# Sediment Toxicity
# of
# Petroleum Hydrocarbon Fractions

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## EXECUTIVE SUMMARY

There is a recognized need by regulatory agencies, such as the Massachusetts Department of Environmental Protection (MADEP) for the development of petroleum cleanup goals in sediment that are protective of aquatic receptors. This is due to the close proximity of many petroleum-contaminated sites to marine or fresh surface waters where petroleum products that have been released to the environment may reach the surface water and sediment, adversely affecting aquatic receptors. The first step toward developing cleanup goals is identifying toxicity-based sediment benchmarks.

The proposed approach for the development of sediment benchmarks is based on a methodology that divides the individual hydrocarbons from petroleum into several classes or groupings of compounds referred to as fractions, with similar chemical and toxicological properties. Four aliphatic and four aromatic fractions were chosen for the development of sediment benchmarks for the protection of aquatic receptors. Current MADEP analytical methods for petroleum in sediments, however, divide the hydrocarbons into different fractions based on human health risk. It is recommended that the existing MADEP methods be closely reviewed and method modifications be considered and evaluated, which will enable revised versions of those methods to be applied to sediment characterization for ecological risk.

The approach described in this report for estimating the acute and chronic toxicity of hydrocarbon fractions to aquatic organisms is based on equilibrium partitioning (EqP) theory. This theory states that the toxicity of hydrocarbons in sediments to benthic organisms is caused by the hydrocarbons that partition from the organic fraction of sediment particles into porewater and from porewater into the tissues of sediment-dwelling organisms. Both bioaccumulation and toxicity of hydrocarbons increase as the octanol-water partition coefficient ($K_{ow}$) of the hydrocarbon increases. A regression of toxicity data versus Log $K_{ow}$ produces a straight line from which toxicities of other hydrocarbons can be estimated if their Log $K_{ow}$s are known. Using the final chronic aquatic toxicity value, the sediment organic carbon/water partition coefficient ($K_{oc}$), and the fraction of organic carbon in sediment, equilibrium partitioning sediment benchmarks were derived for the four aliphatic and four aromatic hydrocarbon fractions of petroleum (Table ES-1). For comparison, sediment benchmarks were also derived based on the carbon fractions currently used by MADEP (Table ES-2).

**Table ES-1. Sediment Benchmarks for Recommended Petroleum Hydrocarbon Fractions**

| Hydrocarbon Fraction | Geometric Mean Log $K_{ow}$ | $K_{oc}$ | Final Chronic Value (µg/L) | Sediment Benchmark (mg/kg oc) | Sediment Benchmark ($f_{oc}$ = 0.001) (mg/kg) |
|---|---|---|---|---|---|
| *Aliphatic Hydrocarbons* | | | | | |
| $C_5 - C_8$ | 4.12 | $7.24 \times 10^3$ | 218 | 1591 | 1.59 |
| $C_9 - C_{12}$ | 6.01 | $4.37 \times 10^5$ | 6.3 | 2722 | 2.72 |
| $C_{13} - C_{18}$ | 8.57 | $1.10 \times 10^8$ | 0.05 [a] | 5543 | 5.54 |
| $C_{19} - C_{36}$ | 11.64 | $8.32 \times 10^{10}$ | 0.0001[a] | 9883 | 9.88 |
| *Aromatic Hydrocarbons* | | | | | |
| $C_6 - C_8$ | 2.82 | $4.47 \times 10^2$ | 1191 | 531 | 0.53 |
| $C_9 - C_{12}$ | 3.94 | $4.90 \times 10^3$ | 46.2 | 228 | 0.23 |
| $C_{13} - C_{15}$ | 4.67 | $2.40 \times 10^4$ | 5.2 | 125 | 0.13 |
| $C_{16} - C_{24}$ | 5.9 | $3.39 \times 10^5$ | 0.12[a] | 40 | 0.04 |

[a] The fraction is not likely toxic because mean $LC_{50}$ exceeds mean aqueous solubility.

**Table ES-2. Sediment Benchmarks for Current MADEP Petroleum Hydrocarbon Fractions**

| Hydrocarbon Fraction | Geometric Mean Log $K_{ow}$ | $K_{oc}$ | Final Chronic Value (µg/L) | Sediment Benchmark (mg/kg oc) | Sediment Benchmark ($f_{oc}$ = 0.001) (mg/kg) |
|---|---|---|---|---|---|
| *Aliphatic Hydrocarbons* | | | | | |
| $C_5 - C_8$ | 4.12 | $7.24 \times 10^3$ | 218 | 1591 | 1.59 |
| $C_9 - C_{18}$ | 7.32 | $7.41 \times 10^6$ | 0.4 | 3167 | 3.17 |
| $C_{19} - C_{36}$ | 11.64 | $8.32 \times 10^{10}$ | 0.0001[a] | 9883 | 9.88 |
| *Aromatic Hydrocarbons* | | | | | |
| $C_9 - C_{10}$ | 3.84 | $3.98 \times 10^3$ | 59.4 | 236 | 0.24 |
| $C_{11} - C_{22}$ | 4.81 | $3.31 \times 10^4$ | 2.8 | 92 | 0.09 |

[a] The fraction is not likely toxic because mean $LC_{50}$ exceeds mean aqueous solubility.

Various uncertainties in using the equilibrium partitioning approach to develop sediment benchmarks for petroleum are presented. These include the various methods for estimating $K_{ow}$ and the resulting $K_{ow}$ values; the limited amount of toxicity data for aliphatic hydrocarbons; the wide range of aromatic hydrocarbon toxicity data for both marine and freshwater species, as well as various test durations; and the selection of the most appropriate application factor, which is applied to account for differences in acute and chronic toxicity values and species sensitivity. These uncertainties were addressed in an appropriately conservative manner consistent with previous work by Hansen et al. (2003), DiToro et al. (1991), Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) (1997), and the European Community (EC) (2003).

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACR | acute-to-chronic ratio |
| AF | application factor |
| BTEX | benzene, toluene, ethylbenzene, xylene |
| EC | European Community |
| ECETOC | European Center for Ecotoxicology and Toxicology of Chemicals |
| EPH | extractable petroleum hydrocarbons |
| EqP | equilibrium partitioning |
| ESB | equilibrium partitioning sediment benchmark |
| FACR | final acute-to-chronic ratio |
| FCV | final chronic value |
| $f_{oc}$ | fraction of organic carbon in sediment |
| GC/FID | gas chromatography/flame ionization detection |
| GC/MS | gas chromatography/mass spectrometry |
| IR | infrared spectroscopy |
| $K_{oc}$ | organic carbon-water partition coefficient |
| $K_{ow}$ | octanol-water partition coefficient |
| $LC_{50}$ | lethal concentration required to cause mortality to 50% of test organisms |
| LOEC | lowest observed effect concentration |
| MADEP | Massachusetts Department of Environmental Protection |
| mg/L | milligrams per liter |
| mM/L | millimoles per liter |
| NAPL | non-aqueous phase liquid |
| NOEC | no observed effect concentration |
| PAH | polycyclic aromatic hydrocarbon |
| PID | photoionization detection |
| ppb | parts per billion |
| TPH | total petroleum hydrocarbons |
| TPHCWG | Total Petroleum Hydrocarbon Criteria Working Group |
| TPH-d | TPH-diesel range |
| TPH-g | TPH-gasoline range |
| TPH-r | TPH-residual range |
| µg/L | micrograms per liter |
| US | United States |
| USEPA | United States Environmental Protection Agency |
| UST | underground storage tank |
| VPH | volatile petroleum hydrocarbons |

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# 1.0 INTRODUCTION

Products derived from refining of crude oil are among the most abundant consumer products in the world. The average consumption of crude oil in the United States (U.S.) is about 714 million gallons/day (Minerals Management Service, 1991; Beck, 1996). About two-thirds of the total crude oil is refined for use as fuel in land vehicles, airplanes, and ships. The consumption of automotive gasoline is approximately 327 million gallons/day (Beck, 1996). About 190 million gallons/day of middle distillate fuels (jet fuel, kerosene, diesel fuels, and home heating oils) and about 48 million gallons/day of residual oil (bunker fuels) are consumed in the U.S. The remainder of the crude oil consumed each day is used for other non-fuel distillate (*e.g.*, lubricating oils) and residual products (*e.g.*, road asphalt), as well as feed stocks for the petrochemical industry.

A small fraction of the petroleum products consumed in the U.S. is released to land, either accidentally or intentionally. Release of refined oils, particularly gasoline, from leaking underground storage tanks (USTs) is the most widely recognized source of petroleum contamination of soils and groundwater (Dowd, 1984; Murphy et al., 1987). Refined oil products also may be released to the land from leaky pipes, during transfer to and from storage tanks, by application of waste oil to dirt roads to control dust, and by land disposal of waste crankcase and other oil products.

It was recognized in the 1970s and 1980s that petroleum hydrocarbons can migrate from petroleum-contaminated soils and adversely affect terrestrial and aquatic ecosystems and humans. Existing cleanup goals for petroleum in soil and groundwater focus on the protection of human health. Because of the close proximity of many petroleum-contaminated sites to marine or fresh waters, the potential exists for petroleum products that have been released to the environment to reach the surface water and adversely affect aquatic receptors. Appropriate cleanup goals need to be established for petroleum hydrocarbons in sediments before remedial actions can be initiated. The level (hydrocarbon concentration) to which a site's sediment must be cleaned should be set low enough to protect the environment, but not necessarily to represent pristine conditions. Certainly, these cleanup goals must be acceptable and consistent with State and Federal environmental regulations.

## 1.1 Objectives

Oil contamination is being recognized with increasing frequency as a major contributor to the hazard to aquatic life in contaminated sediments, particularly in areas of intense anthropogenic activity (Neff, 1979; 2002). However, because refined petroleum products are complex variable mixtures of hundreds or thousands of organic chemicals, it has been extremely difficult to develop cleanup benchmarks for total petroleum hydrocarbon (TPH)[1] concentrations in sediments that are acceptable to both regulatory agencies and regulated entities. Consequently, there is a recognized need by regulatory agencies, such as the Massachusetts Department of Environmental Protection (MADEP) for the development of petroleum cleanup goals that are protective of aquatic receptors. Thus, the intent of this report is to develop scientifically defensible, risk-based cleanup levels for petroleum for the protection of aquatic receptors by incorporating and modifying applicable elements of current scientific approaches from Hansen et al. (2003), DiToro et al. (1991), and the Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) (1997).

