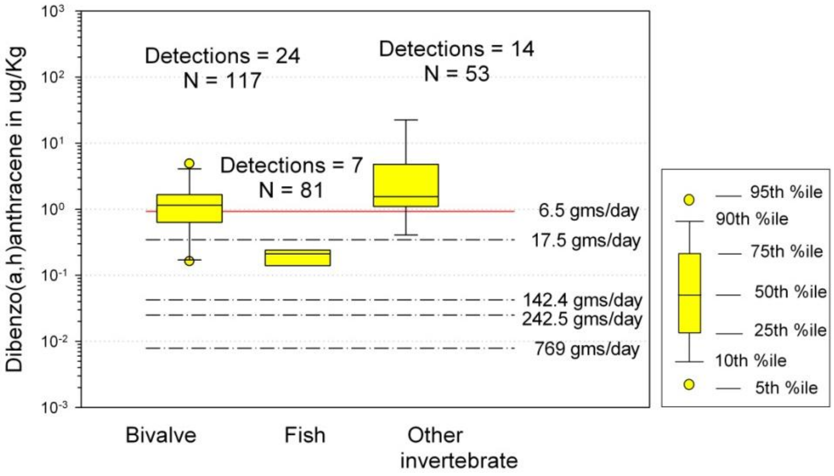

Figure B27 Dibenzo(a,h)anthracene in nearshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

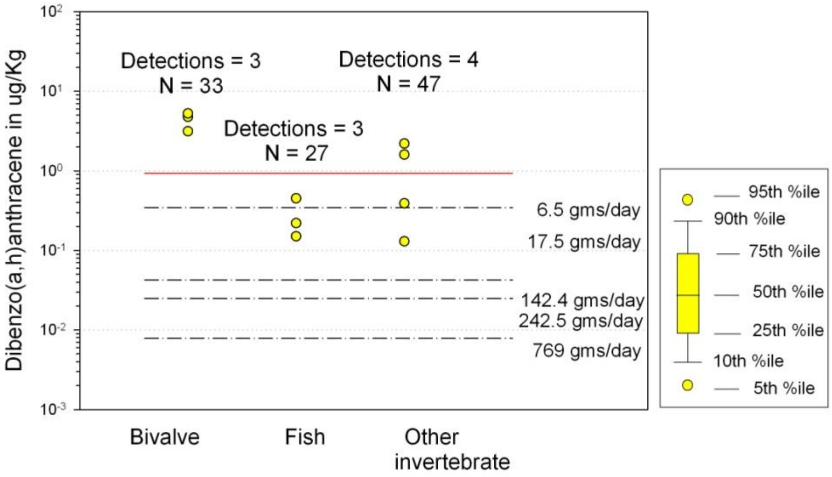

Figure B28 Dibenzo(a,h)anthracene in offshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

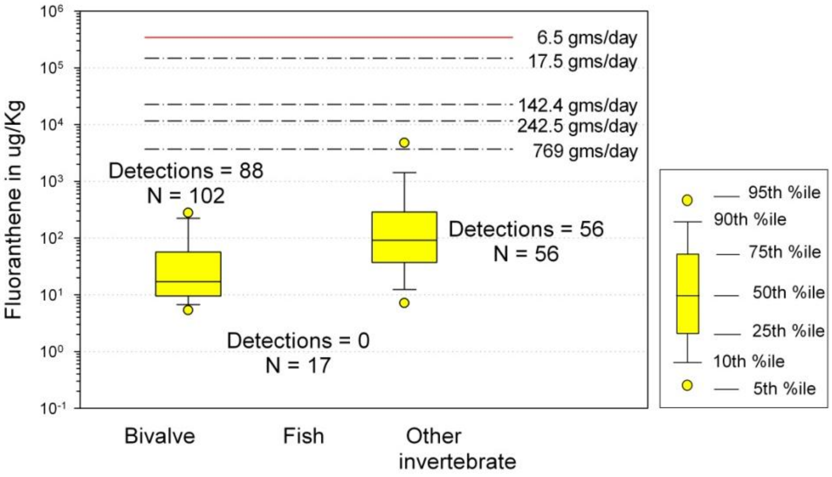

Figure B29 Fluoranthene in freshwater bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

