

Water Quality Assessment and Proposed Objectives for Burrard Inlet: Polycyclic Aromatic Hydrocarbons (PAHs) Technical Report



September 2021



Tsleil-Waututh Nation
səlilwətał



This Technical Report forms part of a series of water quality parameter reports whose purpose is to inform updates to the 1990 Provincial Water Quality Objectives for Burrard Inlet. This report and others in the series assess the current state and impacts of contamination in Burrard Inlet; incorporate new scientific research and monitoring of water quality; and reflect a broader understanding of goals and values, including those of First Nations, to improve the health of the marine waters of Burrard Inlet. Updating the 1990 [Provincial Water Quality Objectives](#) is a priority action identified in the Tsleil-Waututh Nation's [Burrard Inlet Action Plan](#) which has been an impetus for this work.

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Underwater monitoring equipment is installed from the Tsleil-Waututh Nation boat in Burrard Inlet.

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CHAPTER SUMMARY

This chapter presents proposed water quality objectives for several priority polycyclic aromatic hydrocarbons (PAHs) in Burrard Inlet. Tsleil-Waututh Nation identified PAHs as a pollutant of concern in their Burrard Inlet Action Plan (TWN, 2017). These proposed objectives were developed using up-to-date research on relevant values and potential effects, sources and factors influencing PAH levels, benchmark screening, and historic and recent monitoring data for Burrard Inlet.

PAHs are toxic to humans and wildlife, including aquatic life. PAHs may become substantially more toxic when they are in mixtures. The water values generally most sensitive to PAH pollution are aquatic life and human consumption of finfish and shellfish.

PAHs come from both natural and anthropogenic sources. Natural inputs of PAHs to the marine environment include crude oil seeps, coal and shale deposits, and forest fires, while anthropogenic inputs include the burning of fossil fuels, and spills and chronic discharges of fossil fuels from vessels. Anthropogenic sources are categorized as either primary (e.g., wastewater from oil refineries, vehicle exhaust, coal/wood/oil furnaces, industrial emissions and spills from vessels) or secondary (e.g., sewage discharge from wastewater treatment plants and stormwater outfalls). Both primary and secondary sources contribute PAHs to marine environments, but primary inputs are considered the most significant (Hylland, 2006).

Once PAHs reach Burrard Inlet, their fate depends on their individual physico-chemical properties, as well as the nature of the receiving environment. PAHs that are more soluble will remain in the water column and readily undergo photochemical degradation, biodegradation or transport. PAHs that are less soluble will be deposited into the marine sediments, a major environmental repository for PAHs in Burrard Inlet (Government of Canada, 1994).

In this report, several priority PAHs were selected for further assessment and development of water, sediment and tissue quality objectives. These PAHs were selected because concentrations of these chemicals in Burrard Inlet have exceeded either the BC Working Sediment Quality Guidelines (WSQG)/Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs), the BC Approved Water Quality Guidelines (WQGs), or approach human health-based screening values. These PAHs include: acenaphthene, anthracene, benzo(a)pyrene, benzofluoranthenes (especially benzo[k]fluoranthene), chrysene, fluoranthene, fluorene, naphthalene, methylated naphthalenes (especially 2-methylnaphthalene), phenanthrene, and pyrene.

The following have been proposed as water quality objectives for PAHs in Burrard Inlet. In addition to these numerical objectives, an overall objective is proposed as follows: Concentrations of PAHs in sediment, water, and tissue should be reduced in Burrard Inlet to the greatest degree practical, to protect aquatic life and human consumers of fish and shellfish. An overall objective for a decreased trend in PAH concentrations in all media is proposed for this purpose. Furthermore, monitoring should continue for all PAHs in water, sediment and tissue because of the prevalence of PAH sources throughout the Inlet.

Proposed Water Quality Objectives for PAHs in Burrard Inlet

Priority PAH	Proposed Objectives (all sub-basins)
Marine Water (µg/L, mean)¹	
Acenaphthene	6
Benzo(a)pyrene	0.01
Chrysene	0.1
Fluorene	12
Naphthalene	1
Sediment (µg/g dry weight, single-sample maximum)²	
Acenaphthene	0.00671
Anthracene	0.0469
Benzo(a)pyrene	0.088
All benzofluoranthenes ³	2.3
Chrysene	0.108
Fluoranthene	0.113
Fluorene	0.0212
Naphthalene	0.0346
2-methylnaphthalene	0.02
Phenanthrene	0.0867
Pyrene	0.153
Tissue (µg/g wet weight, single-sample maximum)^{4,5}	
Benzo(a)pyrene	0.0036
¹ Based on a minimum of 5 surface samples in 30 days collected during the wet season. ² Based on a minimum of 1 composite sample composed of at least 3 replicates. ³ This objective applies to the sum of all benzofluoranthenes. Concentrations are expressed in terms of sediment containing 1% organic carbon. Adjustments to guidelines are required with different organic carbon content. ⁴ The concentration not expected to cause adverse effects to human consumers, based on a composite sample consisting of at least 5 individual fish or 25 bivalves. See Rao et al. (in prep.) for additional guidance. ⁵ The benzo(a)pyrene WQO provides a benchmark to evaluate exposures to mixtures of carcinogenic PAHs by totaling their measured concentrations adjusted according to their potency equivalence factors (Health Canada 2021). See text and Table 7 for details.	

Because PAHs are known toxins to humans and aquatic species, continued monitoring of all PAHs in water, sediment and tissue is recommended.

Work to reduce the concentrations of PAHs entering Burrard Inlet is currently underway, including the separation of combined sewer overflows (CSOs) in the Vancouver Sewerage Area (which is a provincial goal where each municipality is working under the same target of 2050), the development and implementation of Integrated Stormwater Management Plans (ISMPs), and construction of a new North Shore Wastewater Treatment Plant that will provide tertiary treatment of sewage for North Shore communities. ISMPs will be prepared for all developed watersheds within Burrard Inlet to address drainage, flooding, stream health, and remediation of any water quality issues (see Section 6). Additional management priorities should include implementation and enforcement of best practices related to spills and incidental releases of PAHs from vessels, as well as managing the growth of large commercial vessel traffic in the Inlet.

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ACRONYMS

AET	Apparent Effects Thresholds
BC	British Columbia
BEDS	Biological Effects Database for Sediments
CCME	Canadian Council of Ministers of the Environment
CSO	Combined sewer overflow
DNA	Deoxyribonucleic acid
ECCC	Environment and Climate Change Canada
ENV	(British Columbia) Ministry of Environment and Climate Strategy
HPAH	High molecular weight PAHs
ISMP	Integrated Stormwater Management Plan
ISQG	Interim Sediment Quality Guideline
K _{ow}	Octanol-water partitioning coefficient
LPAH	Low molecular weight PAHs
NSTP	National Status and Trends Program
PAHs	Polycyclic aromatic hydrocarbons
PEF	Potency Equivalence Factor
PEL	Probable effect level
PES	Perimeter Extraction System
POPs	Persistent organic pollutants
SRKW	Southern Resident Killer Whales
TEF	Toxic equivalence factor
TEL	Threshold effect level
TOC	Total organic carbon
TWN	Tsleil-Waututh Nation
US EPA	United States Environmental Protection Agency
WQG	Water Quality Guideline
WQO	Water Quality Objective
WSQG	Working Sediment Quality Guideline
WWTP	Wastewater treatment plant

1. INTRODUCTION

This chapter presents proposed water quality objectives for polycyclic aromatic hydrocarbons (PAHs) in Burrard Inlet. Tsleil-Waututh Nation identified PAHs as a pollutant of concern in their Burrard Inlet Action Plan (TWN 2017). The chapter includes relevant background information, an overview assessment of PAHs levels in water, sediment, fish, and shellfish in Burrard Inlet, including a comparison to benchmarks, and a scientific rationale for the proposed objectives. Recommendations for future monitoring as well as management options to help achieve these proposed objectives are also included.

2. BACKGROUND

PAHs are found in most urbanized coastal areas with elevated concentrations in sediment and biota (Meador, 1995). PAHs are a large and diverse group of substances that have two or more benzene rings in their structure (CCME, 1999b). They are grouped into low molecular weight PAHs (LPAH), which have three or fewer aromatic rings, and high molecular weight PAHs (HPAH), which have four or more rings (CCME, 1999a). LPAHs are more water soluble than HPAHs and are generally more bioavailable. This variation in structure results in diverse physical and chemical properties, which in turn determine the fate and effects of PAHs in marine systems.

There are two major types of PAHs:

- Pyrogenic – formed from the incomplete combustion of organic matter, such as forest fires, vehicle exhaust and industrial emissions, as well as the combustion of coal, coking and production of coal tar and its distillates (e.g. creosote and sealants); and
- Petrogenic – formed in petroleum and coal deposits, and thus are found within fossil fuels (CCME, 2010b; EPRI, 2008).

PAHs have a relatively high affinity for organic matter and particles in aquatic systems, where the relative partitioning between dissolved, colloidal, and particulate fractions depends on the size and the octanol-water partitioning coefficient (K_{ow}) of the compound. The K_{ow} increases as the number of carbon atoms increases (Hylland, 2006). Smaller PAHs tend to be more water soluble than heavier PAHs, and therefore are more bioavailable. Pyrogenic PAHs are mainly parent (non-alkylated) PAH compounds, which are smaller and more water soluble. Since they are soluble in water, pyrogenic PAHs are often more acutely toxic to organisms in the water column. Petrogenic PAHs include a wide range of alkylated compounds (PAHs with an additional carbon containing group), which are more persistent than their parent compounds. They are less soluble in water, tend to bind to suspended particles, accumulate in sediment and, therefore, are more available for uptake by marine organisms from the sediment. They are also more likely to cause chronic toxicity to organisms (CCME, 2010b; EPRI, 2008; Hylland, 2006).

2.1 Values and Potential Effects

The most sensitive values guiding water quality objectives for PAHs are aquatic life and human consumption of shellfish and finfish. The goal of the WQOs is to maintain PAHs levels below values which would be toxic to aquatic life and to humans who consume seafood at rates relevant to coastal Indigenous peoples.

Most PAHs are considered to be persistent organic pollutants (POPs), since most are able to remain in the environment for extended periods of time (Obbard et al., 2007). In addition, PAHs can cause carcinogenic and non-carcinogenic effects in biological systems. CCME (1999a, 2010b) and the US EPA (2014) have identified several priority PAHs that are thought to be carcinogenic and/or otherwise toxic

through multiple routes of exposure and can affect the immune, reproductive, nervous and endocrine systems, with benzo(a)pyrene being the most toxic. The risk or hazards for each of these priority PAHs is summarized in Table 1.

Table 1. PAHs Prioritized by CCME and the US EPA, and Associated Risks/Hazards (CCME 1999a,b, 2010; US EPA 2014, 2020; WHO 2010).

Priority PAH	Known Risks to Humans	Known Risks to Aquatic Life or Wildlife
Acenaphthene	Effects on humans are unknown.	Mutagenic. Very toxic to aquatic life with long lasting effects.
Acenaphthylene	Unknown	Acute toxicity by inhalation, ingestion and dermal contact.
Anthracene	Not classifiable as to its carcinogenicity.	Very toxic to aquatic life with long lasting effects.
Benzo(a)anthracene	Might be mutagenic and possibly carcinogenic.	Very toxic to aquatic life with long lasting effects.
Benzo(a)pyrene	Mutagenic and carcinogenic. May cause an allergic skin reaction. May damage fertility or the unborn child.	Very toxic to aquatic life with long lasting effects.
Benzo(b)fluoranthene	Possibly carcinogenic.	Very toxic to aquatic life. Acute and long-term hazard.
Benzo(g,h,i)perylene	Not classifiable as to its carcinogenicity.	Very toxic to aquatic life with long lasting effects.
Benzo(k)fluoranthene	Possibly carcinogenic.	Very toxic to aquatic life. Acute and long-term hazard. Bioaccumulation risk.
Chrysene	Might be mutagenic. Not classifiable as to its carcinogenicity.	Very toxic to aquatic life. May cause long lasting harmful effects to aquatic life.
Dibenz(a,h)anthracene	Probably carcinogenic.	May be carcinogenic to aquatic organisms. Very toxic to aquatic life. Acute hazard with long lasting effects.
Fluoranthene	Toxic by all routes (i.e., inhalation, ingestion, dermal contact). Not classifiable as to its carcinogenicity.	Very toxic to aquatic life with long lasting effects.
Fluorene	Potential hematological effects. Not classifiable as to its carcinogenicity.	Very toxic to aquatic organisms. May cause long-term adverse effects to aquatic life.
Indeno(1,2,3-cd)pyrene	Possibly carcinogenic.	May be hazardous to the environment.
2-Methylnaphthalene	Skin irritation and photosensitization.	Toxic to at least some aquatic invertebrates. ¹
Naphthalene	Possibly carcinogenic.	Toxic to aquatic organisms. May cause long-term effects in the aquatic environment. Bioaccumulation of this chemical may occur along the food chain.
Phenanthrene	Not classifiable as to its carcinogenicity.	Very toxic to aquatic life with long lasting effects.
Pyrene	Kidney effects. Not classifiable as to its carcinogenicity.	Very toxic to aquatic life with long lasting effects.