[1] TPH is a generic term used to define the sum of hydrocarbon concentrations occurring in crude and refined petroleum that yield a positive hydrocarbon signal when analyzed by a specific analytical method.

## 1.2 Petroleum Hydrocarbons

### 1.2.1 Composition

Crude petroleum is an extremely complex mixture of fossil material, primarily of plant origin (Speers and Whitehead, 1969). It contains thousands of organic, and a smaller number of inorganic, compounds. Crude oils vary tremendously in chemical composition, in relative concentrations of different chemicals, and in physical properties; no two are alike. Crude oils are refined to produce a wide variety of refined and residual products, mostly fuels that contain a smaller number of chemicals that are usually within a defined boiling point range.

A particular crude oil may contain organic compounds ranging in molecular weight from methane (molecular weight 16), a gas at room temperature and pressure, to complex polymeric structures, such as asphaltenes with molecular weights up to at least 100,000 (Kallio, 1976). Hydrocarbons, organic chemicals composed solely of carbon and hydrogen, are by far the most abundant chemicals in crude and refined oils. Variable amounts of organic chemicals containing sulfur, nitrogen, or oxygen also are present in all crude and some refined oils.

The hydrocarbons in petroleum are aliphatic (saturated), aromatic (unsaturated), or a combination of both (Figure 1). Aliphatic hydrocarbons, also called alkanes or paraffins, are composed of chains of carbon atoms linked by single covalent bonds. Chemical bonds not occupied by carbon-carbon bonds are occupied by hydrogen atoms. Aliphatic hydrocarbons in petroleum may be normal (a linear chain), branched, or cyclic. They may range in size from methane ($CH_4$) to at least $C_{78}$ (a chain of 78 carbons). Some refined oils, particularly light fuels, such as gasoline and kerosene, may contain olefins (aliphatic hydrocarbons containing one or more carbon-carbon double, or occasionally triple bonds) generated during the refining process. Olefins usually represent less than a few percent of the hydrocarbons in fuels.

Aromatic hydrocarbons in petroleum are composed of one or more benzene rings, a six-carbon ring containing nine equally shared carbon-carbon covalent bonds. Each carbon atom in benzene is bonded to one hydrogen atom, which can be substituted by a methyl ($-CH_3$), ethyl ($-CH_2-CH_3$), or longer-chain aliphatic group(s) called an alkyl group(s). Benzene and alkyl benzenes with one or two methyl or ethyl groups (toluene, ethylbenzene, and *m*-, *p*-, and *o*-xylene) are the most abundant aromatic hydrocarbons in most crude and refined oils.

Benzene may be linked to other benzene molecules by single covalent bonds to form compounds such as biphenyl and terphenyl. More frequently, two or more benzenes are fused (sharing two carbons) to form polycyclic aromatic hydrocarbons (also called polynuclear aromatic hydrocarbons [PAHs]) (Neff, 1979). Naphthalene, composed of two fused benzene rings, has a molecular weight of 128.2 and is the smallest PAH. Coronene, with six condensed, fused rings and a molecular weight of 300.3 is the highest molecular weight PAH considered to have sufficient environmental mobility (aqueous solubility of approximately 0.1 μg/L: parts per billion [ppb]) to be potentially toxic.

A large number of products, mostly fuels, are produced from crude oil by refining. Refining involves distillation to isolate oil fractions containing hydrocarbons with different boiling points and stimulation of chemical reactions that convert hydrocarbons in the fractions from one form to another. Refined oil products include gasoline and middle distillate fuels, such as diesel fuel, jet fuel, kerosene, and home heating oil. The petroleum fraction remaining after removal of light and middle distillate fractions is called residual oil, which is used to fuel ships and power plants (bunker fuel) or to produce road paving asphalt. Lubricating oils and petroleum tars also are

made from residual oil. Refined and residual petroleum products contain all the chemical classes present in crude petroleum, as well as some compounds produced during refining or added to the finished product to improve its properties (Nyer and Skladany, 1989; King, 1992). Each refined or residual product contains primarily crude oil chemicals over a specified boiling point range. Gasoline has an approximate boiling point range from 40 to 205°C; middle distillate fuels have an approximate boiling point range between 175 and 375°C; residual fuel oils are blended from crude oil fractions generally boiling between about 350 and 700°C.

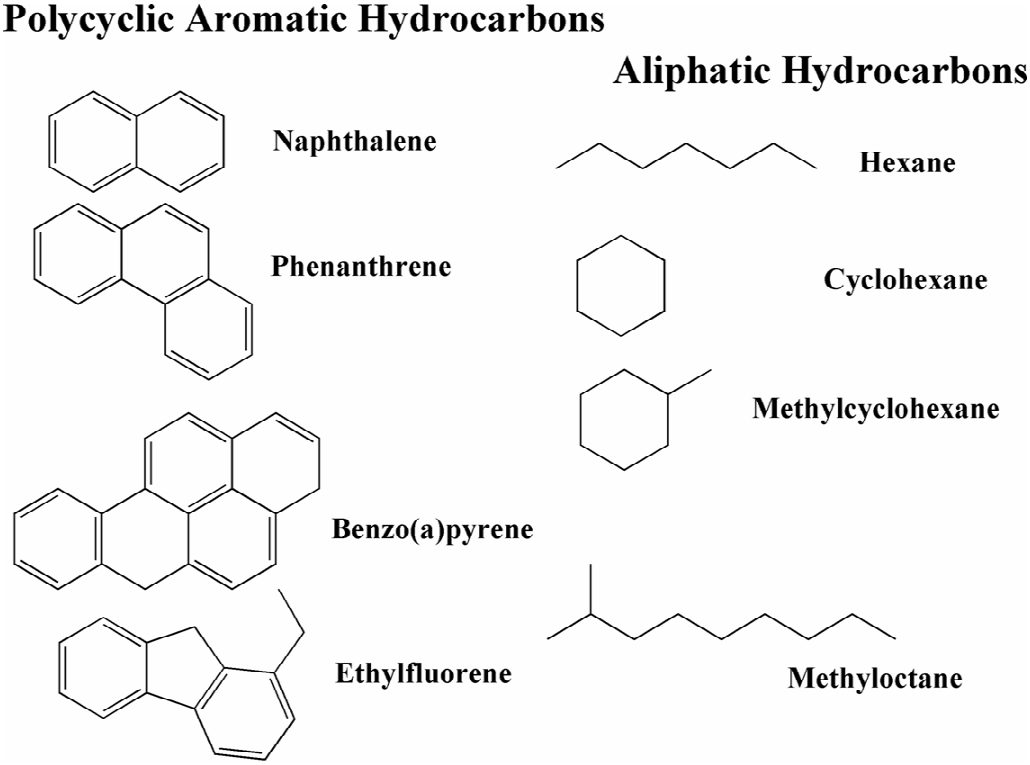


**Figure 1. Molecular Structure of Several Aromatic and Aliphatic Hydrocarbons Found in Petroleum.**

### 1.2.2 Fractionation

Crude and refined petroleum contain hundreds (gasoline) to thousands (middle and heavy fuels and crude oil) of hydrocarbons and related organic compounds that vary widely in persistence in the environment and toxicity. The relative concentrations of different hydrocarbons vary widely in different crude, refined, and residual oil products and hydrocarbon composition changes rapidly following release to the environment (see Section 2.1.1). Therefore, estimation of ecological risk of petroleum products in sediments and groundwater, based on a single TPH value, is an over-simplification, and often contributes to large errors in the risk estimation. Determining risk based on the concentrations of the tens and possibly thousands of individual hydrocarbons in the petroleum contamination is overly complex and costly. The proposed approach for development of sediment cleanup goals is based on a methodology that divides the hydrocarbons into several classes or groupings of compounds referred to as fractions, with similar chemical and toxicological properties. This greatly improves the ability to more accurately

estimate the potential for ecological risk of the weathered petroleum product in sediments and groundwater, compared to a method based only on TPH data.

As a general rule, the aqueous solubility of hydrocarbons decreases and aquatic toxicity increases with increasing molecular weight (number of carbons). Aliphatic hydrocarbons have a lower solubility and toxicity than aromatic hydrocarbons with the same number of carbons. Thus, for risk assessment, the aliphatic and aromatic hydrocarbons in oil-contaminated environmental samples can be divided into several fractions, each covering a limited range of carbon numbers with similar solubility and toxicity. Each fraction, except for the two largest carbon-number fractions, contains hydrocarbons with a small carbon-length range so that the hydrocarbons in each fraction will have a small range of physical/chemical properties and toxicity. Four aliphatic and four aromatic fractions were recommended and used in this method for the development of sediment benchmarks for the protection of aquatic receptors. Table 1 presents the recommended fractions for this method as well as the current MADEP fractions used to characterize human health risk.

**Table 1. Comparison of Different Hydrocarbon Fractions to Characterize Risk**

| **Aliphatic Hydrocarbons** | | **Aromatic Hydrocarbons** | |
|---|---|---|---|
| ***Recommended Fractions*** | ***Current MADEP Fractions*** | ***Recommended Fractions*** | ***Current MADEP Fractions*** |
| $C_5$-$C_8$ | $C_5$-$C_8$ | $C_6$-$C_8$ (Benzene, Toluene, Ethylbenzene, Xylene)[a] | |
| $C_9$-$C_{12}$ | $C_9$-$C_{18}$ | $C_9$-$C_{12}$ | $C_9$-$C_{10}$ |
| $C_{13}$-$C_{18}$ | | $C_{13}$-$C_{15}$ | $C_{11}$-$C_{22}$ |
| $C_{19}$-$C_{36}$ | $C_{19}$-$C_{36}$ | $C_{16}$-$C_{24}$ | |

[a] The BTEX compounds (which are $C_6$ through $C_8$ aromatic compounds) are not recommended for standard ecological risk assessment of sediments, but may be considered for contaminant characterization on a case-by-case basis. When characterized, it is recommended that the BTEX compounds, because of their high volatility, be determined by specific methods, and not $C_6$ through $C_8$ aromatics as a general fraction.