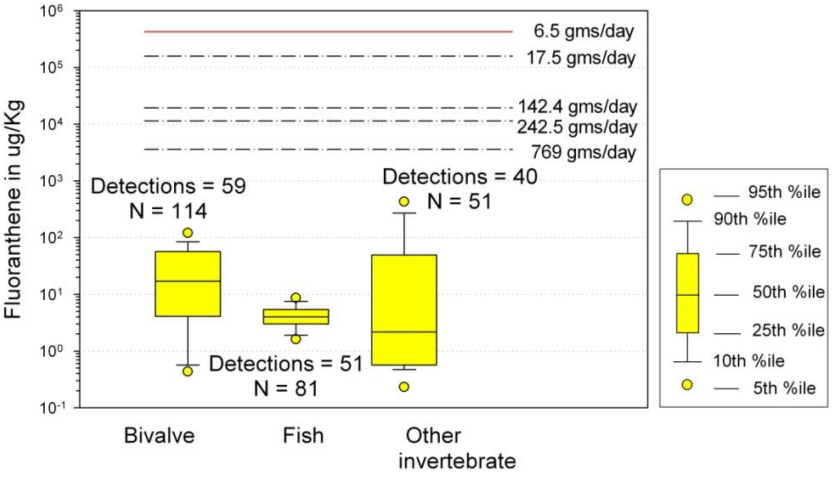

Figure B30 Fluoranthene in nearshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

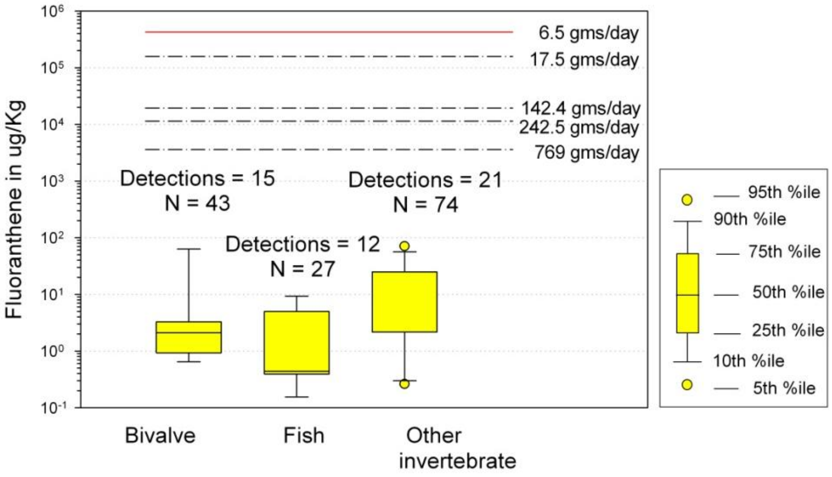

Figure B31 Fluoranthene in offshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

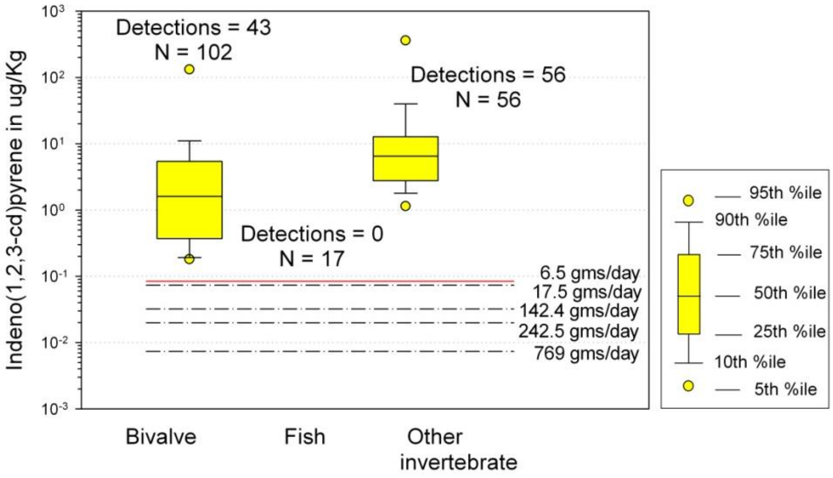

Figure B32 Indeno(1,2,3-cd)pyrene in freshwater bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

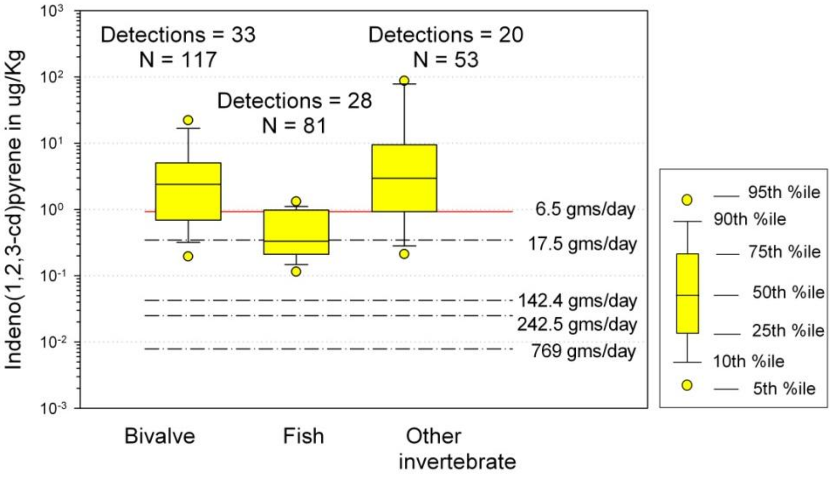

Figure B33 Indeno(1,2,3-cd)pyrene in nearshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