¹ Toxicity information from NCBI (2020)

2.1.1 Potential Ecotoxicology/Effects on Marine Biota

In Burrard Inlet, marine organisms take up PAHs from water directly (diffusion across gills and integument), or indirectly from their diet. Sediment-associated organisms take up PAHs via diffusion across their gills and integument, as well as through direct contact with sediment particles containing bound PAHs (Collier et al., 1992). In vertebrates, such as fish, PAHs are absorbed across the lipid membranes of gills, skin and digestive tracts. Marine mammals are mainly exposed to PAHs through their diet (Ball and Truskewycz, 2013).

Vertebrates are able to metabolize carcinogenic PAHs, as they have both Phase 1 and Phase 2 enzyme systems. Phase 1 cytochrome P450 enzymes have the ability to generate reactive epoxides that can be detoxified through Phase 2 reactions, or bind to other cellular components (Collier et al., 1992). Phase 2 reactions usually take place when Phase 1 metabolism is insufficient to clear PAHs from the system and involve transferase enzymes. In fish, PAHs are readily converted into more polar compounds via biotransformation processes and stored in bile, until they are excreted (Turcotte, 2008).

Invertebrates have a lower capacity for Phase 1 metabolism compared to vertebrates (although there are large differences both between and within taxonomic groups), and the uptake of PAHs is also highly species-specific (Hylland, 2006). PAH accumulation is higher in algae, molluscs and other invertebrate species that are incapable of metabolizing PAHs. Invertebrates are therefore able to bioaccumulate PAHs more readily, with bioconcentration factors increasing with molecular weight and increasing K_{ow} (Hylland, 2006).

Since invertebrates tend to have a lesser ability to metabolize PAHs, they tend to have high concentrations of parent PAHs in their tissues, which better reflect true exposure concentrations (Meador, 1995). In the marine environment, PAHs typically exist as mixtures, with individual PAHs usually being present at low concentrations. As a result, adverse effects related to a single PAH are often negligible; however, because of their additive nature, specific PAHs may become substantially more toxic when they are in mixtures. In addition, PAH metabolites can form reactive intermediates that are often more toxic to organisms than the parent compounds (Ball and Truskewycz, 2013).

Non-carcinogenic PAHs are able to induce oxidative stress, as well as effects on the immune system, endocrine regulation, and development (Hylland, 2006). Adverse effects from PAH exposures in invertebrates vary greatly between species. The polychaete *Nereis virens* is able to survive in sediments heavily contaminated with hydrocarbons for extended periods of time, while the benthic isopod *Asellus aquaticus* shows 100% mortality after only a few hours of exposure (Ball and Truskewycz, 2013). However, extended exposure to PAHs induces severe effects on most invertebrates, such as inhibited reproduction, delayed emergence, oxidative stress and inhibition of immune functions (Ball and Truskewycz, 2013).

In fish, in-vitro experiments with benzo(a)pyrene, indicated that dihydrodiols (precursors to the benzo(a)pyrene metabolite) which are bound to DNA, make up as much as 75% of the metabolites formed by Phase 1 cytochrome P450 enzymes. This experimental result indicated that the enzyme activity present in fish is also able to create reactive products from PAHs that can potentially form DNA adducts, pieces of DNA that are bound to a cancer-causing chemical, which can result in mutagenesis, teratogenesis and carcinogenesis (Tuvikene, 1995). PAHs in fish can also cause malformations, growth reduction, swimming impairments, yolk sac edema, premature hatching and mortality (Harris et al., 2011). In Vancouver Harbour, neoplastic liver lesions were observed in up to 75% of the English sole caught in areas where sediments are highly contaminated with PAHs (Government of Canada, 1994).

For marine mammals, toxic effects can include anemia, increased oxygen consumption, growth retardation, immunotoxicity, reduced reproduction, neurotoxicity, mutagenesis and carcinogenesis (Harris et al., 2011 and De Jong et al., 1999). For the endangered Southern Resident Killer Whales (SRKW), as well as other marine mammal species that reside in or visit Burrard Inlet waters, exposure to PAHs can potentially cause adverse health effects. For example, exposure to toxic chemicals has been identified as one of three threats contributing to the current SRKW population decline (Fisheries and Oceans Canada, 2018). Whales can be exposed to PAHs through the consumption of contaminated prey (Grant and Ross, 2002), and through oil spills. In local waters, Southern Resident Killer Whales are particularly vulnerable to oil spills due to their small population size, slow rate of reproduction, and dietary specializations (Lundin et al., 2018).

In addition to exposure from dietary sources, the engines of commercial shipping, fishing and recreational vessels emit PAHs into the water and atmosphere, and despite rules for minimum approach distances, vessel traffic around whales continues to increase (Lundin et al., 2018). Potential exposure to PAHs in the atmosphere is exacerbated by the deep breaths that whales take at the water's surface, as well as the long retention time of inhaled air (Lachmuth et al., 2011).

2.1.2 Potential Effects on Human health

Although there are several potential routes of PAH exposure for humans, only exposure via consumption of fish and shellfish will be discussed in this section.

Limited studies on the health effects of PAHs in humans suggest that fish and shellfish consumption may pose health risks (Fleming et al., 2009). Once consumed, PAHs can be absorbed by tissues, metabolized by the liver and kidneys, and/or eliminated. Human health outcomes associated with exposure to PAHs include endocrine disruption, cancer and decreased birth rates (Fleming et al., 2009; Ball and Turskewycz, 2013). Clams, mussels and shrimps represent a significant PAH exposure pathway for human dietary exposures since PAHs are not readily eliminated in these species. LPAHs are often acutely toxic, while many HPAHs are known carcinogens and mutagens (Neff, 1979). The type of acute effects on human health can vary based on the length of exposure, concentration, toxicity, route of exposure, pre-existing health conditions and age (Kim et al., 2013). Ferrante et al. (2018) investigated the bioaccumulation of the 16 US EPA priority PAHs in fish (*Sardina pilchardus* and *Solea solea*) and shellfish (*Donax trunculus*) in the Mediterranean and determined that the increase in maritime traffic around the Catania Gulf (approximately 300 km²) led to higher bioaccumulation rates in the muscle tissues of these three species, particularly in the shellfish *D. trunculus*. This PAH contamination can then be further bioaccumulated in humans consuming such shellfish.

2.2 Potential Sources of PAH Pollution

PAHs are either natural or anthropogenic in origin. Natural inputs of PAHs to the marine environment include crude oil seeps, coal and shale deposits, and forest fires, while anthropogenic inputs include the burning of fossil fuels, spills, and chronic discharges of fossil fuels from vessels. Anthropogenic sources are categorized as either primary (e.g. wastewater from oil refineries, vehicle exhaust, coal/wood/oil furnaces, industrial emissions and spills from vessels) or secondary (e.g., sewage discharge from wastewater treatment plants [WWTPs] and stormwater outfalls). Both primary (direct) and secondary (indirect) sources contribute PAHs to marine environments.

2.2.1 Primary sources

Primary, or direct, sources include burning of organic matter (e.g., burning in agricultural areas, vehicular traffic) and industrial emissions, which can all contribute to atmospheric deposition of PAHs

into the inlet (Hylland, 2006). Primary sources in Burrard Inlet also include oil tankers and pipelines, which have contributed to marine PAH pollution. Historically, Burrard Inlet has had several large crude oil spills, including a recent spill of 2,700 liters of bunker fuel oil in 2015 (bulk carrier MV Marathassa; Table 2). Although this oil spill occurred in English Bay, sampling of water, sediment and biota, confirmed that oil from this tanker was found as far as New Brighton Beach (Morales-Caselles, 2017). Evidence of this spill was still visible in the form of dry oil patches on the shores of Burrard Inlet in 2019, for example along the Tsleil-Waututh Nation (TWN) reserve shoreline (TWN unpublished data, 2019). Accidents and malfunctions are one of the most significant potential causes of PAH releases to Burrard Inlet, polluting both the inlet waters and the surrounding shorelines. Releases can vary in size ranging from major spills to relatively small operational releases during loading and offloading activities of petroleum products from tankers. These small but frequent operational releases can contribute the majority of the petroleum that enters marine waters (National Research Council, 2003). Additionally, small fuel spills from recreational and non-commercial vessels occur regularly in Burrard Inlet. While information regarding the volume and frequency of small spills is not readily available, the cumulative effects of these events are a concern and are an area for further study.

In addition to vessel-related hydrocarbon spills, oil can leach through terrestrial soils into the marine environment. An example of this is the hydrocarbon seep at the Burrard Inlet Chevron Refinery in 2010, which leached hydrocarbons from the north side of the refinery into the marine environment. This was later mitigated through the installation of a Perimeter Extraction System (PES) and underground barriers with absorbent materials to prevent further contamination of the Inlet. Foreshore monitoring results have indicated that the systems in place have been effective (Parkland, 2019).

Table 2. Selected Historic Oil Spills That Have Affected Burrard Inlet (Ocean Wise 2018)

Date	Vessel	Location	Spill	Affected Area	Damage
February 1990	Polish fishing trawler	Vancouver Harbour	~40,000 litres of diesel fuel	Vancouver Harbour	More than 1,000 seabirds affected
July 2006	Bulk carrier <i>MV Andre</i>	Burrard Inlet	7.5 m ³ of heavy fuel oil	Burrard Inlet	Information not available
August 2006	Cargo ship <i>Westwood Anette</i>	Squamish	39 m ³ (60 tonnes) of heavy, sticky bunker fuel	Squamish and nearby areas	Information not available
April 2015	Bulk carrier <i>MV Marathassa</i>	English Bay and Burrard Inlet	2,700 litres of bunker fuel oil	City of Vancouver's recreational shoreline	Information not available

2.2.2 Secondary sources

Secondary, or indirect, sources of PAHs can be chronic, non-point sources, as well as point source inputs, such as urban stormwater runoff during rainfall events, and municipal wastewater discharges (e.g., Lions Gate WWTP).

Creosote treatment of wood piers around Burrard Inlet is also a potential source of PAHs. Tissues from mussels (*Mytilus edulis*) in proximity to these creosote-treated piers have shown elevated levels of benzo(a)pyrene (Meador et al., 1995). A study by Goyette and Brooks (1998) looked at creosote-treated pilings in the Sooke Basin of Vancouver Island, B.C. and detected PAH contamination 7.5 m downstream of the pilings.

Another potential source of PAHs into Burrard Inlet comes from a sealcoat that is applied to many parking lots and driveways to protect the underlying asphalt pavement (Mahler et al., 2005). Mahler et al. (2005) measured the particles in runoff from parking lots with coal tar emulsion sealcoat in Austin Texas, USA and detected 65 times higher concentrations of PAHs than the mean concentrations measured from unsealed asphalt and cement lots. The study concluded that runoff from sealed parking lots can account for the majority of stream PAH loadings. At the time of writing, coal tar based sealcoats were available to consumers through local retailers in municipalities surrounding Burrard Inlet (e.g. RONA 2021).

2.3 Factors Influencing PAH Levels in Burrard Inlet

Once PAHs reach Burrard Inlet, their fate depends on a variety of factors, such as the physico-chemical properties of each PAH. PAHs in the marine environment are degraded through both chemical and biological processes, with photo-oxidation² being the major mechanism of breakdown of PAHs in their dissolved form. For PAHs that accumulate in marine sediments, degradation tends to occur very slowly, due to the lack of penetrating radiation and oxygen. The half-lives³ of PAHs in marine waters more than 1,000 m deep are about twice as long as PAH half-lives in depths of 100-150 m and 2.5 times longer than PAH half-lives at 0 to 10 m depth (Tansel et al., 2011). The half-lives of PAHs in sediments are in the range of months to years, which is longer than the half-lives of PAHs in marine waters (Hylland, 2006).

PAHs that are more water-soluble, such as naphthalenes, remain in the water column, and readily undergo photochemical degradation, biodegradation or transport. PAHs that are less soluble will associate with suspended particles and be deposited into the marine sediments, which are a major repository for PAHs in Burrard Inlet (Government of Canada, 1994).

Since the majority of PAHs are hydrophobic in nature, and therefore tend to accumulate in marine sediments, they are usually seen in areas with more particulate matter (Meador, 1995). PAHs are also mainly associated with smaller particle size. As such, PAH concentrations increase in areas with finer textured sediments, such as depositional areas in Port Moody Arm (PICES, 2001). Studies have also demonstrated that organic matter plays an important role in the adsorption of PAHs in marine sediments. The higher the total organic carbon (TOC), the more likely sediments are to contain PAHs (Meador, 1995).

PAHs can exist in deep layers of marine sediment, where they become less available to marine organisms. However, re-suspension of PAHs from sediments is possible. When the wake of large vessels interacts with bottom sediments, high near-bottom current speeds and shear stress can lead to sediment re-suspension and transport of PAHs to other depositional areas where they may become bioavailable to marine organisms again (Rapaglia et al., 2015). Re-suspension of sediments can also occur during dredging of marine sediments in Burrard Inlet.

² Degradation of PAH particle in the presence of oxygen and facilitated by radiant energy.

³ A half-life is the time required for a certain amount of a substance to degrade or decompose to half of its quantity, which is a measure of its persistence.