The recommended fractions in Table 1 group hydrocarbons having similar chemical characteristics and abundance in petroleum, similar toxicities to aquatic organisms, and similar physicochemical properties related to fate and transport. The $C_9$-$C_{12}$ aromatic fraction contains naphthalene ($C_{10}$) and mono-methyl- and dimethyl-naphthalenes ($C_{11}$ and $C_{12}$); the $C_{13}$-$C_{15}$ aromatic fraction contains fluorene ($C_{13}$), methylfluorene ($C_{14}$), phenanthrene/anthracene ($C_{14}$), methyl phenanthrene/anthracene ($C_{15}$), and tri- and tetra-methyl naphthalenes. The high molecular weight $C_{16}$-$C_{24}$ aromatic fraction contains four- and five-ring PAHs, including fluoranthene/pyrene ($C_{16}$) and higher molecular weight parent (unalkylated) and akylated PAHs, including the carcinogen, benzo(a)pyrene ($C_{20}$). The highest molecular weight PAHs in the $C_{16}$-$C_{24}$ aromatic fraction have such low solubility that they have low mobility in sediments and porewater.

The fractions recommended for this method are similar to the fractions recommended by the TPHCWG (1997) and MADEP (2002) to estimate human health risks of TPH in sediments, with minor changes. The aromatic $C_{11}$-$C_{22}$ fraction recommended by MADEP is large and includes hydrocarbons from methyl-naphthalene to dibenz(a,h)anthracene. For this method, this fraction has been divided into two fractions, $C_{13}$-$C_{15}$ and $C_{16}$-$C_{24}$ (Table 1), based on the observation that saturated aqueous solutions of aromatic hydrocarbons larger than fluoranthene ($C_{16}$) have such low aqueous solubilities that they may not be acutely toxic to aquatic organisms (Di Toro et al., 2007).

Furthermore, the relatively volatile, and generally more water soluble aromatic compounds (such as benzene, toluene, ethylbenzene, and xylenes [BTEX]) are quite mobile in aquatic environments and are not expected to accumulate in sediments to concentrations that would pose a significant ecological risk. Aliphatic hydrocarbons in the $C_5$-$C_8$ aliphatic fraction have higher $K_{ow}$ values (are less soluble) than aromatic hydrocarbons in the $C_6$-$C_9$ fraction, but are more biodegradable, reducing their persistence in sediments. However, the light aliphatic hydrocarbons in the $C_5$-$C_8$ and $C_9$-$C_{12}$ fractions are sufficiently soluble that they probably contribute to the toxicity of sediments contaminated with light and middle distillate fuels, which almost always contain much higher concentrations of aliphatic than aromatic hydrocarbons, unless the light aliphatic hydrocarbons have been depleted by weathering (Neff et al., 2000). The high molecular weight aliphatic hydrocarbons (aliphatic fractions $C_{13}$-$C_{18}$ and $C_{19}$-$C_{36}$) have such low solubilities and high log $K_{ow}$s (7.2 – 13.07) that they have a high affinity for the sediment organic carbon phase or oil phase in the sediments and little partitions into the water phase where it can be bioconcentrated by aquatic organisms. Thus, the high molecular weight aliphatic hydrocarbons probably do not contribute significantly to the chemical toxicity of oil-contaminated sediments.

### 1.2.3 Analytical Methods

Analytical methods available to quantify TPH in soils, sediments, and water include solvent extraction/gravimetry, infrared spectroscopy (IR), immunoassay, and gas chromatography/flame ionization detection (GC/FID). TPH is comprised of aliphatic and aromatic hydrocarbons, as well as other non-polar organic compounds in petroleum; a number of non-petroleum organic compounds may also contribute to the measured value, depending on the specificity of the method. The methods give different results for TPH in soils, sediments, and water, because they measure different groups of petroleum hydrocarbons and are subject to interferences from non-petroleum organic compounds, such as biogenic hydrocarbons, lipids, and waxes from decaying plant and microbial matter and other types of organic chemicals frequently found in soils, sediments, and groundwater. Depending on the physical and chemical properties of the environmental samples and the objectives of the analysis (quantitative for screening or qualitative and quantitative to support a risk assessment), the analytical measurement approach has a profound effect on the biases (over- or under-estimation of the true petroleum concentration) associated with the generated results. Because of the limitations of all the TPH analytical methods, there is a danger of making a risk-based decision with inaccurate or less-than-adequate information.

To remove some of the inherent problems, a first-level evaluation/interpretation of sample composition is critical. Interpretive errors commonly occur when a naturally occurring biogenic hydrocarbon signature (either as the sole hydrocarbon or in a mixed hydrocarbon assemblage) or a non-hydrocarbon present in the sample is mistakenly identified as part of a petroleum hydrocarbon mixture. All the methods tend to overestimate the true TPH concentration in environmental samples. There are many classic examples of “mistaken identity” in reports of TPH in soils, sediments, and water.

Gravimetry, IR, and immunoassay methods for TPH are not qualitative (they do not identify individual hydrocarbons) and, therefore, have limited applicability in risk assessment. Therefore, this discussion will focus on quantifying and characterizing TPH in environmental matrices by GC/FID. The four analytical methods for TPH analysis differ in ease and speed of performance, cost, and types and quality of results obtained. Another method, based on temperature-programmed capillary column gas chromatography with analyte identification and quantification by mass spectrometry (GC/MS), is the best method for differentiating between petroleum-derived and other (mostly biogenic or combustion sourced) hydrocarbons in environmental samples. However, because of its technical difficulty and high cost, it is rarely used in assessments at sites where TPH is the primary driver. GC/MS is particularly useful for analyzing specific compounds or classes of compounds, such as aromatic hydrocarbons. A high quality GC/FID is generally the preferred analytical approach for determining saturated hydrocarbons and TPH, as discussed below.

#### *1.2.3.1 USEPA Method 8015*

Gas chromatography methods, particularly USEPA Method 8015 modified for hydrocarbon analysis, are generally preferred for measuring bulk petroleum in environmental samples, and specifically saturated hydrocarbons. This is because of their specificity in product identification if most interferences are removed by suitable cleanup methods, and because of their greater accuracy than gravimetric and IR methods in quantification of petroleum hydrocarbons. Method 8015 uses GC/FID for the determination of TPH. This method is the most commonly used tool for the analysis of TPH in environmental samples. The technique is capable of measuring a wide range of hydrocarbon classes, from approximately $C_6$ through $C_{44}$ (when optimized), although the reliability is lower for compounds with a molecular weight of less than $C_9$[2]. The strength of the method is that it is both quantitative and qualitative and can therefore be used in risk assessments.

Method 8015 is used routinely as a first-level identification of both product type and weathering state. The GC/FID method is used to quantify different types of refined and residual petroleum in environmental samples, including TPH-gasoline range (TPH-g), TPH-diesel range (TPH-d), and TPH-residual range (TPH-r). These types of hydrocarbon assemblages are based on quantification of the area under chromatographic peaks in a certain segment of the gas chromatogram corresponding to hydrocarbons of a defined carbon number and boiling point range. The area under the chromatogram (including both aromatic and aliphatic hydrocarbons) between $C_6$ and $C_{10}$ is defined as TPH-g; the area under the chromatogram between $C_{10}$ and $C_{24}$ is defined as TPH-d; and the area under the chromatogram $>C_{24}$ is defined as TPH-r.

Method 8015 is susceptible to misinterpretations of the chromatographic results, especially by inexperienced chemists. These misinterpretations can have dramatic effects on results of a site assessment or risk assessment. For example, unnecessary site cleanups of sediments have been performed due to the misinterpretation of chromatograms because the GC/FID signature of sediment often closely resembles that of a weathered fuel oil #6. Other common misinterpretations involve misidentification of biogenic materials, including some coals and some plant organic material containing high molecular weight components, such as plant waxes.

Unless rigorous cleanup of the sample extract is performed before analysis by GC/FID (not specifically required by USEPA), Method 8015 may give erroneously high values for TPH, due to interference from oil microdroplets (frequently neither in solution nor water soluble) or co-extracted non-hydrocarbon chemicals in the samples (Zemo, 1997). Interfering non-hydrocarbon

[2] The $C_6$-$C_8$ (BTEX) compounds are best analyzed by a purge and trap technique, with the instrument fitted with an MS rather than an FID for greatest reliability.

compounds may co-elute from the GC column with hydrocarbons and be quantified as part of one of the petroleum product classes. Method 8015 provides tremendous flexibility for analytical laboratories with regard to the actual GC conditions for the analysis. To expedite analysis time, high GC oven rates often are used, resulting in poor resolution of compounds and a greater propensity to misidentify non-hydrocarbons as hydrocarbons.

Method 8015 is used in most remedial investigations and risk assessments at petroleum-contaminated sites in the U.S. The method can provide useful data if its limitations are clearly understood; with proper extract preparation, GC analytical conditions, and interpretation, Method 8015 can be adequate for TPH.

#### *1.2.3.2 MADEP EPH and VPH Method Adoption and Recommendations*

The proposed analytical method for petroleum hydrocarbons will, as much as possible, be based on the analytical approach described in the MADEP method documents *Method for the Determination of Extractable Petroleum Hydrocarbons (EPH)* and the *Method for the Determination of Volatile Petroleum Hydrocarbons (VPH)* (MADEP, 2004a;b). The MADEP EPH method may be considered a modified version of EPA Method 8015, because it is a GC/FID based analysis of extractable petroleum hydrocarbons. The MADEP VPH method is also GC/FID based (in conjunction with photoionization detection [PID]). However, the MADEP methods are notably enhanced from the USEPA method by employing a fractionation scheme for separating the petroleum hydrocarbons into multiple aliphatic and aromatic molecular size and boiling point fractions prior to final determination on the analytical instrument. This generates additional information for improved risk analysis and other site cleanup decisions. The MADEP methods are also enhanced by including better sample purification methods than those described in Method 8015, which results in more specific and reliable data.