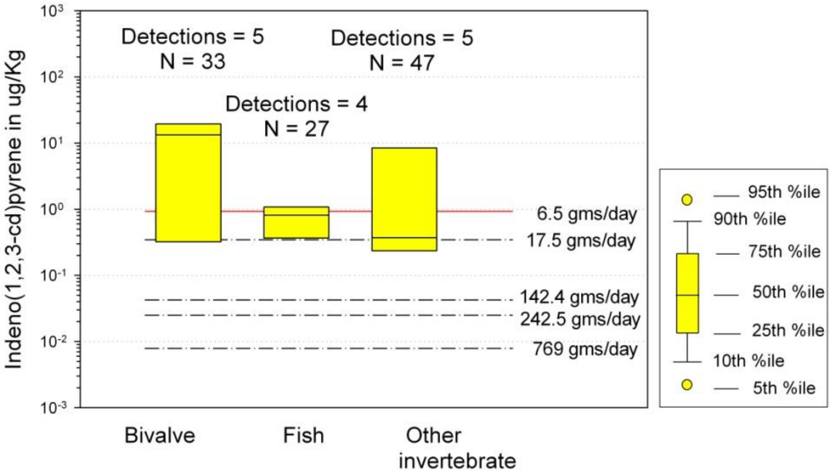

Figure B34 Indeno(1,2,3-cd)pyrene in offshore bivalve, fish and other invertebrate tissues compared to 5 different human consumption scenarios derived from the National Toxics Rule.

Appendix C San Francisco’s alternatives to arsenic treated wood

Alternatives List for Arsenic-Treated Wood
Acceptable Materials by Use
Adopted September 10, 2003

(List will be updated periodically to allow for the inclusion of new materials.)

Results of Criteria Screening

Treatment	**Result**
CuN	Acceptable for some uses. See table below.
Cu8	Not acceptable.
Creosote	Not acceptable.
PCP	Not acceptable.
ACA	Not acceptable. Exception for salt water immersion.
ACC	Not acceptable.
ACQ	Acceptable for some uses. See table below.
ACZA	Not acceptable. Exception for salt water immersion.
CA-B	Acceptable for some uses. See table below.
CBA	Acceptable for some uses. See table below.
CCA	Not acceptable. Exception for salt water immersion.
CC	Acceptable for some uses. See table below.
DOT, borates	Acceptable for some uses. See table below.
CDDC	Not acceptable.
ZnN	Acceptable for some uses. See table below

The treatments that passed the screening criteria for at least some uses were then crosschecked with the AWPA standards. Those for which standards exist are listed in the table below as acceptable materials.

Summary of Acceptable Materials by Use

(List will be updated periodically to allow for the inclusion of new materials.)

DESCRIPTION OF USE	***UCS (AWPA Use Classifications)***	***C (AWPA Standard)***	***Acceptable Materials (must also be allowed by building code for specific intended use)***
BEAMS & TIMBERS (GLUE LAM.)			
Dry environment, above ground	1,2	C28	CuN[1]
Damp environment, above ground	3B	C28	CuN[1]
Ground contact	4A	C28	CuN[1]
Highway construction	4B, 4C	C14	ACQ[2,3]
BUILDING CONSTRUCTION MATERIAL			