2.4 1990 Provisional Water Quality Objectives for PAHs

The 1990 provisional water quality objectives for PAHs in Burrard Inlet are outlined in Table 3. They were based upon existing PAH concentrations in marine sediments in areas of the Lower Mainland at the time, and on Apparent Effects Thresholds (AET) determined for PAHs in sediments in Puget Sound, USA (Ministry of Environment, 1990). Objectives were not developed for water or tissue. The 1990 objectives for PAHs were set to protect aquatic life, wildlife and primary contact recreation.

Table 3. 1990 Provisional Water Quality Objectives for PAHs in Burrard Inlet (Nijman and Swain 1990)

PAH	1990 Provisional Water Quality Objectives for Burrard Inlet
Marine Sediment	µg/g dry weight maximum in sediment, long-term
Total LPAHs (in sediment)	0.5
Naphthalene	0.2
Acenaphthylene	0.06
Acenaphthene	0.05
Fluorene	0.05
Phenanthrene	0.15
Anthracene	0.1
Total LHAHs	1.2
Fluoranthene	0.17
Pyrene	0.26
Benzo(a)anthracene	0.13
Chrysene	0.14
Benzo(a)fluoranthene	0.32
Benzo(a)pyrene	0.16
Indeno(1,2,4-c,d)pyrene	0.06
Dibenzo(a,h)anthracene	0.06
Benzo(g,h,i)perylene	0.07

3. WATER QUALITY ASSESSMENT

In this report, eleven priority PAHs were selected for further assessment and water quality objective development. These PAHs were selected because concentrations of these PAHs in Burrard Inlet were determined to have exceeded the BC and the CCME guidelines during an initial scoping study. These eleven PAHs are: acenaphthene, anthracene, benzo(a)pyrene, benzo(k)fluoranthene, chrysene, fluoranthene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene. Benzo(k)fluoranthene was chosen specifically over benzofluoranthenes, since this particular PAH was detected at elevated concentrations in Burrard Inlet.

3.1 Benchmarks Used in this Assessment

Benchmarks were used to screen available data for potential effects and to inform the derivation of proposed objectives for PAHs levels in Burrard Inlet. Based on the available literature, aquatic life is the value most sensitive to PAH levels in the water column and sediments. Finfish and shellfish consumption by humans may be the most sensitive values for PAH levels in tissue, based on the scope of this study, though impacts on marine mammals were not assessed.

Canadian guidelines for the protection of these values were used as screening benchmarks, where available. Potential sources of screening benchmarks were prioritized as follows:

1. BC Approved Water Quality Guidelines (WQGs), published by the BC Ministry of Environment and Climate Change Strategy (BC ENV 2019b; Nagpal, 1993); and
2. BC Working Sediment Quality Guidelines (WSQGs, BC ENV 2019a), which are based on the Canadian Environmental Quality Guideline (CCME) Interim Sediment Quality Guidelines (ISQG), published by Canadian Council of Ministers of the Environment (CCME, 1999a).

If no benchmarks were available from the above sources, then guidelines or benchmarks available from other sources or jurisdictions were used.

The screening benchmarks chosen for the data assessment in this report are summarized in Table 4a,b,c. Water and sediment benchmarks were used to screen for protection of aquatic life while fish and mussel tissue benchmarks were used to screen for human health. Guidelines for PAHs in tissue were not available, so human-health based screening values for fish and shellfish tissue were derived from Health Canada toxicological reference values and risk assessment methodologies (Health Canada 2010a,b,c, 2012, 2021; Richardson 1997, Richardson and Stantec 2013).

Table 4. Benchmarks for PAHs Used in this Assessment

Table 4a. Benchmarks for PAHs in Marine Water Used in this Assessment

PAH	CCME/USA EPA Priority List PAH?	Screening Benchmark (µg/L, mean)	Status	Value	Reference
Acenaphthene		6	Approved	Marine aquatic life	BC Water Quality Guideline, from Nagpal 1993
Benzo(a)pyrene		0.01			
Chrysene		0.1			
Fluorene		12			
Methylated naphthalene		1			
Naphthalene	Yes	1			

Table 4b. Benchmarks for PAHs in Sediment Used in this Assessment

PAH	CCME/USA EPA Priority List PAH?	Screening Benchmark (µg/g dry weight, maximum)	Status	Value	Reference
Acenaphthene	Yes	0.00671	Working	Marine aquatic life	BC Working Water Quality Guideline ISQG, BC ENV 2019a, CCME 1998
Anthracene	Yes	0.0469			
Benzo(a)pyrene	Yes	0.0888			
All benzofluoranthenes (includes benzo[k]fluoranthene)	Yes	2.3*			Washington State DoE, 2013
Chrysene	Yes	0.108			BC Working Water Quality Guideline, BC ENV 2019a, CCME 1998
Fluoranthene	Yes	0.113			
Fluorene	Yes	0.0212			
2-methylnaphthalene		0.02			
Naphthalene	Yes	0.0346			
Phenanthrene	Yes	0.0867			
Pyrene	Yes	0.153			

*Concentrations are expressed as µg/g sediment containing 1% organic carbon. Adjustments to guidelines are only required when they are expressed in terms of the sediment containing 1% organic carbon (Washington State DoE, 2013).

Table 4c. Benchmarks for PAHs in Tissue Used in this Assessment

PAH	CCME/ USA EPA Priority List PAH?	Screening Benchmark** µg/g wet weight, maximum			Status	Value	Reference
		toddler subsistence fisher	adult subsistence fisher	adult recreational fisher			
Benzo(a)pyrene	Yes	N/A	0.0036	0.0071	N/A	Human consumption of finfish and shellfish	Thompson and Stein, 2021
2-methylnaphthalene	Yes	0.14	0.28	0.55			
Naphthalene	Yes	0.7	1.4	2.7			
Pyrene	Yes	1.0	2.1	4.1			

** Calculated screening value for which PAH concentrations in tissue can be compared and assessed for potential risks to human health. These are single benchmarks for all tissue types (e.g., fish muscle, bivalves, crustaceans) as data are not available to resolve to the level of objectives for different tissue types at this time.

The science on the effects of PAHs has progressed since the development of the 1990 provisional water quality objectives for Burrard Inlet, and BC and national water and sediment quality guidelines for PAHs have since been updated (BC ENV, 2019, 2020; CCME, 1999a,b). Detection limits have also improved since 1990, which allows for PAH assessment at lower thresholds. The objectives calculated in 1990 are

less relevant because they are site specific to Puget Sound, and they fail to separate combined effects from single contaminant effects of PAHs (Tri-Star Environmental Consulting, 2009). Therefore, the 1990 objectives were not used as screening benchmarks.

Benchmarks for PAH levels in water are based on the BC Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture (ENV, 2019a; Nagpal, 1993). The Approved BC WQGs were determined from literature reviews of toxicity studies within various marine biota, guidelines from other jurisdictions, and assessments of the overall conditions of PAHs in BC marine environments. Since laboratory conditions are not always a perfect replica of field conditions, the province has included conservative built-in safety factors to reflect environmental conditions (Nagpal, 1993). The water quality guidelines are intended to protect the most sensitive species, as well as early life stage exposure to sub-lethal and lethal effects for indefinite exposure times (Nagpal, 1993).

Benchmarks for PAH levels in sediment are based on the BC Working Sediment Quality Guidelines (BC ENV 2019a) because there are no published BC approved sediment quality guidelines for PAHs in sediment. These working guidelines adopt the Interim Sediment Quality Guidelines (ISQGs) from CCME (1998) threshold effect levels (TEs), which represent concentrations that will protect aquatic life from the adverse effects of a toxic substance in most situations. The exception is the working sediment quality guideline for benzofluoranthenes (including benzo(k)fluoranthene), which was adopted from the Washington State Department of Ecology (DoE, 2013). The majority of the data used to derive the ISQGs are from field-collected sediments that measured PAH concentrations (plus concentrations of other chemicals) and associated biological effects (compiled in a Biological Effects Database for Sediments [BEDS]). The CCME ISQGs were developed using a modification of the USA National Status and Trends Program (NSTP) approach and are developed for the top 5 cm of sediment. For benzo(k)fluoranthene in sediment, the guideline value for all benzofluoranthenes was used as the screening benchmark, as there is no guideline specific to benzo(k)fluoranthene.

In the absence of relevant guidelines for human consumption of fish and shellfish tissue, a risk-based approach was used to calculate human health-based tissue screening values for fish and shellfish tissue (Thompson and Stein, 2021). The approach considers: the contaminant *receptors* (people who are exposed to the contaminant, in this case subsistence/Indigenous, recreational, and general BC populations, with screening values calculated for the most sensitive life stage within each population), *exposure* to the contaminant (how much fish the receptors consume), and the contaminant *toxicity* (what is known about the contaminant and how it affects different receptors). Receptor characteristics were defined from Richardson and Stantec (2013), exposure was calculated through fish ingestion rates from Richardson (1997) and Health Canada (2010c), and toxicity was defined through toxicological reference values (TRVs) prescribed by Health Canada (2010a) or other international agencies (i.e., United States Environmental Protection Agency and the World Health Organization).

Tissue screening values are defined as conservative threshold values against which contaminant concentrations in fish tissue can be compared and assessed for potential risks to human health (Thompson and Stein, 2021). Fish and shellfish tissue in this report refer to country foods, that is, foods produced in an agricultural (not for commercial sale) backyard setting or harvested through hunting, gathering or fishing activities (Health Canada 2010b). Screening values provide general guidance to environmental managers and represent a suggested safe level of a contaminant in fish tissue based on a conservative estimate of a person's fish consumption per day; they do not provide advice regarding consumption limits or constitute a fishing advisory. Exceedances of a screening value may indicate that further investigation to assess human health risk at a particular site is warranted; however, exceeding a screening value does not imply an immediate risk to human health (Thompson and Stein, 2021).

Tissue screening values were calculated by Thompson and Stein (2021) using equations from Health Canada (2012). For the non-carcinogenic PAHs (2-methylnaphthalene, naphthalene and pyrene), an allocation factor of 0.2 was used in the calculation to reflect the fraction of PAHs assumed to come from country foods (in this case, wild seafood). A toddler from a subsistence fishing population is the most sensitive receptor of these non-carcinogenic PAHs. Screening values were also calculated for an adult from a subsistence fishing population, and an adult from a recreational fishing population (Table 4). As benzo(a)pyrene is a carcinogen, the most sensitive receptor is an adult from a subsistence fishing population as the toxicity of benzo(a)pyrene is based on an adult lifetime of exposure (60 years). Further details on the methodology and equations used are explained in Thompson and Stein (2021).

3.2 Data Sources

Data on PAH levels in Burrard Inlet were gathered from several recent and historic studies and monitoring programs. A summary of the datasets used for this assessment is presented in Table 5. Sampling sites are indicated on the heat maps provided in Appendix A.

Table 5. Studies and Monitoring Programs Contributing Data Used for the Assessment

Source	Study/Monitoring Program	Year(s)	No. of Obs.	No. of Sites	Sampling Frequency	Parameters Sampled
Environment Canada	PAH and Dioxin/Furan in Sediments	1991	416 sediment	24	January 23-24, 1991	PAHs
British Columbia Ministry of Environment (BC ENV)	Attainment Monitoring	1994 to 2002	224 water 362 sediment	6 water 12 sediment	1994, 2000, 2002 2001 (water)	PAHs
Ocean Wise	<i>PollutionTracker</i>	2015 to 2016	1328 sediment 994 tissue	15 sediment 9 of these sites for mussel tissue	2015 and 2016	PAHs
Metro Vancouver	Ambient sediment program	2008 to 2015	1680 water 4983 sediment 32 tissue	7	2008, 2011, 2013 and 2015	PAHs
Environment and Climate Change Canada (ECCC)	Disposal at sea sediment sampling	2009 to 2017	5907 sediment	11	2009, 2013 and 2017	PAHs

3.3 Assessment Results

The results of the data assessment for PAHs are summarized below. Monitoring data were compared to benchmarks and temporal and spatial observations are presented by sub-basin, where appropriate. Because of variation in the sampling and analytical methods and distribution of sites, results from each monitoring program are discussed separately. Programs that collect samples at sites close to the shore are expected to produce different results compared to programs that collect samples at depth for ambient conditions. Therefore, there are limitations on comparing results between the monitoring programs. Where PAH levels were below detection limits, values were plotted at the detection limit value in the figures. Samples that were below detection limits were excluded from the evaluation of mean and maximum levels at the sample locations. Overall summaries of status and observations for

water, sediment and tissue are provided alongside the rationale for the proposed water quality objectives in Section 4.2.

To determine trends in PAH concentrations in Burrard Inlet, data were taken from monitoring events between 1991 and 2017, which sampled mainly sediment. Given the abundance of sediment data, and a lack of water and tissue data, this report focuses on PAHs in sediment, with brief sections for water and tissue. Concentrations of PAHs in water are reported in $\mu\text{g/L}$, in sediment are reported in $\mu\text{g/g}$, dry weight; and in tissue are reported in $\mu\text{g/g}$, wet weight, unless stated otherwise.