Currently, in the MADEP methods, the hydrocarbon fractions span a wide range of carbon numbers and physical/chemical and toxicological properties. The fractions recommended in this guidance are somewhat similar to the fractions already used by MADEP in soil assessment (*Characterizing Risks Posed by Petroleum Contaminated Sites: Implementation of MADEP VPH/EPH Approach MADEP, October 31, 2002*), which are generated using the MADEP EPH and VPH analytical methods. However, the carbon fractions described in this document have been modified to be more appropriate for the management of petroleum risk in aquatic sediment, and, consequently, the MADEP EPH and VPH analytical methods cannot be directly applied.

A review of the recommended fractionation scheme in Table 1, and the fractions described in the referenced MADEP analytical method and risk characterization documents, indicates some overlap, particularly with the aliphatic hydrocarbons, and some components with less in common. It is recommended that the existing MADEP methods be closely reviewed and method modifications be considered and evaluated, which will enable revised versions of those methods to be applied to sediment risk characterization. Method modifications that are recommended should be considered for evaluation, and a revised method should be incorporated if methods are successful. Recommendations include the following:

- Concurrent analysis of the three aromatic fractions ($C_9$-$C_{12}$, $C_{13}$-$C_{15}$, and $C_{16}$-$C_{24}$) as part of a revised EPH method.
- Concurrent analysis of the three highest molecular weight aliphatic fractions ($C_9$-$C_{12}$, $C_{13}$-$C_{18}$, and $C_{19}$-$C_{24}$) as part of a revised EPH method.
- The aliphatic $C_5$-$C_8$ would still require the VPH analysis. However, we recommend that the inclusion of this fraction be considered on a site-by-site basis, and, if appropriate, be

excluded from the chemical analysis and risk characterization. The elimination of $C_5$-$C_8$ aliphatic fraction would mean sampling and analytical cost savings, since this fraction would require separate handling and analysis.

- It is recognized that there would likely be greater loss of the $C_9$-compounds than most other compounds, using a revised EPH method that would include the $C_9$s. However, it is expected that these compounds will contribute less to the risk, on a relative basis, than the other measured petroleum related compounds, and the benefit of incorporating the $C_9$s into the first fraction of a revised EPH method would likely outweigh the drawbacks.

The suggested method revisions will require method development and validation work by a laboratory experienced in developing and modifying analytical methods. Further adjustments to these initial technical assumptions may be required, based on the outcome of the initial method development and validation work. A revised analytical method would then be written. MADEP may then wish to conduct a round robin study, as part of a method validation and refinement process, and then finalize the method.

Although analytical methodology changes are needed to fully support the ecological risk assessment objectives of this project, the method modifications will likely not be substantial from a technical perspective. It is anticipated that the new method can be based on the existing MADEP method(s), with some potential modifications to components such as (1) solvent elution of chromatography columns, (2) sample extract concentration temperatures and techniques, (3) GC temperature program, and (4) selection of compounds for fraction markers. It is also anticipated that any laboratories that are currently employing the MADEP VPH and EPH methods will be able to master the new method developed for the ecological risk assessment of sediments.

# 2.0 CONCEPTUAL SITE MODEL

## 2.1 Fates of Petroleum Products

Following release to the environment, refined and residual petroleum products may accumulate in soils and sediments where they undergo several dispersal and weathering processes that affect the composition and toxicity of the hydrocarbon mixtures (Neff et al., 1994). The most important weathering processes for refined and residual petroleum include dispersion, evaporation, dissolution, and biodegradation.

When released in large volumes to aquatic environments and sediment, refined and residual petroleum products tend to retain their identity as a separate oil phase (*i.e.*, nonaqueous-phase liquid [NAPL]). The rate and extent of migration of a NAPL into and through soil, sediment, and groundwater depends on the viscosity, density, and interfacial tension of the oil, and the permeability and porosity of the medium (Sale et al., 1992).

Volatile hydrocarbons, such as those in the lowest carbon fractions of aliphatic and aromatic hydrocarbons (Table 1) evaporate rapidly from the surface of sediments and the overlying water column. They evaporate slower from deep sediment layers, particularly if the sediments are fine-grained (silts and clays) with low permeability. Hydrocarbons are lost from buried sediment layers mainly by dissolution or dispersion in water percolating through the oiled sediment layer, or by microbial degradation. If the subsurface oil NAPL comes in contact with surface water or infiltrating water, hydrocarbons will dissolve from the oil phase into the water phase in direct relation to their relative solubilities in the two phases. Generally speaking, the aqueous solubility of petroleum hydrocarbons is inversely proportional to molecular weight, and aliphatic hydrocarbons are less soluble than aromatic hydrocarbons of similar molecular weight. Thus, low molecular weight aromatic hydrocarbons and, to a lesser extent, lower molecular weight aliphatic hydrocarbons tend to dissolve slowly from the petroleum-contaminated sediment or NAPL into the porewater and are carried away from the oil deposit with porewater or surface water flow (Figure 2).

Sediment bacteria and fungi may degrade petroleum hydrocarbons (Figure 2). Low molecular weight normal alkanes are degraded most rapidly, followed by branched alkanes and higher molecular weight normal alkanes. Low molecular weight, soluble aromatic hydrocarbons also may be degraded rapidly. PAHs and cyclic alkanes are more resistant to microbial degradation and degrade more slowly. Thus, as oil weathers, its composition changes with loss of low molecular weight aliphatic and aromatic hydrocarbons, and slower declines in concentrations of higher molecular weight hydrocarbons.

The effects of the combined weathering processes generally reduce the concentration of low molecular weight slightly soluble aliphatic and aromatic hydrocarbons in petroleum-contaminated sediment. Thus, the composition of a TPH fraction that has weathered for some time is quite different from that of the TPH fraction of the refined or residual petroleum product that was originally released. The relative toxicity of TPH fractions also changes, usually decreasing, during natural weathering (Di Toro et al., 2007). Because the compositions of TPH fractions of different refined and residual petroleum products vary widely and change during natural weathering, it is difficult to predict the concentration of TPH in sediment that does not pose a potential risk to the aquatic environment.

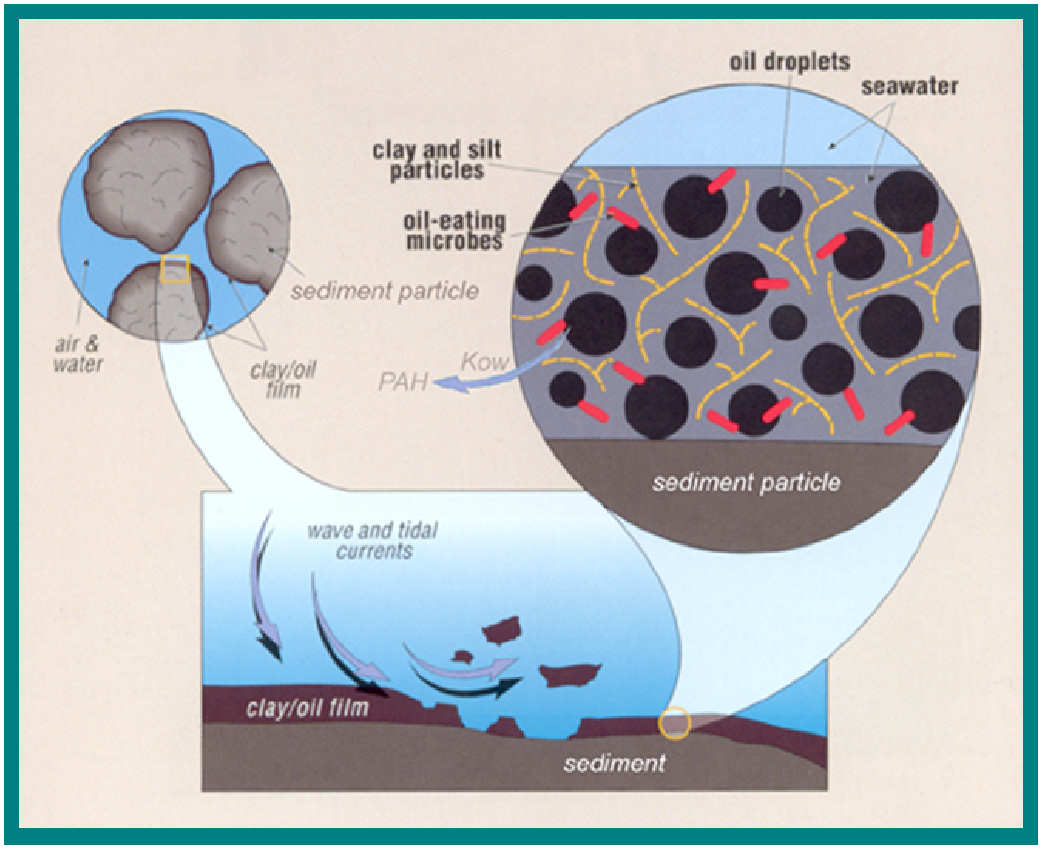


**Figure 2. Partitioning of Hydrocarbons in Sediment**

## 2.2 Equilibrium Partitioning

Toxic organic contaminants in bottom sediments of lakes, rivers, wetlands, and coastal waters create the potential for continued environmental degradation, even when water column contaminant levels comply with established water quality criteria (DiToro et al., 1991). Hydrocarbons have low aqueous solubilities and high affinities for adsorption to sediment organic matter. They also adsorb to dissolved and suspended organic matter and readily partition across permeable external (*e.g.*, gills) and internal (gut epithelium) membranes of water column and sediment dwelling organisms, where they accumulate in tissue lipids (Neff, 2002). Hydrocarbons in solution in sediment porewater are more bioavailable and toxic to sediment-dwelling organisms than hydrocarbons adsorbed to sediment particles, particularly combustion soot (Thorsen et al., 2004) or associated with a NAPL (*e.g.*, petroleum, creosote, or tar) (DiToro et al., 1991; Hansen et al., 2003; Neff et al., 2005).