Floor plate	2, 3B	C2, 15, 31	ACQ3, CA-B, CBA, CC, DOT or other borates
Flooring, residential			
Damp environment	3B	C2	ACQ3, CA-B, CBA, CC
Dry environment	1, 2	C2, 31	DOT or other borates
Framing, interior	1, 2	C2, 15, 31	DOT or other borates
Joists			
Interior, above ground	1, 2	C2, 15, 31	DOT or other borates
Exterior, above ground	3B	C2, 15	ACQ3, CA-B, CBA, CC
Soil contact	4A	C2, 15	ACQ3, CA-B, CBA
Lumber			
Above ground	3B	C2	CuN1, ACQ3, CA-B, CBA, ZnN1
Ground contact	4A	C2	CuN1, ACQ3, CA-B, CBA
Tree stakes	4A	C2	CuN, ACQ3, CA-B, CBA
Fresh water use	4A	C2	Plastic-coated lumber4, CuN, ACQ3
No ground contact, protected from liquid water	2	C31	DOT or other borates
Permanent wood foundation (lumber or plywood)	4B	C22	None
Plywood			
Sub-floor, damp above ground	2	C9	ACQ3, CA-B, CBA, CC
Exterior, above ground	3B	C9	ACQ3, CA-B, CBA, CC
Ground contact	4A	C9	ACQ3, CA-B, CBA, CC
Fresh water use	4A	C9	None
No ground contact, protected from liquid water	2	C31	DOT or other borates
Poles, building			
Round	4A, 4B	C4, 16	ACQ
Sawn	4A, 4B	C2, 16	CuN1, ACQ3, CA-B, CBA, CC, DOT or other borates
Studs	3B	C2, 15	DOT or other borates
DECKING			
Highway bridge	4B	C2, 14	CuN, ACQ3
Above ground			
Not over or near water	3B	C2, 15	CuN, ACQ3, CA-B, CBA,
Over or near water	3B	C2, 15	Plastic-coated wood4, CuN, ACQ, ZnN
Ground contact	4B	C2, 15	CuN, ACQ3, CA-B, CBA
FENCES			
Pickets, slats, trim	3A, 3B	C2, 15	CuN, ACQ3, CA-B, CBA
Posts, sawn	4A	C2, 15	ACC, ACQ3, CA-B
Posts, round	4A	C5	CuN, ACQ3, CA-B, CC
HIGHWAY MATERIAL			
Lumber and timbers for bridges, structural members, cribbing, and culverts	4B	C2, 14	CuN, ACQ3
Structural lumber and timbers			

In salt water use	5A, 5B, 5C	C3, C14	See note 5
Piles, foundation, land use	4C	C3, 14	No acceptable non-arsenic materials available
Piles, foundation, fresh water use	4C	C3, 14	No acceptable non-arsenic materials available
Piling in salt water use	5A, 5B, 5C	C3, 14	See note 5
Posts: round, half-round, quarter round	4A	C5, 14	CuN, ACQ3
Posts: sawn	4A	C2, 14	CuN, ACQ3, CA-B, CBA
Handrails and guardrails	3B	C2, 14	CuN, ACQ3, CA-B, CBA
Posts, guardrail			
Round	4A	C2, 14	CuN, ACQ3
Sawn	4A	C2, 14	CuN, ACQ3, CA-B, CBA
MARINE LUMBER & TIMBERS			
Fresh water	4A	C2	Plastic-coated wood4, CuN,
			ACQ3, CA-B
Brackish water or salt water	5A, 5B, 5C	C2, 18	Plastic-coated wood4
PILES			
Foundation (round)	4C	C3	No acceptable non-arsenic materials available
Land use (round)	4C	C3	CuN
Fresh water use (round)	4C	C3	Plastic-coated piles, CuN
Marine (round) in salt or brackish water	5A, 5B, 5C	C3, 18	See note 5
Marine, dual treatment (round)	5A, 5B, 5C	C3, 18	See note 5
Sawn timber piles	4B	C24	See note 5
UTILITY POLES			
Sited in soil	4A, 4B	C4	CuN, ACQ3
Sited in impervious surface	4A, 4B	C4	CuN (butt-treatment preferred)

Notes:

1. CuN and ZnN allowed for indoor use only as pressure-treated wood. Other applications are not registered for indoor use.
2. Only standardized if treated before lamination.
3. Select either ACQ-B or ACQ-D as appropriate based on AWPA standards.
4. Non-PVC plastic only. Lumber should not be treated with arsenic.
5. Non-wood materials are preferred. When pressure treated wood is required, an exemption exists for saltwater immersion environments for structures such as pilings and piers until a viable alternative is available.

List of Abbreviations

AAC Alkyl ammonium compound
ACA Ammoniacal copper arsenate
ACC Acid copper chromate
ACQ Ammoniacal (or amine) copper quat (see below)
ACQ-B: Ammoniacal copper quat
ACQ-D: Amine copper quat
ACZA Ammoniacal copper zinc arsenate
AWPA American Wood Preservers’ Association
CA-B Copper azole
CBA Copper boron azole
CC Copper citrate (or ammoniacal copper citrate)
CCA Chromated copper arsenate
CDDC Copper bis(dimethyldithiocarbamate)
CuN Copper naphthenate
Cu8 Copper-8-quinolinolate
DOT Disodium octaborate tetrahydrate
PCP Pentachlorophenol
ZnN Zinc naphthenate