Heat maps illustrating the distribution of PAH levels in sediment and tissue in 5-year increments across all monitoring programs and years where data are present are provided in Appendix A. It is important to recognize that while historic data may indicate that PAH levels in parts of Burrard Inlet may have differed in the past compared to the present, differences in sampling frequency and method detection limits do not allow for direct comparison of historic data with recent data. Instead, the heat maps may be used to illustrate the best understanding of potential areas where PAH levels may be relatively high in comparison to the rest of Burrard Inlet.

3.3.1 Discussion of Marine Water Data

2001 – BC Ministry of Environment (BC ENV) Sampling

Marine water samples were collected in 2001 from six locations around Burrard Inlet, which included Inner Harbour, Central Harbour, False Creek and Port Moody.

Most of the PAHs in marine water were below detection limits, but benzo(a)pyrene and chrysene were above the screening benchmarks. Benzo(a)pyrene was detected at concentrations above the BC WQG ($0.01 \mu\text{g/L}$) in Port Moody (Ioco) (Figure 1). Chrysene concentrations were above the BC WQG ($0.10 \mu\text{g/L}$) at two False Creek sites, and the Port Moody (Ioco) site (Figure 2).

2008, 2011, 2013 & 2015 – Metro Vancouver’s Burrard Inlet Ambient Monitoring Program (BIAMP)

All samples measured below detection limits. Detection limits ranged between $0.009 \mu\text{g/L}$ for benzo(a)pyrene to $0.1 \mu\text{g/L}$ for 2-methylnaphthalene and naphthalene.

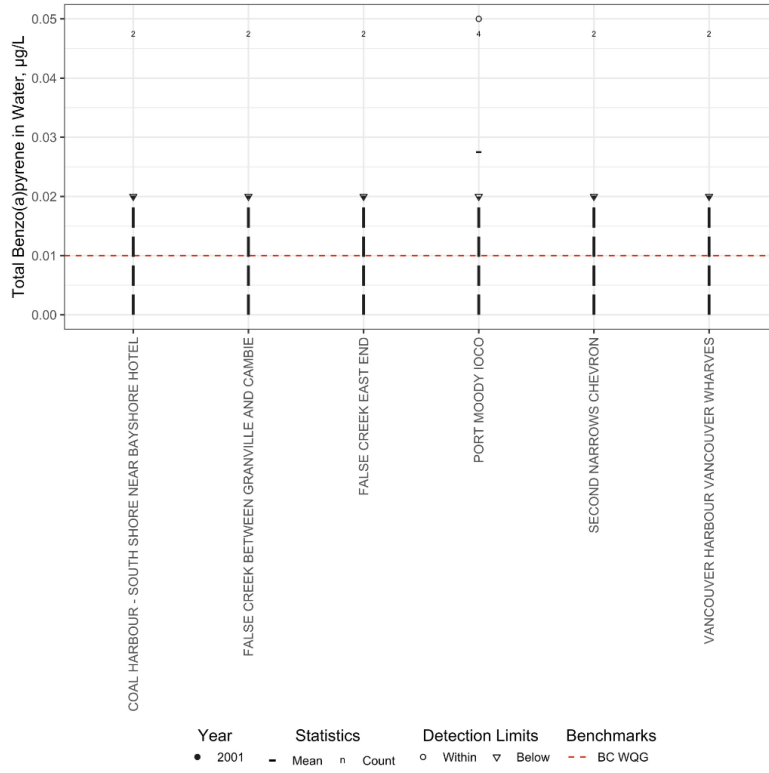


Figure 1. Benzo(a)pyrene levels in BC ENV water column samples (2001) in µg/L

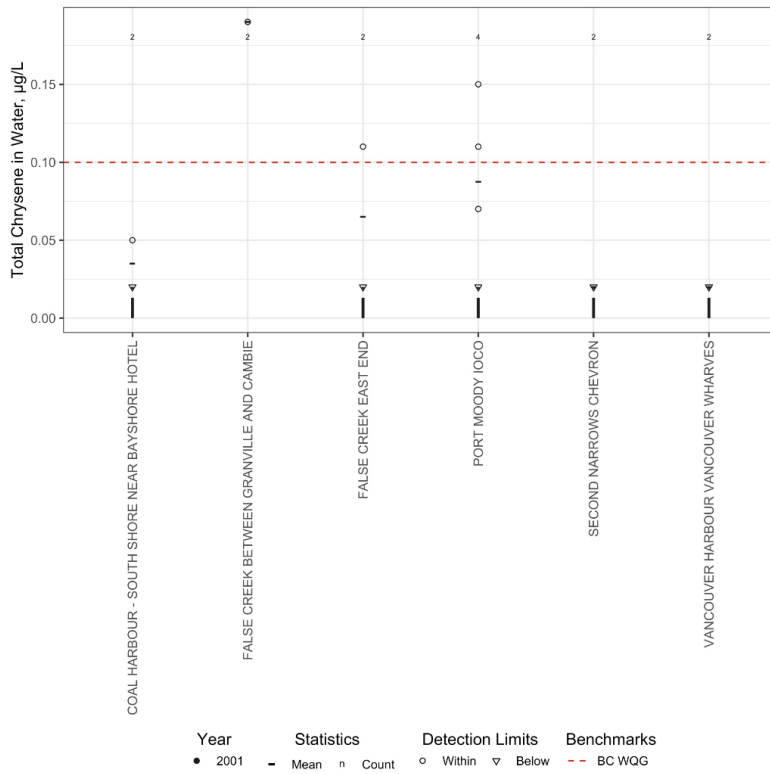


Figure 2. Chrysene levels in BC ENV water column samples (2001) in µg/L

3.3.2 Discussion of Marine Sediment Data

1991 – Environment Canada Conservation and Protection Pacific and Yukon Region Sampling

The ECCC program sampled sediment within Burrard Inlet on January 23 and 24, 1991. Monitoring was conducted at 24 locations across all sub-basins in Burrard Inlet. An illustration of the monitoring locations is provided in Figure 3.

In 1991, the highest total PAH levels ($117.38 \mu\text{g/g}$) were recorded at Site F in Inner Harbour. This site was located in close proximity to Coal Harbour. Station A, located in False Creek, ranked second for total PAH levels ($80.18 \mu\text{g/g}$). The elevated PAH levels may have been due to past industrial activity in False Creek including coal gasification plants, sawmills, shingle mills and wood preserving operations (Goyette and Boyd, 1993).

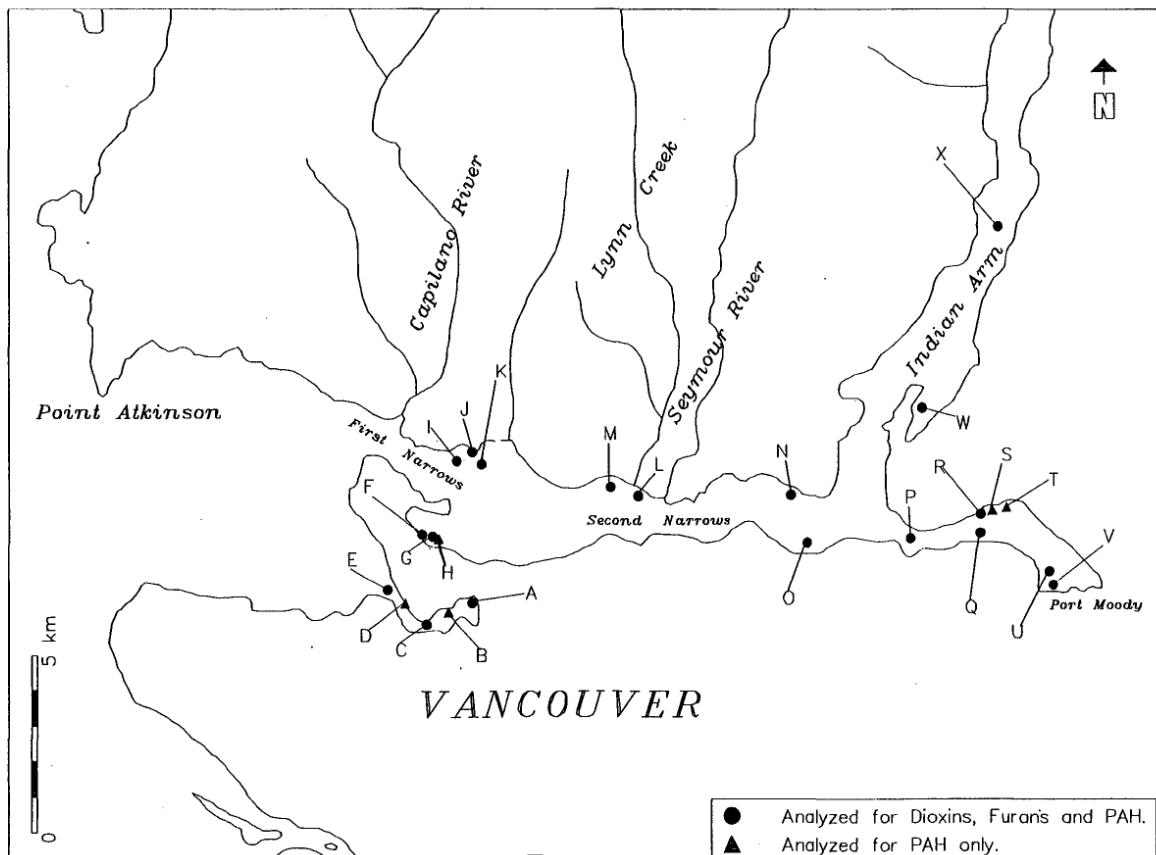


Figure 3. Environment Canada sediment sampling stations, 1991

The following is a brief description of the specific findings for PAH concentrations within the Inlet:

- Acenaphthene – All sites except for Site W in Indian Arm exceeded the benchmark ($0.007 \mu\text{g/g}$). The highest level ($3.10 \mu\text{g/g}$) was measured at Site F in the Inner Harbour.
- Anthracene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark ($0.047 \mu\text{g/g}$). The highest level ($3.70 \mu\text{g/g}$) was measured at Site F in the Inner Harbour.

- Benzo(a)pyrene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark (0.089 µg/g). The highest level (7.00 µg/g) was measured at Site F in Inner Harbour.
- Benzofluoranthenes were not measured in this monitoring program.
- Chrysene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark (0.108 µg/g). The highest level (13.00 µg/g) was measured at Site F in the Inner Harbour.
- Fluoranthene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark (0.113 µg/g). The highest level (23.00 µg/g) was measured at Site F in the Inner Harbour.
- Fluorene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark (0.021 µg/g). The highest level (3.50 µg/g) was measured at Site F in the Inner Harbour.
- 2-methylnaphthalene was not measured in this monitoring program.
- Naphthalene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark (0.035 µg/g). The highest level (16.00 µg/g) was measured at Site V in Port Moody Arm; however, for this sample the laboratory reported that compounds in the sample interfered with recovery of some analytes. The second highest level (5.40 µg/g) was measured at Site A in False Creek.
- Phenanthrene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark (0.087 µg/g). The highest level (9.50 µg/g) was measured at Site F in the Inner Harbour.
- Pyrene – All sites except for Site L in the Inner Harbour and Site W in Indian Arm exceeded the benchmark (0.153 µg/g). The highest level (18.00 µg/g) was measured at Site F in the Inner Harbour.

1994 to 2002 – BC Ministry of Environment Water Quality Objective Attainment Monitoring (BC ENV)

The BC ENV program sampled sediment within Burrard Inlet in 1994, 2000 and 2002. Sites sampled included the Outer Harbour, False Creek, Inner Harbour, Central Harbour and Port Moody Arm. The following is a brief description of the findings for PAH concentrations within the inlet for the individual years sampled.

- Acenaphthene – All the sites sampled exceeded the benchmark (0.007 µg/g) or were below detection limits (0.01 µg/g to 0.04 µg/g). The highest concentrations occurred in the Outer Harbour (English Bay) in 1994 (0.064 µg/g) and the Inner Harbour (Vancouver Wharves) in 2000 (0.12 µg/g).
- Anthracene – The sites that exceeded the benchmark (0.0469 µg/g) included the Outer Harbour (Vancouver Wharves), Inner Harbour, (False Creek East and Coal Harbour), Central Harbour (Clarke Drive and Loch Katrine) and Port Moody Arm (Ioco and Pacific Coast). The Ioco site in Port Moody had the highest concentrations (0.24 µg/g to 0.27 µg/g) between 1994 and 2000, but decreased to below the benchmark in 2002. False Creek (east end) and the Inner Harbour (Vancouver Wharves) also had relatively high concentrations (approximately 0.2 µg/g) in 2000.
- Benzo(a)pyrene – Most of the sites exceeded the benchmark (0.088 µg/g), except for the Outer Harbour sites (Figure 4). At one of the Port Moody sites (Ioco), the greatest concentration occurred in 1994 (approximately 0.6 µg/g), but concentrations decreased to below the guideline in 2002. At the False Creek site, benzo(a)pyrene was only detected in 1994 and 2000 and exceeded the guideline in both years.