Hydrocarbons associated with sediment particles are considered slightly bioavailable; bioaccumulation of particle-associated hydrocarbons by direct contact with external body surfaces or following ingestion of the particles is thought to involve an intermediate step in which the hydrocarbons desorb from the particle into the water and then are absorbed across an epithelium (Di Toro et al., 1991; 2000; Neff, 2002; Hansen et al., 2003). Hydrocarbons associated with sediment particles must partition from the sediment particles into solution before they can

move across biological membranes and be taken up by the organism. For low molecular weight hydrocarbons (log $K_{ow}$< 5.5) with high solubility, sufficient levels of hydrocarbons are present in the porewater to allow rapid bioaccumulation across external permeable membranes or across the gut epithelium when particles and porewater are ingested. In the gut, "solubilization" of particulate hydrocarbons is aided by surfactants and enzymes secreted by the animal (Mayer et al., 1996). For high molecular weight hydrocarbons (log $K_{ow}$> 5.5) with low solubility and high affinity for particles, few hydrocarbons are able to partition from the particles into bulk porewater. However, if hydrocarbon-contaminated sediment particles come into direct contact with permeable epithelia (*e.g.*, gill, gut epithelium), some high molecular weight hydrocarbons may dissolve in the thin film of water between the particle and membrane surfaces and partition into the membrane. In the gut of fish, the natural surfactants are particularly important in facilitating this transfer. However, the assimilation efficiency for high molecular weight hydrocarbons in the gut of benthic invertebrates is low (generally <10%). The uptake of non-polar organic chemicals with Log $K_{ow}$ > 5 by fish is almost exclusively from food or ingested sediments, while the uptake of chemicals with Log $K_{ow}$ < 5 is primarily from the water (via the gills). The same is likely true for benthic invertebrates (Neff, 2002).

The best approach for estimating the toxicity of hydrocarbons in sediments to benthic organisms is to estimate the hydrocarbon concentration in sediment porewater and then compare the estimated concentration to water quality criteria for the hydrocarbon (Figure 3) as described in USEPA Guidance (DiToro et al., 1991; Hansen et al., 2003). The dissolved phase of hydrocarbons in sediment porewater can be estimated based on equilibrium partitioning theory (EqP) as described by Hansen et al. (2003). Equilibrium partitioning refers to the assumption that a state of equilibrium exists between the chemical sorbed to the particulate sediment organic carbon and the sediment porewater and between sediment porewater and the tissues of an organism in contact with the water (Figure 3). It makes several additional assumptions:

1) The partitioning of hydrocarbons between sediment organic carbon and porewater (interstitial water) and between porewater and tissues of aquatic organisms in contact with the porewater is at or near equilibrium;

2) The concentration in each phase (sediment, porewater, and tissue) can be predicted using appropriate partition coefficients and the measured or estimated concentration in the other phases;

3) The effective sediment exposure concentration of hydrocarbons to organisms is the same regardless of the exposure route (*e.g.*, from sediment porewater via respiration or from sediment via ingestion)[3];

[3] Only the bioavailable forms of chemicals are toxic to aquatic organisms (Di Toro et al., 1991; Neff, 2002). A chemical is said to be bioavailable if it is in a form that can move through or bind to the surface membranes of an organism (*e.g.*, skin, gill epithelium, gut lining, cell membrane). Thus, the exposure concentration of hydrocarbons to aquatic and sediment-dwelling organisms is the fraction of the total hydrocarbon in the ambient medium (including the gut) that is in a bioavailable form (dissolved in the water and in contact with a permeable membrane). It is assumed that particulate hydrocarbons (adsorbed to sediment particles or associated with an oil phase) must first desorb or partition from the solid or NAPL into the water before they can be bioaccumulated. Thus, the effective exposure concentration is the measured or predicted concentration of the hydrocarbon in solution in the water bathing external and internal permeable membranes of the aquatic organism. Partitioning of hydrocarbons from the solid phase into water may be facilitated in the gut of sediment-ingesting animals by the natural detergents secreted by the animal into the digestive tract.

4) Effects concentrations of hydrocarbons in sediments can be estimated using the organic carbon-to-water partition coefficient ($K_{oc}$) and effects concentrations in water; and,

5) The derived equilibrium partitioning sediment benchmark (ESB) is protective of benthic and water column organisms.

Thus, the toxicity of hydrocarbons in sediments to benthic organisms is caused by the hydrocarbons that partition from the organic fraction of sediment particles into porewater and from porewater into the tissues of the organisms (Figure 3). The sediment benchmark, which is protective of benthic organisms, can be estimated from the $K_{oc}$ and the chronic aquatic toxicity value for each hydrocarbon fraction.

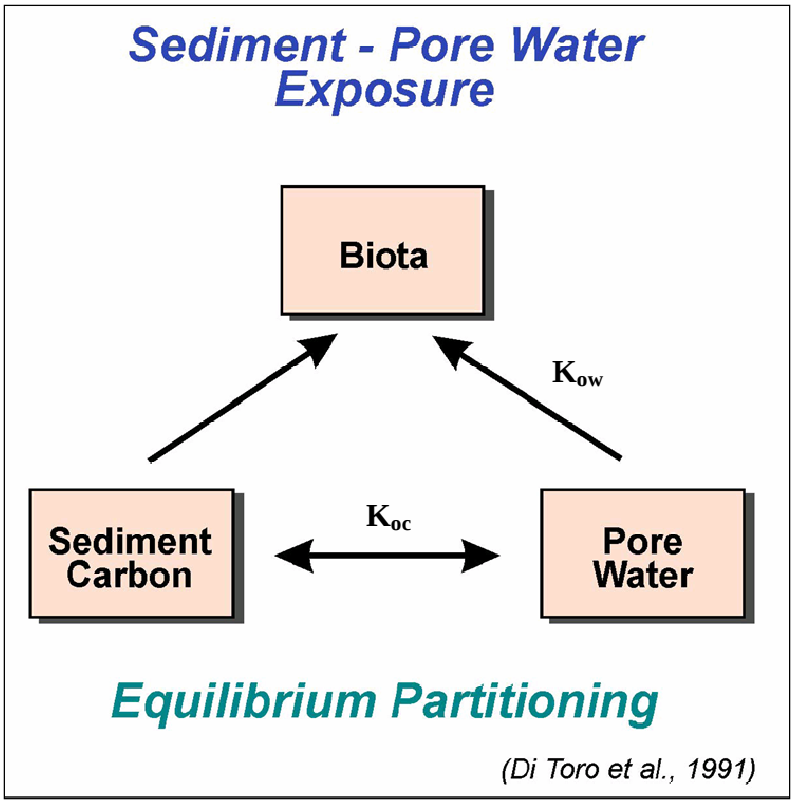


**Figure 3. Equilibrium Partitioning Conceptual Site Model**

### 2.3 Toxicity

For non-polar organic chemicals, such as petroleum hydrocarbons, properties such as water solubility, sorption to sediment particles, bioconcentration, and toxicity are proportional to hydrophobicity, which is expressed as the octanol-water partition coefficient ($K_{ow}$).[4] Because octanol is a good surrogate for tissue lipids of aquatic organisms, $K_{ow}$ can be used to predict the

[4] $K_{ow}$ is an expression of the relative affinity of a chemical for dissolution in the octanol and water phases of a 50/50 octanol/water mixture. It is measured as the ratio of the concentration of the chemical in the octanol phase to its concentration in the aqueous phase after equilibration.

bioconcentration of hydrocarbons from water into the lipid-rich tissues of aquatic organisms (Connell, 1993; McCarty et al., 1992; Di Toro et al., 2000). Toxicity depends on attainment of a critical concentration of the chemical in the tissues of an aquatic organism (McCarty et al., 1992); therefore, $K_{ow}$ can also be used to predict the concentration of hydrocarbons in the porewater that is toxic to aquatic organisms. Both bioaccumulation and toxicity of hydrocarbons increase as Log $K_{ow}$ increases. A regression of toxicity data versus Log $K_{ow}$ produces a straight line from which acute toxicities of other hydrocarbons can be estimated if their Log $K_{ow}$s are known. This is the approach described in this report for estimating the acute and chronic toxicity of hydrocarbon fractions to aquatic organisms (see Section 3.0).

## 2.4 Toxicological Data

Toxicological data were compiled from USEPA's ECOTOX database (http://www.epa.gov/ecotox/) on September 14, 2005 using search criteria for aquatic animals and specific chemical names. The list of chemical names that was searched in the database is presented in Appendix A (Table A-1). The data field descriptions from ECOTOX are listed and defined in Appendix A (Table A-2).

The downloaded data consisted of acute, chronic, and sublethal effects data from a variety of field and laboratory studies. Laboratory toxicity studies of 24 hours or more were selected over field studies because of the variability and higher potential of confounding factors in the field. Selected toxicity studies included static, flow-through, leaching, and renewal exposures, which were selected over studies listed as dietary exposure or injection. Because there is little to no difference in the sensitivity of freshwater and marine organisms to hydrocarbons, both freshwater and saltwater data were used for invertebrates (*e.g.*, *Daphnia* sp., brine shrimp) and fish (*e.g.*, bluegill, rainbow trout, salmon) (Di Toro et al., 1991; European Community [EC], 2003).

To ensure the robustness of the dataset, both acute and chronic toxicity data were used to derive benchmarks, as recommended by the Technical Guidance Document (TGD) (EC, 2003). Acute data is expressed as the concentration of a toxin (in this case petroleum hydrocarbons) which causes death in 50 percent of the organisms ($LC_{50}$), or the median sublethal effects concentration ($EC_{50}$) following exposure for 24 to 96 hours. Chronic toxicological data are expressed as the no observed effects concentration (NOEC) and lowest observed effects concentration (LOEC) following exposure of a particularly sensitive life stage or for a significant fraction of the life span of the test organism.

Acute data were selected using $LC_{50}$s (also expressed as $EC_{50}$s, $ED_{50}$s, or $LT_{50}$s) and mortality as the endpoint. Results of acute toxicity tests lasting 24 hours or more were used. The short (24 hour) tests are used most frequently for small, short-lived animals, such as water fleas (*Daphnia* spp.) and are equivalent to longer (96 hour or more) acute tests with larger, longer-lived animals, such as fish. Smaller animals are often more sensitive to chemicals than larger animals, so the use of acute data consisting of toxicity tests of various durations did not bias the geometric mean toxicity values for hydrocarbons with different amounts of toxicity data. Chronic data were selected using the NOEC and LOEC for endpoints of growth and reproduction.

Any toxicity data listed as less than (<) were rejected. In addition, three obvious data outliers were removed from the aromatic dataset; there were no obvious data outliers in the aliphatic dataset.

Information such as molecular weight, solubility, and $K_{ow}$ were obtained for each hydrocarbon. The solubility of each hydrocarbon was compared to the toxicity data and any toxicity values that

were substantially higher than the solubility were eliminated, because this indicated the presence of the chemical in a separate phase and, in these cases, mortality occurred for some reasons other than toxicity of the dissolved chemical (*e.g.*, physical abrasion or adherence).

For the aliphatic hydrocarbons, 58 data points were retained, representing a total of 12 hydrocarbons; no chronic data were found. For the aromatic hydrocarbons, 718 acute data points were retained, representing a total of 25 hydrocarbons. Thirty-six chronic data points (18 NOECs and 18 LOECs) were retained for five aromatic hydrocarbons (benzene, xylene, ethylbenzene, floranthene, and phenanthrene) and included in the dataset. Data from the ECOTOX downloads for both aliphatic and aromatic hydrocarbons are presented in Appendix A.

# 3.0 DERIVATION OF RISK-BASED SEDIMENT BENCHMARKS

## 3.1 Derivation of the Aquatic Toxicity Value

Because the toxicity data were not normally distributed, the geometric mean toxicity value for each hydrocarbon best characterizes the central tendency for the dataset and was used in the regression, as recommended by Hansen et al. (2003). The geometric mean of the acute and chronic toxicity data in mg/L (see Section 2.3) for each hydrocarbon was obtained and converted to millimoles per liter (mM/L) by dividing by its molecular weight. Tables 2 and 3 present the data used to plot the regression equations, including various aliphatic and aromatic hydrocarbons from ECOTOX, their geometric mean $LC_{50}$s, Log $K_{ow}$s, and solubility. The log of the mean $LC_{50}$ was plotted against the Log $K_{ow}$ for both the aromatic and aliphatic hydrocarbons (Figures 4 and 5, respectively) to obtain a relationship between $K_{ow}$ and toxicity. The resulting regression equations were as follows:

Aromatic Hydrocarbons: Log $LC_{50}$ (mM/L) = -1.4347Log $K_{ow}$ + 3.3624, $r^2$ = 0.89 (Equation 1)

Aliphatic Hydrocarbons: Log $LC_{50}$ (mM/L) = -0.08953Log $K_{ow}$ + 2.241, $r^2$ = 0.90 (Equation 2)

These equations were used to derive a mean aquatic toxicity value ($LC_{50}$) for each hydrocarbon fraction, based on the Log $K_{ow}$ of various individual hydrocarbons within the fraction. Results are presented in Tables 4 and 5 and in more detail in Appendix B.

**Table 2. Solubility, Mean Log $LC_{50}$s, and Log $K_{ow}$s for Aliphatic Hydrocarbons Used to Form the Regression Equation**

| Chemical Name | Solubility (mg/L) at 25°C[a] | Geometric Mean $LC_{50}$[b] (mg/L) | Log $LC_{50}$[c] (mM/L) | Log $K_{ow}$[a] |
|---|---|---|---|---|
| Cyclopentane | 156 | 19.64 | -0.55 | 3.00 |
| Cyclohexane | 55 | 17.20 | -0.69 | 3.44 |
| Pentane | 38 | 11.90 | -0.78 | 3.45 |
| Methylcyclohexane | 14 | 4.46 | -1.34 | 3.88 |
| 1,3-Dimethylcyclohexane | 11.7 | 7.71 | -1.16 | 4.01 |
| 1,1-Dimethylcyclohexane | 10.9 | 5.99 | -1.27 | 4.05 |
| Dimethylcyclohexane | 10.9 | 2.19 | -1.71 | 4.05 |
| Hexane | 9.5 | 2.97 | -1.46 | 4.11 |
| 1,2-Dimethylcyclohexane | 6 | 1.69 | -1.82 | 4.39 |
| 1,4-Dimethylcyclohexane | 3.84 | 2.05 | -1.74 | 4.39 |
| Ethylcyclohexane | 6.3 | 3.39 | -1.52 | 4.56 |
| Octane | 0.66 | 0.40 | -2.46 | 5.15 |

a. Solubility and Log $K_{ow}$s from TPHCWG, 1997.
b. Geometric mean $LC_{50}$s based on data from ECOTOX database (Appendix A).
c. Each mean $LC_{50}$ was then converted to mM/L by dividing by the molecular weight and then obtaining the logarithm at base 10.

**Table 3. Solubility, Mean Log $LC_{50}$s, and Log $K_{ow}$s for Aromatic Hydrocarbons Used to Form the Regression Equation**

| Chemical Name | Solubility (mg/L) at 25°C[a] | Geometric Mean $LC_{50}$[b] (mg/L) | Log $LC_{50}$[c] (mM/L) | Log $K_{ow}$[a] |
|---|---|---|---|---|
| Benzene | 1770 | 47.37 | -0.22 | 2.13 |
| Toluene | 526 | 27.32 | -0.53 | 2.69 |
| 1,2-Dimethylbenzene | 178 | 10.95 | -0.99 | 3.12 |
| Ethylbenzene | 169 | 16.77 | -0.80 | 3.13 |
| 1,4-Dimethylbenzene | 162 | 2.90 | -1.56 | 3.15 |
| Xylene | 106 | 13.63 | -1.37 | 3.16 |
| 1,3-Dimethylbenzene | 161 | 8.57 | -1.09 | 3.2 |
| Naphthalene | 31 | 3.17 | -1.61 | 3.37 |
| 1,2,4-Trimethylbenzene | 57 | 5.28 | -1.36 | 3.58 |
| 1,3,5-Trimethylbenzene | 48.2 | 6.87 | -1.24 | 3.58 |
| Isopropylbenzene | 61.3 | 0.601 | -2.30 | 3.63 |
| Propylbenzene | 52.2 | 1.55 | -1.89 | 3.69 |
| 2-Methylnaphthalene | 24.6 | 1.48 | -1.98 | 3.86 |
| 1-Methylnaphthalene | 25.8 | 4.18 | -1.53 | 3.87 |
| 1,1'-Biphenyl | 6.94 | 2.36 | -1.82 | 3.69 |
| 2,6-Dimethylnaphthalene | 2 | 0.77 | -2.31 | 4.1 |
| 1,2,4,5-Tetramethylbenzene | 3.48 | 0.47 | -2.46 | 4.1 |
| Phenanthrene | 1.15 | 0.11 | -3.21 | 4.36 |
| Dibenzothiophene | 1.47 | 0.28 | -2.82 | 4.38 |
| 1,3-Dimethylnaphthalene | 8 | 1.14 | -2.14 | 4.42 |
| Anthracene | 0.0434 | 0.01 | -4.37 | 4.54 |
| Pyrene | 0.135 | 0.003 | -4.78 | 5.18 |
| Fluoranthene | 0.26 | 0.023 | -3.95 | 5.22 |
| Chrysene | 0.002 | 0.0007 | -5.51 | 5.79 |
| Benzo(a)pyrene | 0.00162 | 0.0053 | -4.68 | 6.04 |

a. Solubility and Log $K_{ow}$s from TPHCWG, 1997.

b. Geometric mean $LC_{50}$s based on data from ECOTOX database (Appendix A).

c. Each mean $LC_{50}$ was then converted to mM/L by dividing by the molecular weight and then obtaining the logarithm at base 10.