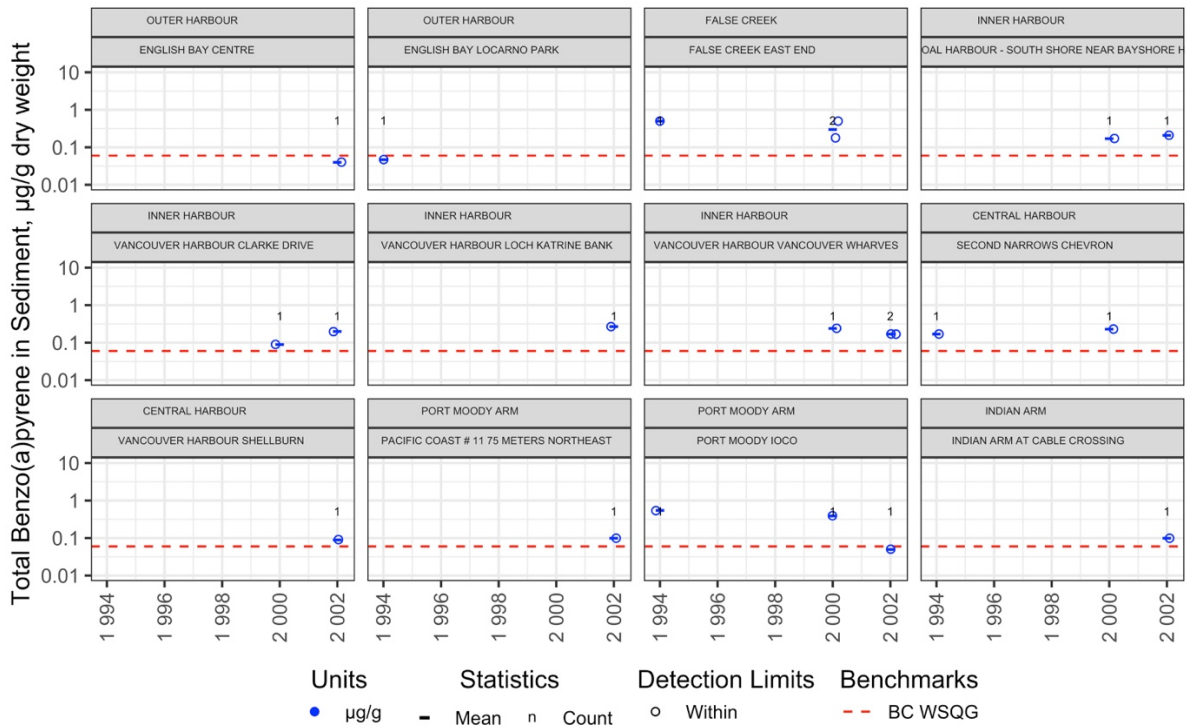


Figure 4. Benzo(a)pyrene levels in BC ENV sediment samples (1994 to 2002) in µg/g

- Benzofluoranthenes – Benzo(b)fluoranthene and benzo(k)fluoranthene were measured in this monitoring program and the results were summed together for this assessment. None of the sites sampled exceeded the benchmark for benzofluoranthenes (2.3 µg/g). The highest value calculated was 1.08 µg/g at Port Moody loco.
- Chrysene – Most sites exceeded the benchmark (0.2 µg/g), except for the Outer Harbour sites, the Central Harbour, and the Indian Arm site. The highest concentrations were in Port Moody (loco site) in 1994 and 2000 at 1.2 and 0.7 µg/g, respectively. These concentrations fell below the guideline in 2002. False Creek (east) also exceeded the guideline, with a slight increase in 2000. The Inner Harbour sites had a slight increase in concentrations over the sampling years, except for the Vancouver Wharves site, which decreased.
- Fluoranthene – All sites, except the Outer Harbour (English Bay) were above the benchmark (0.113 µg/g). The highest concentration occurred at the loco site in Port Moody in 1994 (3.6 µg/g).
- Fluorene – All concentrations were below the benchmark (0.2 µg/g). The highest value recorded was 0.11 µg/g at Port Moody loco.
- 2-methylnaphthalene was not measured in this monitoring program.
- Naphthalene – Most of the sites exceeded the benchmark (0.0346 µg/g), except English Bay, Indian Arm (at cable crossing), and the Central Harbour (at Shellburn). The highest concentration was measured in False Creek (east) at 0.39 µg/g in 2000.
- Phenanthrene – The False Creek, Inner Harbour and Port Moody sites, and one Central Harbour site exceeded the benchmark (0.087 µg/g). The highest concentration occurred in 2000 at the loco site in Port Moody (0.6 µg/g).

- Pyrene – Most sites exceeded the benchmark guideline (0.153 µg/g), except for the Outer Harbour sites. The highest concentration occurred at the loco site in Port Moody in 1994 (2.7 µg/g).

2015 & 2016 – Ocean Wise PollutionTracker

PollutionTracker sediment sampling in Burrard Inlet was conducted in partnership with the Vancouver Fraser Port Authority, Metro Vancouver and the Tsleil-Waututh Nation. *PollutionTracker* surface sediment samples were collected coast-wide in BC in 2015 and 2016. Sites in Burrard Inlet included the Outer, Inner, and Central Harbours, Port Moody Arm, and two sites in Indian Arm (Figure 5). The following is a brief description of PAH results for the inlet sites.

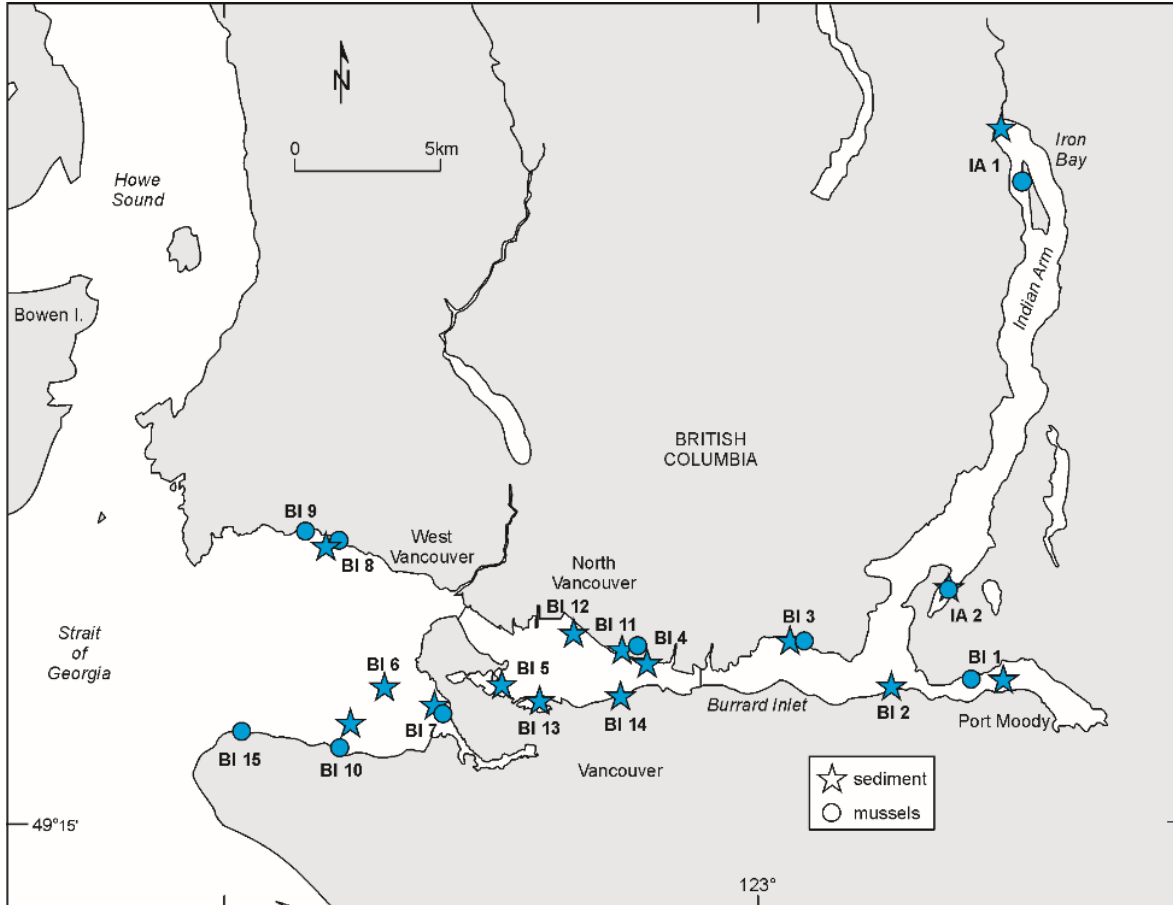


Figure 5. *PollutionTracker* sampling stations (2015 to 2016)

- Acenaphthene – Almost all sites exceeded the benchmark (0.007 µg/g), except for the Central Harbour (BI 3: 0.00188 µg/g), two Inner Harbour sites (BI 4: 0.00341 µg/g; BI 11: 0.00528 µg/g), and both Indian Arm sites (0.000964 µg/g and 0.00125 µg/g). The highest concentration occurred in the Inner Harbour (BI 5) in 2015 (0.0621 µg/g).
- Anthracene – Sites that exceeded the benchmark (0.047 µg/g) included Port Moody (BI 1 and 2), the Inner Harbour (BI 5, 12, 13 and 14), and the Outer Harbour (BI 6, 7, and 8). The highest concentration occurred on the south side of the Inner Harbour (BI 5: 0.2 µg/g), followed by the Outer Harbour (BI 6: 0.15 µg/g).

- Benzo(a)pyrene – Concentrations at most of the sites exceeded the benchmark (0.088 µg/g), except for the two north Inner Harbour sites (BI 4 and 11), one Central Harbour site (BI 3) and both Indian Arm sites (Figure 6). The highest concentrations occurred in the Outer Harbour (BI 6: 0.7 µg/g), followed by the Inner Harbour site (BI 5: 0.5 µg/g).

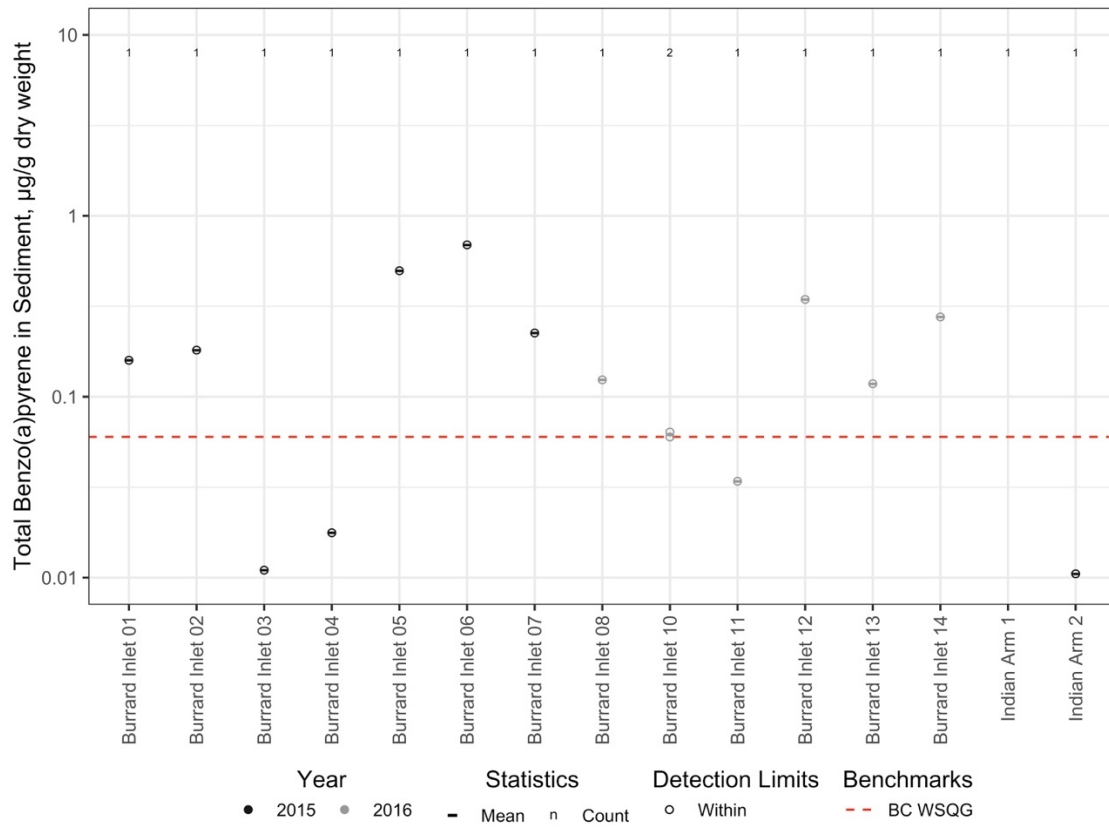


Figure 6. Benzo(a)pyrene levels in PollutionTracker sediment samples (2015 to 2016) in µg/g

- Benzofluoranthenes – Only benzo(b)fluoranthene was measured in this monitoring program and none of the sites sampled exceeded the benchmark for benzofluoranthenes (2.3 µg/g). The highest value measured was 0.0117 µg/g at Indian Arm 2. Benzo(k)fluoranthene and benzo(j)fluoranthene were not measured, so whether total benzofluoranthenes exceeded the benchmark is inconclusive. Additional monitoring data would be required to determine total benzofluoranthenes and the relative proportion of individual isomers.
- Chrysene – Sites that exceeded the benchmark (0.108 µg/g) included Port Moody Arm (BI 1), three Inner Harbour sites (BI 5, 12 and 14) and two Outer Harbour sites (BI 6 and 7). The highest concentration occurred at the southern Outer Harbour site (BI 6) and Inner Harbour site (BI 5) at concentrations of 0.54 µg/g and 0.4 µg/g, respectively. The Inner Harbour sites, BI 12 and BI 14, also had relatively high concentrations that exceeded the benchmark.
- Fluorene – None of the sites sampled exceeded the benchmark (0.2 µg/g).
- Fluoranthene – The sites that exceeded the benchmark (0.113 µg/g) were the Port Moody sites (BI 1 and 2), some of the Outer Harbour sites (BI 6, 7 and 8), and the Inner Harbour sites (BI 5, 12, 13 and 14). The highest concentration occurred in the Inner Harbour (BI 5 and 12) at 0.66 and 0.63 µg/g, respectively. Other sites with relatively high concentrations were the Outer Harbour site BI 6 and the Inner Harbour site BI 14.