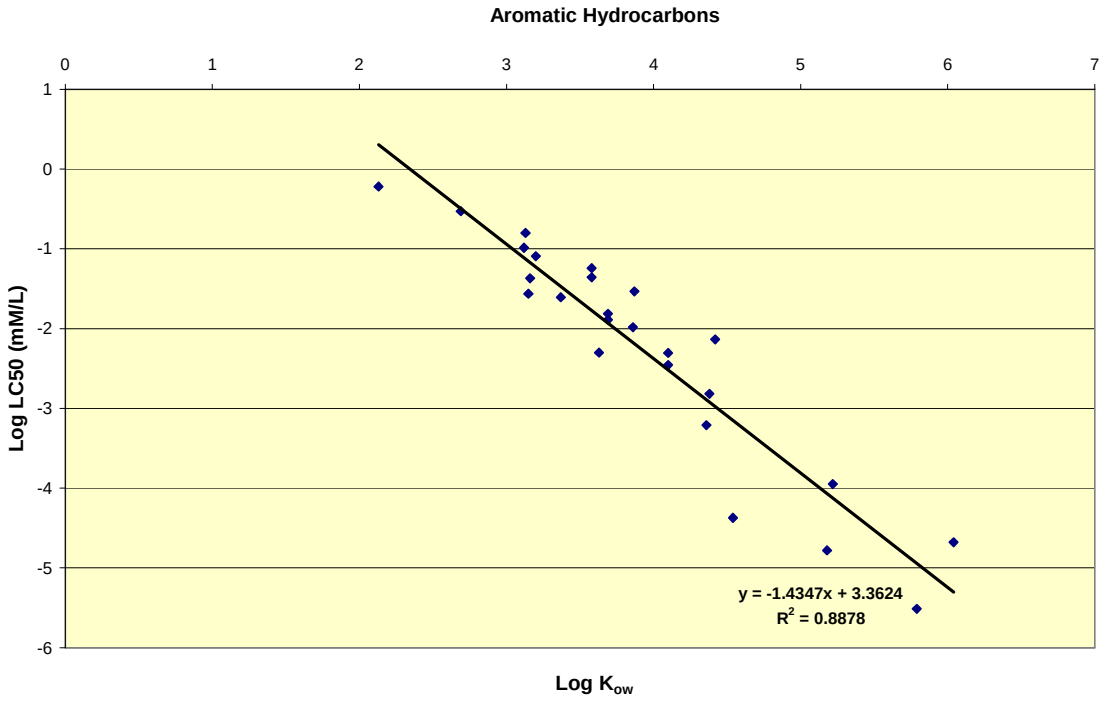


**Figure 4. Regression of Log $LC_{50}$ verses Log $K_{ow}$ for Aromatic Hydrocarbons**

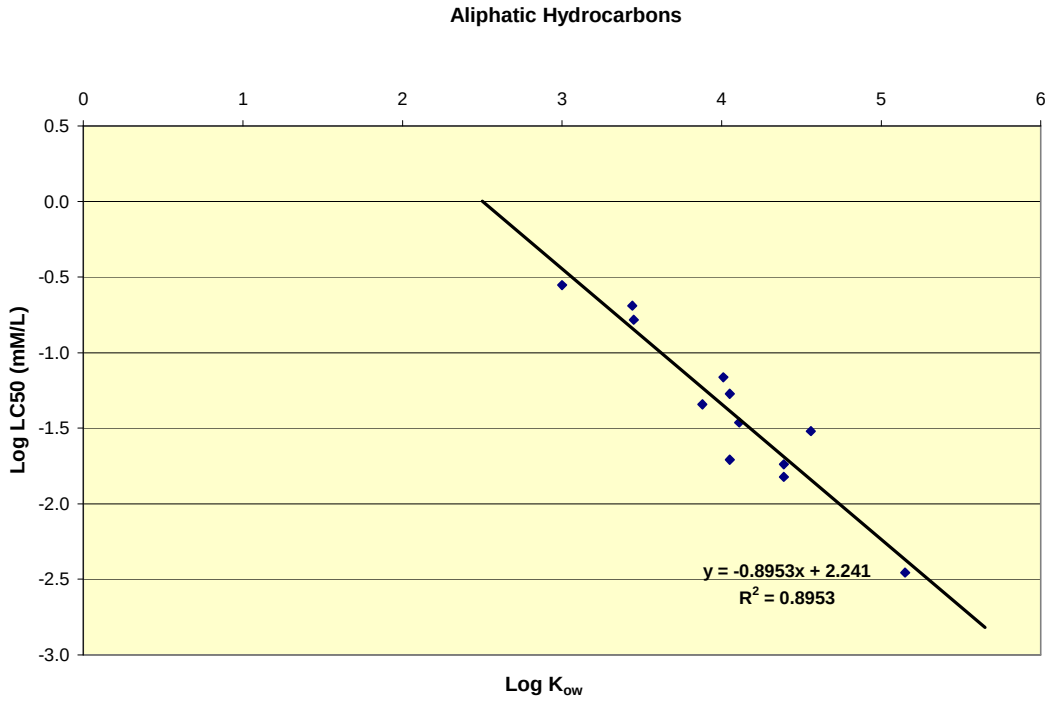


**Figure 5. Regression of Log $LC_{50}$ verses Log $K_{ow}$ for Aliphatic Hydrocarbons**

**Table 4. Geometric Mean Acute Aquatic Toxicity ($LC_{50}$) Values for Four Aliphatic Hydrocarbon Fractions**

| Fraction | Aliphatic Hydrocarbons | Log $K_{ow}$ | Geometric Mean Log $K_{ow}$ | Log $LC_{50}$[a] (mM/L) | $LC_{50}$ (mg/L) | Geometric Mean $LC_{50}$[b] (mg/L) |
|---|---|---|---|---|---|---|
| $C_5$-$C_8$ | n-Pentane | 3.45 | 4.12 | -0.85 | 10.24 | 3.27 |
| | 2,2-Dimethylbutane | 3.82 | | -1.18 | 5.71 | |
| | Cyclopentane | 3.00 | | -0.44 | 25.18 | |
| | 2,3-Dimethylbutane | 3.85 | | -1.21 | 5.36 | |
| | 2-Methylpentane | 3.74 | | -1.11 | 6.73 | |
| | 3-Methylpentane | 3.6 | | -0.98 | 8.98 | |
| | n-Hexane | 4.11 | | -1.44 | 3.14 | |
| | cycloheptane | 4.00 | | -1.34 | 4.49 | |
| | 2,2-Dimethylpentane | 4.14 | | -1.47 | 3.43 | |
| | Methylcyclopentane | 3.37 | | -0.78 | 14.09 | |
| | 2,4-Dimethylpentane | 4.14 | | -1.47 | 3.43 | |
| | 2,2,3-Trimethylbutane | 4.03 | | -1.37 | 4.30 | |
| | 3,3-Dimethylpentane | 4.14 | | -1.47 | 3.43 | |
| | Cyclohexane | 3.44 | | -0.84 | 12.20 | |
| | 2,3-Dimethylpentane | 4.14 | | -1.47 | 3.43 | |
| | 3-Methylhexane | 4.27 | | -1.58 | 2.62 | |
| | 2,2,4-Trimethylpentane | 4.54 | | -1.82 | 1.71 | |
| | Heptane | 5.00 | | -2.24 | 0.58 | |
| | Methylcyclohexane | 3.88 | | -1.23 | 5.75 | |
| | 1,1,3-Trimethylcyclopentane | 4.35 | | -1.65 | 2.49 | |
| | 2,3,4-Trimethylpentane | 4.54 | | -1.82 | 1.71 | |
| | 2-Methylheptane | 4.80 | | -2.06 | 1.00 | |
| | 3-Methylheptane | 4.80 | | -2.06 | 1.00 | |
| | 1,4-Dimethylcyclohexane | 4.39 | | -1.69 | 2.29 | |
| | 2,2,5-Trimethylhexane | 5.06 | | -2.29 | 0.66 | |
| | 1,2-Dimethylcyclohexane | 4.39 | | -1.69 | 2.29 | |
| | Octane | 5.15 | | -2.37 | 0.49 | |
| $C_9$-$C_{12}$ | 3-Methyloctane | 5.32 | 6.01 | -2.52 | 0.39 | 0.094 |
| | Nonane | 5.65 | | -2.82 | 0.20 | |
| | Decane | 6.25 | | -3.35 | 0.06 | |
| | Undecane | 6.94 | | -3.97 | 0.02 | |
| $C_{13}$-$C_{18}$ | Tetradecane | 7.20 | 8.57 | -4.21 | 0.0124 | 0.0008 |
| | Pentadecane | 8.63 | | -5.49 | 0.0007 | |
| | Hexadecane | 8.25 | | -5.15 | 0.0016 | |
| | Heptadecane | 9.69 | | -6.43 | 0.0001 | |
| | Octadecane | 9.32 | | -6.10 | 0.0002 | |
| $C_{19}$-$C_{36}$ | Nonadecane | 10.72 | 11.64 | -7.36 | 1.18E-05 | 1.77E-06 |
| | Eicosane | 11.27 | | -7.85 | 4.00E-06 | |
| | Tetracosane | 13.07 | | -9.46 | 1.17E-07 | |

a Values obtained from the regression equation and corresponding Log $K_{ow}$.

b Presented as the geometric mean acute aquatic toxicity value. To obtain the final chronic value, the mean $LC_{50}$ for each hydrocarbon fraction is divided by an application factor (AF) of 15 (Section 3.2).

**Table 5. Geometric Mean Acute Aquatic Toxicity ($LC_{50}$) Values for Four Aromatic Hydrocarbon Fractions**

| Fraction | Aromatic Hydrocarbons | Log $K_{ow}$ | Geometric Mean Log $K_{ow}$ | Log $LC_{50}$[a] (mM/L) | $LC_{50}$ (mg/L) | Geometric Mean $LC_{50}$[b] (mg/L) |
|---|---|---|---|---|---|---|
| $C_6$-$C_8$ | Benzene | 2.13 | 2.82 | 0.31 | 158.18 | 17.86 |
| | Toluene | 2.69 | | -0.50 | 29.33 | |
| | Ethylbenzene | 3.13 | | -1.13 | 7.91 | |
| | p-Xylene | 3.18 | | -1.20 | 6.70 | |
| | o-Xylene | 3.15 | | -1.16 | 7.40 | |
| $C_9$-$C_{12}$ | Isopropylbenzene | 3.63 | 3.94 | -1.85 | 1.72 | 0.69 |
| | n-Propylbenzene | 3.69 | | -1.93 | 1.41 | |
| | 1-Methyl-4-ethylbenzene | 3.63 | | -1.85 | 1.72 | |
| | 1,3,5-Trimethylbenzene | 3.58 | | -1.77 | 2.02 | |
| | Naphthalene | 3.37 | | -1.47 | 4.32 | |
| | 2-Methylnaphthalene | 3.86 | | -2.18 | 0.95 | |
| | 1-Methylnaphthalene | 3.87 | | -2.19 | 0.92 | |
| | 2-Ethylnaphthalene | 4.40 | | -2.95 | 0.18 | |
| | Biphenyl | 3.69 | | -1.93 | 1.80 | |
| | 2,6-Dimethylnaphthalene | 4.10 | | -2.52 | 0.47 | |
| | 2,3-Dimethylnaphthalene | 4.40 | | -2.95 | 0.18 | |
| | Dibenzothiophene | 4.38 | | -2.92 | 0.22 | |
| | Acenaphthene | 3.92 | | -2.26 | 0.84 | |
| | 1-Methyl-4-isopropylbenzene | 4.10 | | -2.52 | 0.41 | |
| | Isobutylbenzene | 4.01 | | -2.39 | 0.55 | |
| | n-Butylbenzene | 4.26 | | -2.75 | 0.24 | |
| | Sec-Butylbenzene | 4.10 | | -2.52 | 0.41 | |
| | 1,2,4,5-Tetramethylbenzene | 4.10 | | -2.52 | 0.41 | |
| $C_{13}$-$C_{15}$ | Fluorene | 3.97 | 4.67 | -2.33 | 0.77 | 0.078 |
| | Phenanthrene | 4.36 | | -2.89 | 0.23 | |
| | 2-Methylanthracene | 5.15 | | -4.03 | 0.02 | |
| | 9-Methylanthracene | 5.07 | | -3.91 | 0.02 | |
| | 1-Methylphenanthrene | 4.93 | | -3.71 | 0.04 | |
| $C_{16}$-$C_{24}$ | Benzo(a)fluorene | 5.40 | 5.90 | -4.38 | 0.0089 | 0.002 |
| | Benz(a)anthracene | 5.91 | | -5.12 | 0.0017 | |
| | Chrysene | 5.79 | | -4.94 | 0.0026 | |
| | Benzo(a)pyrene | 6.04 | | -5.30 | 0.0013 | |
| | Pyrene | 5.18 | | -4.07 | 0.02 | |
| | Fluoranthene | 5.22 | | -4.13 | 0.02 | |
| | Coronene | 6.75 | | -6.32 | 0.0001 | |
| | Benzo(ghi)perylene | 6.29 | | -5.66 | 0.0006 | |
| | Dibenz(a,h)anthracene | 6.75 | | -6.32 | 0.0001 | |