- 2-methylnaphthalene – The majority of sites exceeded the benchmark (0.02 µg/g), except the Indian Arm sites, one Central Harbour site (BI 3), and one Inner Harbour site (BI 4). The highest concentration occurred at one of the Port Moody sites (BI 1) at 0.103 µg/g, followed by the two Inner Harbour sites (BI 5 and BI 14) at 0.917 and 0.910 µg/g, respectively.
- Naphthalene – All sites exceeded the benchmark (0.035 µg/g), except the Indian Arm sites, one Central Harbour site (BI 3), and two Inner Harbour sites (BI 4 and BI 11). The highest concentration occurred at one of the Port Moody sites (BI 1) at 0.26 µg/g, followed by the two Inner Harbour sites (BI 5 and 14) at 0.24 and 0.22 µg/g, respectively.
- Phenanthrene – The sites that exceeded the benchmark (0.087 µg/g) included three Outer Harbour sites (BI 6, 7 and 8), Inner Harbour sites (BI 5, 12, 13 and 14), and both Port Moody sites. The highest concentration occurred at one of the Inner Harbour sites (BI 5) (0.58 µg/g).
- Pyrene – Sites exceeding the benchmark of guideline (0.153 µg/g) included the Port Moody sites (1 and 2), Inner Harbour sites (BI 5, 12, 13 and 14) and Outer Harbour sites (BI 6, 7 and 8). The highest concentration occurred at Outer Harbour site BI 6 (1.1 µg/g).

2008, 2011, 2013 & 2015 – Metro Vancouver’s Burrard Inlet Ambient Monitoring Program (BIAMP)

Ambient sediment sampling was conducted by Metro Vancouver at seven locations in 2008, 2011, 2013 and 2015. The following summarizes sediment PAH concentrations within the inlet.

- Acenaphthene – Most sites sampled exceeded the benchmark (0.007 µg/g), except the Central Harbour (0.0012 µg/g in 2008) and south Outer Harbour site (0.005 µg/g in 2015). The highest concentration occurred in Port Moody Arm in 2015 (0.013 µg/g).
- Anthracene – Most of the sampled sites exceeded the benchmark (0.047 µg/g), except for the north Indian Arm site and the south part of the Outer Harbour. The highest concentration occurred in Port Moody Arm in 2011 (0.12 µg/g), followed by Indian Arm and Central Harbour sites in 2011 (0.10 µg/g).
- Benzo(a)pyrene – All sites exceeded the benchmark (0.088 µg/g; Figure 7). The highest concentration occurred in Port Moody Arm in 2011 (0.45 µg/g).

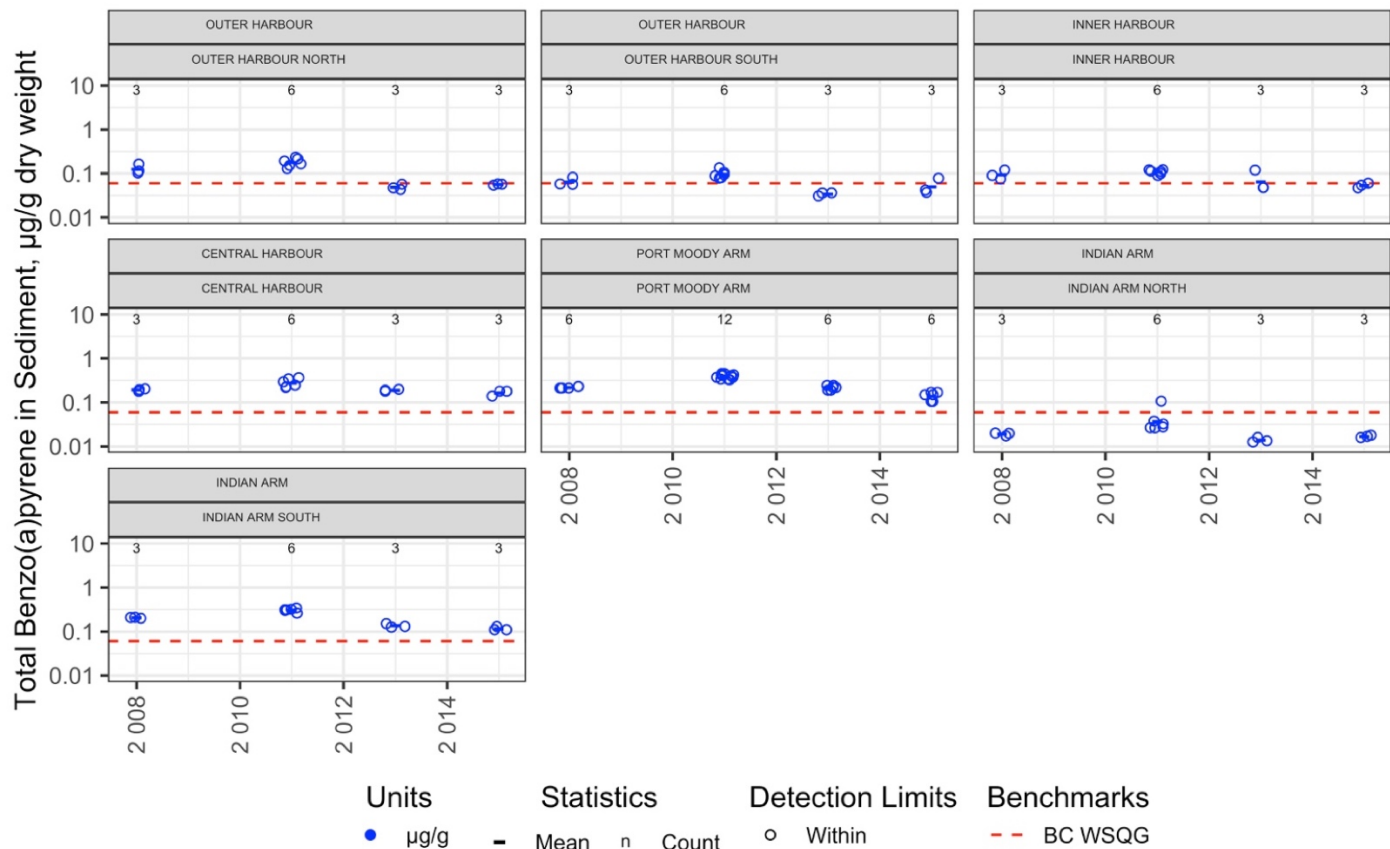


Figure 7. Benzo(a)pyrene levels in for Metro Vancouver sediment samples (2008 to 2015) in µg/g

- Benzofluoranthenes – Benzo(b)fluoranthene, benzo(k)fluoranthene and benzo(j)fluoranthene were measured in this monitoring program, though benzo(j)fluoranthene was not measured in 2013. The concentrations for the three isomers were summed together for this assessment and all the calculated levels were below the benchmark (2.3 µg/g). The highest calculated level was 0.669 µg/g at Port Moody Arm in 2013 (which does not include benzo[j]fluoranthene as it was not measured).
- Chrysene – All sites were below the benchmark (0.2 µg/g), except for the Central Harbour and south Indian Arm site. The Port Moody Arm site had the highest concentration in 2011 (0.37 µg/g).
- Fluoranthene – All sites exceeded the benchmark (0.113 µg/g), except for the north Indian Arm site. The highest concentrations occurred in Port Moody Arm in 2011 and in Indian Arm in 2008 (0.55 µg/g), and at the Central Harbour site (0.44 µg/g).
- Fluorene – All sites were below the benchmark (0.2 µg/g).
- 2-methylnaphthalene – All sites have measured levels above the benchmark (0.02 µg/g). However, levels recorded in 2015 were lower at all sites in comparison to levels measured in 2011 and 2013. The highest levels were recorded in the Central Harbour and Port Moody Arm in 2011 (0.357 µg/g and 0.335 µg/g, respectively).
- Naphthalene – All of the sampled sites exceeded the benchmark (0.034 µg/g). The highest concentration occurred at the Port Moody Arm site in 2015 (0.5 µg/g).

- Phenanthrene – Most sites exceeded the benchmark (0.087 µg/g), except for the north Indian Arm site. The highest concentration was found in the Port Moody Arm and south Indian Arm sites in 2008 (0.35 µg/g).
- Pyrene – All sites exceeded the benchmark (0.153 µg/g), except for the north Indian Arm site. The highest concentration occurred in Port Moody Arm in 2011 (0.6 µg/g), followed by the Central Harbour site in the same year (0.48 µg/g).

2009 to 2017 – Environment and Climate Change Canada Disposal at Sea Program (ECCC 2017)

As part of Environment and Climate Change Canada’s (ECCC) Disposal at Sea Program, 11 sites were sampled around Burrard Inlet. Sampling was done in 2009 and from 2013 to 2017.

- Acenaphthene – All sites sampled exceeded the benchmark (0.007 µg/g). The highest concentration occurred at the Inner Harbour site (site 11) in 2016 (0.8 µg/g).
- Anthracene – The sites that exceeded the benchmark (0.047 µg/g), included the Inner Harbour site (site 11) and Port Moody Arm site (site 10). The other sites had concentrations that were either at or below the guideline, with one Inner Harbour site (site 7) being slightly above the guideline at 0.5 µg/g. The highest concentration was in the Inner Harbour (site 11) (6.7 µg/g in 2017). The Port Moody Arm sites also showed exceedances in 2009 (1 µg/g).
- Benzo(a)pyrene – All sites exceeded the benchmark, except for sites in the Inner Harbour (site 2 and 6) and in Port Moody (site 8) (Figure 8). The highest concentrations were at the Inner Harbour site 11 in 2016 (2.3 µg/g to 9.7 µg/g), followed by site 10 in Port Moody Arm in 2009 (1.9 µg/g).

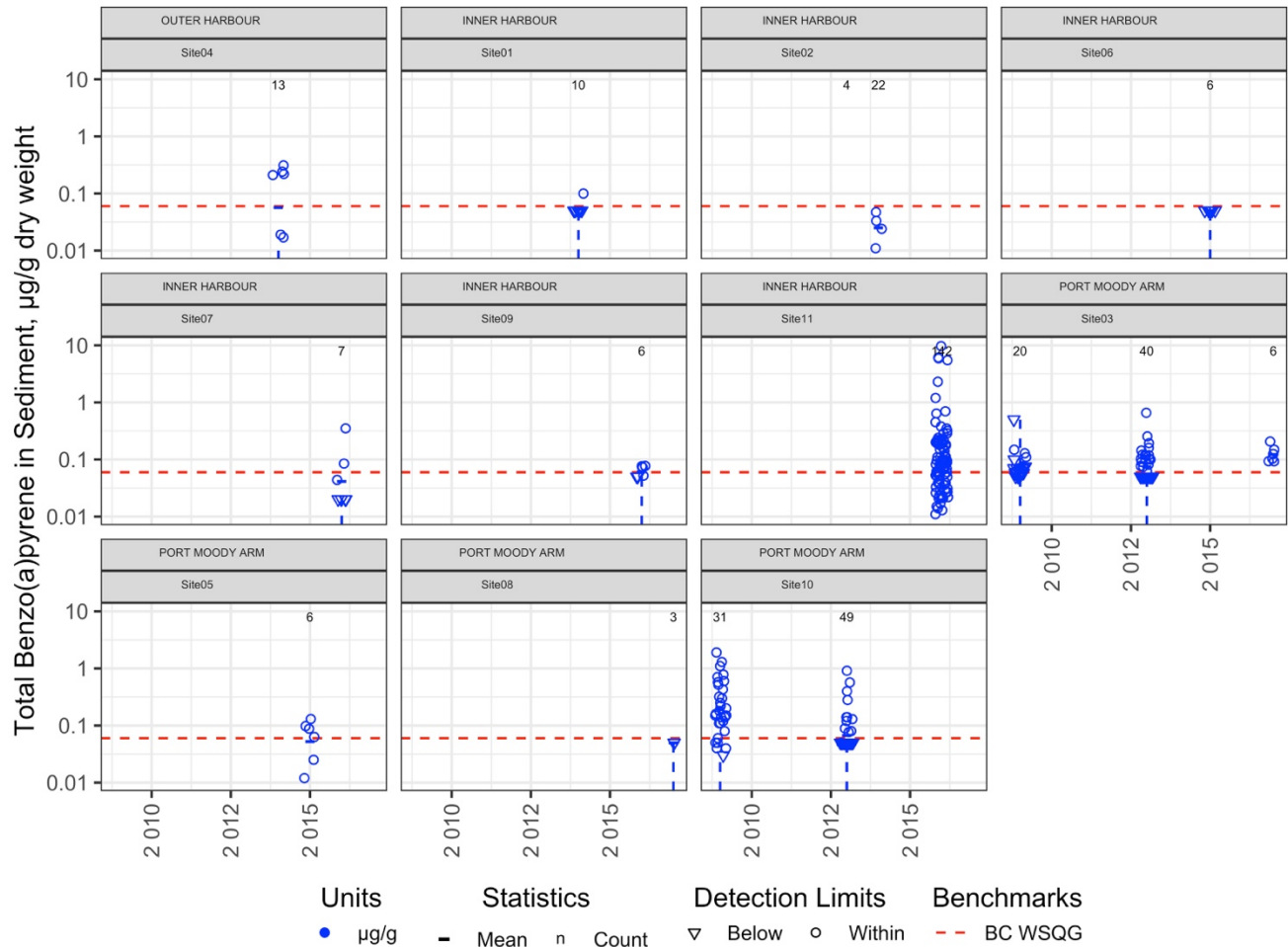


Figure 8. Benzo(a)pyrene levels in ECCC sediment samples (2008 to 2015) in $\mu\text{g/g}$

- Benzofluoranthenes – Only benzo(k)fluoranthene was measured in this monitoring program. Only the Inner Harbour site 11 exceeded the benchmark ($2.3 \mu\text{g/g}$). The concentration at this site was $5.3 \mu\text{g/g}$ in 2016. Other sites with elevated benzo(k)fluoranthene levels include Site 3 ($1.3 \mu\text{g/g}$ in 2013) and Site 10 ($1.7 \mu\text{g/g}$ in 2013). Other benzofluoranthene isomers were not measured, so whether total benzofluoranthenes exceeded the benchmark is inconclusive. Additional monitoring data would be required to determine total benzofluoranthenes and the relative proportion of individual isomers.
- Chrysene – The only sites that exceeded the benchmark ($0.2 \mu\text{g/g}$) were the Port Moody Arm sites (sites 5 and 10), and the Inner Harbour site (site 11). Port Moody site 10 had the highest concentration ($4.3 \mu\text{g/g}$ in 2013).
- Fluoranthene – All sites exceeded the benchmark ($0.113 \mu\text{g/g}$), except for one of the Inner Harbour sites (site 6). Inner Harbour site 11 had the greatest exceedance in 2016 ($45 \mu\text{g/g}$).
- Fluorene – Only Port Moody site 10 and one of the Inner Harbour sites (site 11) exceeded the benchmark ($0.2 \mu\text{g/g}$). Inner harbour site 11 had the highest concentration ($1.3 \mu\text{g/g}$ in 2016).
- 2-methylnaphthalene – Most sites exceeded the benchmark ($0.02 \mu\text{g/g}$), except for one Inner Harbour site (site 2). The highest concentration occurred at one of the Inner Harbour sites in

2016 (site 11, 0.29 µg/g), and at Port Moody Arm site 10 (0.23 µg/g in 2009). Levels at Port Moody Arm site 10 fell slightly between 2009 to 2013 but were still above the benchmark.

- Naphthalene – Most sites exceeded the benchmark (0.035 µg/g), except for two Inner Harbour sites (site 2 and 6 - not detected). The highest concentration occurred at one of the Inner Harbour sites in 2016 (site 11, 1 µg/g), and at Port Moody Arm site 3 (1 µg/g in 2009 and 2017).
- Phenanthrene – Most sites exceeded the benchmark (0.0867 µg/g), except for Inner Harbour sites 2 and 6 (not detected). The highest concentration occurred at one of the Inner Harbour sites (site 11: 5 µg/g in 2016).f
- Pyrene – Most sites exceeded the benchmark (0.153 µg/g), except for Inner Harbour sites 2, 6 and 9. Inner Harbour site 11 had the highest concentration (50 µg/g in 2016).

3.3.3 Discussion of Tissue Data

Although it has not been done in this data assessment, mixtures of carcinogenic PAHs (anthracene, benzo[a]pyrene, chrysene, fluoranthene, phenanthrene and others) should be evaluated by totaling their individual measured concentrations adjusted according to their toxic equivalence factors (TEFs), and comparing that total to the benchmark for benzo(a)pyrene in tissue (0.0036 µg/g wet weight, single sample maximum). This guidance has been built into the proposed objectives; for details and a list of TEFs, please see Section 4 and Table 7.

2015 & 2016 – Ocean Wise PollutionTracker

PollutionTracker mussel sampling in Burrard Inlet was conducted in partnership with the Vancouver Fraser Port Authority, Metro Vancouver and the Tsleil-Waututh Nation. Ten sites were sampled for mussels within Burrard Inlet in 2015 and 2016.

- Acenaphthene – The Port Moody site BI 1 (0.0016 µg/g) and Central Harbour site BI 3 (0.002 µg/g) had the highest concentrations of acenaphthene in mussel tissues.
- Anthracene – The Outer Harbour site (site 10) had the highest tissue concentration (0.0022 µg/g). The Port Moody site (BI 1) and the Central Harbour site (BI 3) also had high concentrations compared to the other sampled sites (0.0018 and 0.0015 µg/g, respectively).
- Benzo(a)pyrene - The north side of the Central Harbour (BI 3) had the highest concentration (0.0016 µg/g), which is below the most conservative benchmark of 0.0036 µg/g (Figure 9). The south side of the Outer Harbour (BI 10) also had a relatively high concentration of benzo(a)pyrene in mussel tissue (0.0009 µg/g). All samples were at least one order of magnitude higher than detection limits.

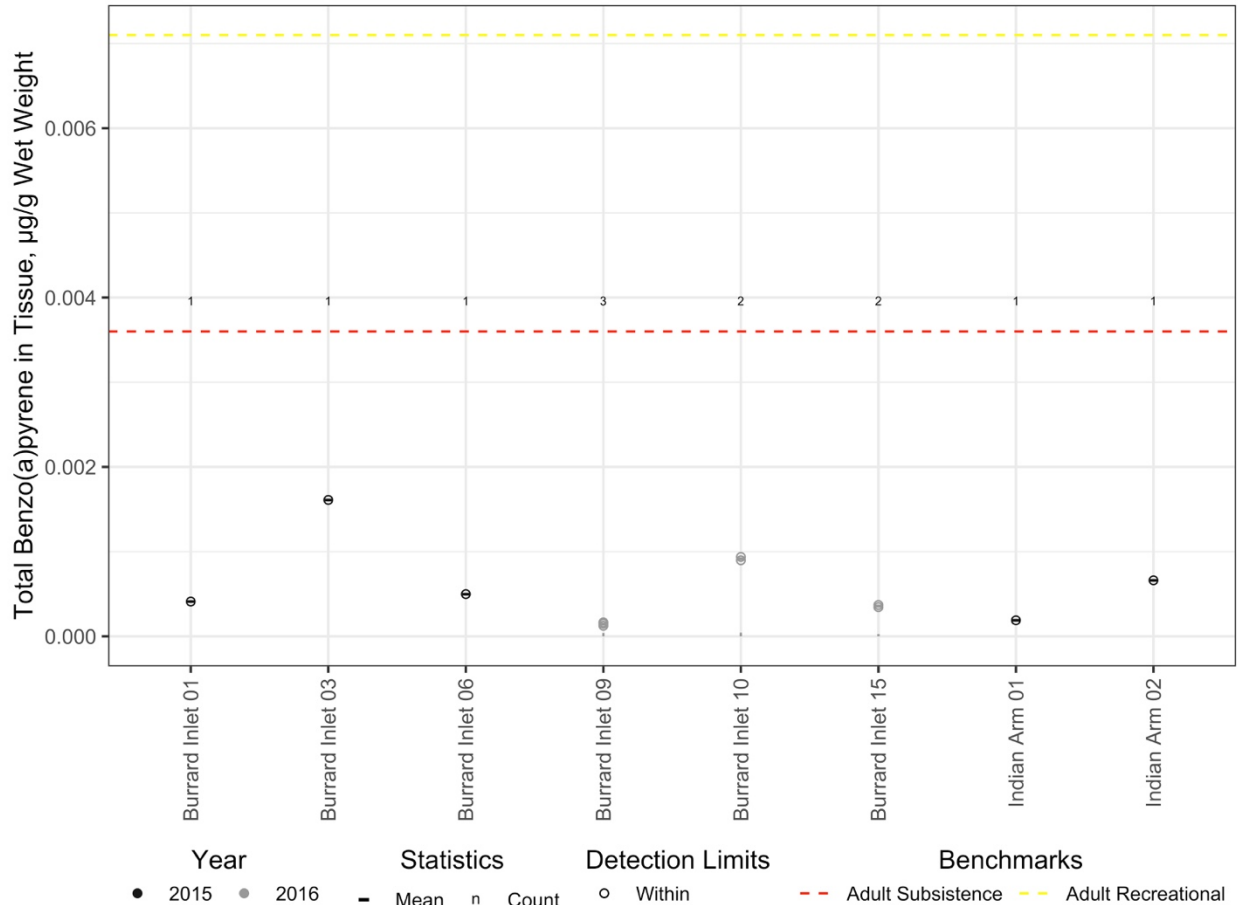


Figure 9. Benzo(a)pyrene levels in PollutionTracker blue mussel tissue samples (2015 to 2016) in µg/g

- Chrysene – Tissue concentrations were highest in the Central Harbour (BI 3: 0.0078 µg/g), followed by the Outer Harbour (BI 10: 0.0072 µg/g) and the south Indian Arm site (Indian Arm 2: 0.0069 µg/g).
- Fluoranthene – Concentrations in tissues were highest in Port Moody Arm (BI 1: 0.015 µg/g), the Central Harbour (BI 3: 0.014 µg/g), and at the southern Indian Arm site (Indian Arm 2: 0.014 µg/g).
- Fluorene – Tissue concentrations were highest at Port Moody site BI 1 and Central Harbour site BI 3 (0.0011 and 0.0012 µg/g, respectively).
- 2-methylnaphthalene - Tissue concentrations for 2-methylnaphthalene were highest at Outer Harbour site BI 6 (0.059 µg/g). Measured levels in the Central Harbour, Port Moody Arm and Indian Arm were 0.049 µg/g to 0.054 µg/g. These values do not approach the most conservative benchmark of 0.14 µg/g.
- Naphthalene – Tissue concentrations for naphthalene were highest at Outer Harbour site BI 15 (0.0023 µg/g). Other Outer Harbour sites (BI 9 and 10) also had relatively high tissue concentrations in relation to the rest of the sampled sites (0.00164 µg/g and 0.00169 µg/g, respectively). These values do not approach the most conservative benchmark of 0.7 µg/g.
- Phenanthrene – Concentrations of phenanthrene in tissues were highest at the Central Harbour site BI 3 (0.012 µg/kg), followed by the Outer Harbour site BI 10 (0.009 µg/g) and the Port Moody Arm site BI 1 (0.008 µg/g).

- Pyrene – Tissue concentrations for pyrene were highest at the southern Indian Arm site (0.0075 µg/g), while Port Moody Arm site BI 1 and Central Harbour site BI 3 had slightly lower concentrations (0.062 and 0.067 µg/g, respectively). These values do not approach the most conservative benchmark of 1.0 µg/g.

2007 – Metro Vancouver’s Burrard Inlet Ambient Monitoring Program (BIAMP)

- Metro Vancouver measured benzo(a)pyrene levels in English Sole muscle tissue samples in 2007. All values were measured below the detection limit of 0.02 µg/g. The detection limit for the analysis was significantly higher than the most conservative benchmark of 0.0036 µg/g.

3.4 Knowledge Gaps and Research Needs

The assessment of available PAH data, key monitoring programs, and previous reports identified the following knowledge gaps and research needs:

- Monitoring of PAHs in fish using detection limits that are below benchmark levels for human health screening.
- Monitoring of PAHs in fish and shellfish in Indian Arm, especially where PAHs may be introduced through sediment transport. PAHs are a potential concern to fishing and shellfish harvesting.
- Characterizing the effects of PAHs in sediments on fish, by exposing fish to individual PAHs and PAH mixtures at environmentally relevant concentrations (Government of Canada, 1994).
- Understanding interactions between co-contaminants and their effects on marine biota.
- Incorporation of phototoxicity into the development of PAH guidelines.
- Consideration of PAH mixtures during guideline development, as PAHs are likely to exist as mixtures in the marine environment.
- Development of PAH guidelines protective of marine mammals and other higher trophic level organisms.
- Estimation of PAH source volumes from recreational and non-commercial vessels, non-reported hydrocarbon spills and urban runoff.

4. PROPOSED OBJECTIVES FOR PAHS IN BURRARD INLET

4.1 Proposed Objectives

Proposed objectives for priority PAHs in Burrard Inlet are presented in Table 6. The water and sediment objectives are set to protect marine aquatic life. The tissue objectives are set to protect consumption of shellfish and finfish by individuals from a subsistence fishing population. The benzo(a)pyrene WQO should also be used as a benchmark to evaluate exposures to mixtures of carcinogenic PAHs by totaling their measured concentrations adjusted according to their potency equivalence factors (Health Canada 2021); see Table 7 for details. In addition to these numeric objectives, an overall objective is proposed for a decreasing trend in PAH concentrations in all media.

Table 6. Proposed Water Quality Objectives for PAHs

Priority PAHs	Proposed Objectives (all sub-basins)
Marine Water (µg/L, mean)¹	
Acenaphthene	6
Benzo(a)pyrene	0.01
Chrysene	0.1
Fluorene	12
Naphthalene	1
Sediment (µg/g dry weight, maximum for a single composite sample)²	
Acenaphthene	0.00671
Anthracene	0.0469
Benzo(a)pyrene	0.088
All benzo(a)fluoranthenes ³	2.3
Chrysene	0.108
Fluoranthene	0.113
Fluorene	0.0212
Naphthalene	0.0346
2-methylnaphthalene	0.02
Phenanthrene	0.0867
Pyrene	0.153
Tissue (µg/g wet weight, maximum for a single composite sample)^{4,5}	
Benzo(a)pyrene	0.0036
<p>¹ Based on a minimum of 5 surface samples in 30 days collected during the wet season.</p> <p>² Based on a minimum of 1 composite sample composed of at least 3 replicates.</p> <p>³ This objective applies to the sum of all benzo(a)fluoranthenes. Concentrations are expressed in terms of sediment containing 1% organic carbon. Adjustments to guidelines are required with different organic carbon content.</p> <p>⁴ The concentration not expected to cause adverse effects to human consumers, based on a composite sample consisting of at least 5 individual fish or 25 bivalves. See Rao et al. (in prep.) for additional guidance.</p> <p>⁵ The benzo(a)pyrene WQO provides a benchmark to evaluate exposures to mixtures of carcinogenic PAHs by totaling their measured concentrations adjusted according to their potency equivalence factors (Health Canada 2021). See text and Table 7 for details.</p>	

Table 7. Carcinogenic PAHs and their toxic equivalency factors to calculate B[a]P toxic equivalency concentration (from Health Canada 2021).

Carcinogenic PAH	Toxic Equivalence Factor (TEF)
anthracene	0.1
benzo(a)pyrene	1
benzo(a)anthracene	0.1
benzo(b)fluoranthene	0.1
benzo(g,h,i)perylene	0.01
benzo(k)fluoranthene	0.1
chrysene	0.01
dibenzo(a,h)anthracene	1
fluoranthene	0.001
indeno(1,2,3-cd)pyrene	0.1
phenanthrene	0.001

4.2 Rationale

These particular PAHs are included in the updated objectives because their concentrations in Burrard Inlet were above or approached the water, sediment or tissue benchmarks. Objectives are proposed for individual, rather than total, PAHs. Laboratory analyses for PAHs is typically done for specific PAHs and homologue groups and the PAHs analyzed may differ at each laboratory. Total PAHs are then reported out as the sum of these. PAHs also differ in their toxicities and warrant individual objectives (A. Tillmanns, BC ENV, pers. comm., June 2020).

The 1990 provisional objectives for PAH levels in Burrard Inlet sediments are not recommended for use going forward because the science on the effects of PAHs has progressed since 1990, the objectives were based on data from Puget Sound, and more current provincial working guidelines now exist. In addition, detection limits have improved since 1990, allowing for assessment of PAH levels at lower thresholds. For tissue, criteria for the protection of humans consuming fish and shellfish were developed by BC ENV (Nagpal, 1993) for benzo(a)pyrene only, but more recent toxicological information and human health risk assessment guidance from Health Canada is available (as described in Section 3.1), rendering those criteria out of date.

In Burrard Inlet, the proposed objectives for PAHs in marine water are the BC approved WQGs (BC ENV 2019b): acenaphthene 6 µg/L, benzo(a)pyrene 0.01 µg/L, chrysene 0.1 µg/L, fluorene 12 µg/L and naphthalene 1 µg/L, all means based on a minimum of 5 samples in 30 days collected during the wet season. Marine water quality guidelines were informed by Nagpal (1993), and limited by data availability. In marine water, the 2001 BC ENV water sampling program indicated that chrysene and benzo(a)pyrene concentrations were above the BC WQGs. These PAH guidelines were also exceeded at the False Creek and Port Moody (loco) sites.

The proposed sediment quality objectives for PAHs in Burrard Inlet are the BC working WQGs, since these guidelines are lower than the Burrard Inlet objectives of 1990 and are based on more recent data (CCME, 1999a). They are as follows: acenaphthene 0.00671 µg/g, anthracene 0.0469 µg/g, benzo(a)pyrene 0.088 µg/g, benzofluoranthenes 2.3 µg/g, chrysene 0.108 µg/g, fluoranthene 0.113 µg/g, fluorene 0.0212 µg/g, naphthalene 0.0346 µg/g, 2-methylnaphthalene 0.02 µg/g, phenanthrene 0.0867 µg/g and pyrene 0.153 µg/g, all dry weight, single sample maximums based on a minimum of one composite sample composed of at least 3 replicates. For benzo(k)fluoranthene, the BC WSQG (based on Washington State DoE, 2013) for all benzofluoranthenes is used as a recommended guideline. Review of the sediment data showed that sites in the Inner Harbour, Outer Harbour, and Port Moody Arm frequently exceeded the benchmarks for priority PAH compounds. The north Indian Arm site had the lowest PAH concentrations; possibly because it is geographically removed from many PAH sources.

Benchmarks protective of all marine biota are currently not available for PAHs, since the current benchmarks are only designed to protect invertebrates in contact with sediment, and do not consider bioaccumulation in fish or marine mammals.

The proposed objective for benzo(a)pyrene (a carcinogen) in fish and shellfish tissue is the updated calculated screening value for benzo(a)pyrene, 0.0036 µg/g wet weight, single sample maximum, based on a minimum of 1 composite sample composed of at least 10 specimens. This objective should also be used as a benchmark to evaluate exposures to mixtures of carcinogenic PAHs by totaling the concentrations of all carcinogenic PAHs sampled, with each adjusted according to their potency equivalence factors as provided in Table 7, and compared to the WQO for benzo(a)pyrene. For example:

If the benzo(a)pyrene concentration in fish or shellfish tissue was 1 µg/g,
benzo(k)fluoranthene was 4 µg/g, chrysene was 5 µg/g, and phenanthrene was 6 µg/g,

then the benzo(a)pyrene toxic equivalency concentration = $1 + (4 \times 0.1) + (5 \times 0.01) + (6 \times 0.001) = 1.456 \mu\text{g/g}$, which exceeds the proposed WQO (screening value) for benzo(a)pyrene in tissue (Thompson and Stein 2021).

Tsleil-Waututh Nation has a goal to obtain 10% of their diet from Burrard Inlet. A WQO is proposed for benzo(a)pyrene in tissue because its levels in blue mussel tissue samples measured by *PollutionTracker* in the Central Harbour approach the screening benchmark to protect individuals from a subsistence fishing population. The measured levels of other PAHs in tissue for which data were available (2-methylnaphthalene, naphthalene, and pyrene) were well below their screening benchmarks so it was not deemed useful to use those screening benchmarks to set objectives that would be well above measured values. Thus, WQOs for these and other PAHs in tissue are not proposed; instead, an overarching, qualitative objective is proposed as follows:

Concentrations of PAHs in sediment, water, and tissue should be reduced in Burrard Inlet to the greatest degree practical, to protect aquatic life and human consumers of fish and shellfish. An overall objective for a decreased trend in PAH concentrations in all media is proposed for this purpose. Furthermore, monitoring should continue for all PAHs in water, sediment and tissue because of the prevalence of PAH sources throughout the Inlet.

5. MONITORING RECOMMENDATIONS

Monitoring recommendations help refine the existing monitoring programs and inform future assessments to determine whether the PAHs objectives are attained. The following are recommendations for future PAH monitoring in Burrard Inlet:

- Conduct ongoing monitoring of all PAHs in water, sediment and tissue; compare results to the Burrard Inlet WQOs as per this document, or to BC water quality guidelines for PAHs that have not been assigned WQOs specific to Burrard Inlet. Additional WQOs may be established in future if PAH levels are observed to increase. In the absence of BC marine water quality guidelines for any PAH, comparisons can be made to available BC freshwater guidelines; marine and freshwater organisms are expected to respond similarly to non-polar organic substances (A. Tillmanns, BC ENV, *pers. comms.*, January 2021).
- Add the following to monitoring programs:
 - Conduct PAH sampling in water and sediment at sewage outflows, stormwater outfalls and around creosote-coated surfaces to assess their PAH contributions to levels in the Inlet.
 - Conduct PAH sampling in water and sediment near private marinas and fueling stations.
 - Currently, a new North Shore WWTP is being built to replace the existing Lions Gate WWTP and will provide tertiary treatment to North Shore communities (completion by 2024). Conduct monitoring of the WWTP effluent following this upgrade to determine its PAH contribution to the inlet.
 - Conduct further sampling for PAHs and metabolites in fish, as well as monitoring in clams, crabs and prawns from areas where harvesting occurs, or may occur in the future (assuming that laboratories are able to achieve lower detection limits in tissue).
 - Conduct monitoring of PAHs in water at ditches adjacent to railway and utility lines and assess their potential contributions to Burrard Inlet.

- Since PAH compounds are mostly found adsorbed to sediment or suspended particles, sediment transport patterns should be used to determine the best sampling locations. Port Moody Arm and Indian Arm are considered areas of net sediment deposition (McLaren, 1994), which may be a concern for aquatic species and for humans consuming fish and shellfish harvested from these areas.
- Further investigate the effects of PAHs on sediment-dwelling fish and invertebrate populations.
- Sample tissue in species that are preferred for human consumption, following guidance by TWN, and compare results to those in species used in monitoring programs to date.
- Ensure all monitoring data becomes open data and is made available to regulatory agencies, municipalities, and the public on timely basis.

6. MANAGEMENT OPTIONS

The following initiatives are planned or underway and will help reduce PAH levels in Burrard Inlet:

- Tsleil-Waututh Nation’s ongoing work to restore the health of the Inlet through implementation of the Burrard Inlet Action Plan.
- Continued advancement of strategies to reduce combined sewer overflows (CSOs). Separating combined sewers in the City of Vancouver and the City of Burnaby and implementing green infrastructure for rainwater retention and infiltration are two strategies that have demonstrated success and can decrease the amount of PAHs reaching marine species and habitats. In Metro Vancouver, combined sewer separation is in progress. Metro Vancouver’s strategy is to work with Burnaby and Vancouver to eliminate combined sewer overflows (CSOs) by 2050. CSO separation is a provincial goal, with each municipality working under the same target of 2050 in the Vancouver Sewerage Area (Metro Vancouver, 2017). The City of Vancouver has also developed ambitious goals for green infrastructure as part of their Rain City Strategy whose objectives include the removal of pollutants from water and air and reduction of the volume of rainwater entering the pipe system (City of Vancouver, 2019).
- Develop and implement Integrated Stormwater Management Plans (ISMPs) for all developed watersheds that flow into Burrard Inlet. The ISMPs will address erosion, drainage, flooding, stream health, and remediation of any potential water quality issues within watersheds. Under the federal Fisheries Act, Metro Vancouver and its member municipalities are not permitted to discharge stormwater that would negatively impact fish and their habitat. Metro Vancouver facilitates the Stormwater Interagency Liaison Group (SILG), which shares information on the development and implementation of each municipality’s stormwater management (Metro Vancouver, 2017).

The following management options that have the potential to further reduce anthropogenic sources of PAHs to Burrard Inlet are recommended for consideration, although this is not an exhaustive list of tools and actions:

- Limit oil tanker traffic to reduce the potential for an accident/malfunction and potential contribution of PAHs to Burrard Inlet.
- Reduce large vessel wakes to reduce the effects of sediment re-suspension, and possible remobilization of PAHs into the water column.

- Increase oversight and monitoring of unreported oil and fuel spills in Burrard Inlet. Currently, Transport Canada, under the Canadian Shipping Act requires the reporting of any accidental discharge of deleterious substances (including oil and fuel).
- Motorized vehicle reduction strategies, including encouraging the use of active transportation, public transit and electric-powered vehicles (private and commercial) to decrease atmospheric inputs of PAHs to Burrard Inlet.
- Ensure land use planning includes improvements to rainwater management such as plant based bio-filtration and other green infrastructure to improve rainwater quality as a goal for all urban areas.
- Reduce impervious surfaces in the Burrard Inlet watershed.
- Limit or ban the use of creosote pilings in Burrard Inlet.
- Implement green infrastructure measures and other upland improvements to reduce entry of PAHs into marine waters via stormwater. For example, require stormwater mitigations as part of new projects, and regular cleanout of catch basins and testing of the material for leachability (e.g. Greenland 1999), for example through inclusion in ISMPs.
- Develop benchmarks for PAHs and PAH mixtures that are protective of higher trophic levels including Southern Resident Killer Whales.

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APPENDIX A: HEAT MAP ILLUSTRATIONS OF PAH LEVELS IN BURRARD INLET SEDIMENT AND TISSUE

(provided as a separate document)