a Values obtained from the regression equation and corresponding Log $K_{ow}$.
b Presented as the geometric mean acute aquatic toxicity value. To obtain the final chronic value, the mean $LC_{50}$ for each hydrocarbon fraction is divided by an application factor (AF) of 15 (Section 3.2).

## 3.2 Derivation of the Application Factor (AF)

Because of the small number of toxicity tests available and the small number of taxa of animals used in the tests, an application factor (AF) was applied to the estimated mean toxicity values to obtain a conservative final chronic toxicity value, which is protective of most aquatic species. The EC (2003), in its TGD, recommends applying an application factor to combine acute and chronic toxicity data and uncertainty about the sensitivity of untested species for a chemical. The application factor recommended by the TGD varies from 10 to 1000, depending on the number of acute and chronic tests performed, and the number of different aquatic taxa tested.

Due to variability between acute and chronic tests, the European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC) evaluated the acute-chronic ratio (ACR) for organic chemicals in aquatic organisms (Länge et al., 1998). The ratios between the median lethal concentration ($LC_{50}$) or median effects concentration ($EC_{50}$) and the no observed effects concentrations (NOEC) were determined for 71 chemicals. Länge et al. (1998) calculated the upper 90$^{th}$ percentile ratio for the whole data set and for different subsets of chemicals of different types. The 90$^{th}$ percentile ACR for the entire data set was 73. Highest ACR values were for metals and organochlorine pesticides. A subgroup of chemicals classified as aromatic hydrocarbons had a mean ACR for invertebrates and fish of 6.2 and a 90$^{th}$ percentile ACR of 21.3.

Hansen et al. (2003) estimated a final acute-chronic ratio (FACR) of 4.16 from the geometric mean of various species' mean ACRs for six PAHs. Included in the dataset were toxicity data for the water flea *Daphnia* (2.41), the midge *Paratanytarsus* (6.68), the fathead minnow *Pimephales* (2.61), the rainbow trout *Oncorhynchus* (7.9), the mysid *Americamysis* (3.59), and the killifish *Cyprinodon* (4.36).

ECETOC recommended using an ACR of 15 to 25 in risk assessments for all chemicals except metals and pesticides to adjust for uncertainties in the data between acute and chronic studies. Based on these reported ACRs for hydrocarbons and closely related non-polar organic chemicals and the AF values recommended for non-polar organics in the Technical Guidance Document, the AF used for this report was set at 15. This value represents a conservative estimate of the AF for all hydrocarbons. For example, Suter and Rosen (1988) evaluated the comparative acute and chronic/sublethal toxicity of several chemicals to marine fish and crustaceans. ACRs for aromatic hydrocarbons calculated from their data ranged from 2 to 4. Niederlehner et al. (1998) reported an ACR of 1.76 ± 1.12 for several monocyclic aromatic hydrocarbons and chlorinated ethylenes and the water flea *Ceriodaphnia dubia*. Thus, an AF of 15 is expected to be fully protective of the most sensitive species in the affected freshwater or marine environment.

The AF of 15 was applied to the mean aquatic toxicity value (mean $LC_{50}$) for each hydrocarbon fraction to account for variability among acute and chronic effects, as well as variability among different species' sensitivities to the various hydrocarbons (Appendix B). The resulting value is a final chronic value (FCV) for each hydrocarbon fraction (Table 6).

## 3.3 Calculating Sediment Benchmarks

The sediment benchmark for each hydrocarbon fraction was then determined from the final aquatic chronic toxicity value, $K_{ow}$, $K_{oc}$, and the fraction of organic carbon in sediment ($f_{oc}$). The Log organic carbon-to-water partitioning coefficient (Log $K_{oc}$) is related to Log $K_{ow}$ for each hydrocarbon (Tables 4 and 5) by the following equation (Di Toro et al., 1991):

$$\text{Log } K_{oc} = 0.00028 + 0.938\text{Log } K_{ow} \qquad \text{(Equation 3)}$$

The $K_{oc}$ for each hydrocarbon fraction was calculated using the above equation and the geometric mean of the Log $K_{ow}$s (Tables 4 and 5) for the hydrocarbons in the fraction. This was then multiplied by the FCV for each hydrocarbon fraction and by the fraction of organic carbon in the sediment ($f_{oc}$) (Equation 4). The average amount of organic carbon in site sediments usually ranges between 0.1% and 20%. Nonpolar organic chemicals may adsorb to other solids (*e.g.*, clay particles) in sediments containing less than 0.1 % organic carbon, decreasing the reliability of this EqP approach to estimating sediment benchmarks. An $f_{oc}$ of 0.1% ($f_{oc}$ = 0.001) was used here to give the lowest (most conservative) estimated benchmarks.

Sediment Benchmark (mg/kg) = $K_{oc}$ x FCV x $f_{oc}$ (0.001) (Equation 4)

Table 6 presents the FCVs and sediment benchmarks (with and without normalization to organic carbon) for each hydrocarbon fraction. The spreadsheet of data and calculations for these equations is included in Appendix B. Sediment benchmarks for aliphatic fractions increase with increasing carbon number in the fractions; sediment benchmarks for aromatic hydrocarbons show the opposite pattern (decreasing values with increasing carbon number). This is caused by the larger increase in $K_{ow}$ and associated $K_{oc}$ with increasing molecular weight (and carbon number) for aliphatic than for aromatic hydrocarbons. Very little of the aliphatic hydrocarbons in the two highest aliphatic carbon fractions (mean log $K_{ow}$ 8.57 and 11.64) desorb from sediment particles into porewater where they are available for bioaccumulation. Thus, it requires more of the high molecular weight aliphatic hydrocarbons in bulk sediments to generate a potentially toxic dose of bioavailable, high molecular weight aliphatic hydrocarbons in sediment porewater.

The FCVs for PAHs in the EPA guidance for deriving ESBs (Hansen et al., 2003) were based on the critical body burden concept (McCarty et al., 1992). Aquatic toxicity values were normalized to a Log $K_{ow}$ of 1 (the Log $K_{ow}$ at which the PAH concentration in water and organism lipids would be equivalent). Resulting ESBs increased with molecular weight from 385 mg/kg oc for naphthalene to 1128 mg/kg oc for dibenz(a,h)anthracene. In the method used in this document, sediment benchmarks were based on non-normalized FCVs based on published or estimated acute toxicity values divided by an application factor. Values decreased with increasing molecular weight (carbon number) from 531 mg/kg oc for the $C_6$-$C_8$ aromatic fraction (mainly BTEX) to 40 for the $C_{16}$-$C_{24}$ aromatic fraction (mainly four- to six-ring PAHs. This may be due to the lower slope for the $K_{oc}$ versus FCV regression for non-normalized data.

The aqueous solubility of all the aliphatic hydrocarbons in the two highest carbon number aliphatic fractions and the higher molecular weight PAHs in the highest carbon number aromatic fraction is below the estimated acute toxicity value and in many cases the FCV. Thus, the benchmarks for these fractions are conservative. If the benchmarks for these fractions are exceeded, it will be difficult to distinguish between toxicological effects and potential physical impacts. In these cases, consideration should be given to further site evaluations to examine the potential for physical alterations to the habitat, physical impacts to the community structure, or even potential aesthetic impairments. Currently there are no other published sediment guidelines for aliphatic hydrocarbons that can be substituted.

**Table 6. Sediment Benchmarks for Recommended Petroleum Hydrocarbon Fractions**

| Hydrocarbon Fraction | Geometric Mean Log $K_{ow}$ | $K_{oc}$ | Final Chronic Value (µg/L) | Sediment Benchmark (mg/kg oc) | Sediment Benchmark ($f_{oc}$ = 0.001) (mg/kg) |
|---|---|---|---|---|---|
| *Aliphatic Hydrocarbons* | | | | | |
| $C_5 - C_8$ | 4.12 | $7.24 \times 10^3$ | 218 | 1591 | 1.59 |
| $C_9 - C_{12}$ | 6.01 | $4.37 \times 10^5$ | 6.3 | 2722 | 2.72 |
| $C_{13} - C_{18}$ | 8.57 | $1.10 \times 10^8$ | 0.05 [a] | 5543 | 5.54 |
| $C_{19} - C_{36}$ | 11.64 | $8.32 \times 10^{10}$ | 0.0001[a] | 9883 | 9.88 |
| *Aromatic Hydrocarbons* | | | | | |
| $C_6 - C_8$ | 2.82 | $4.47 \times 10^2$ | 1191 | 531 | 0.53 |
| $C_9 - C_{12}$ | 3.94 | $4.90 \times 10^3$ | 46.2 | 228 | 0.23 |
| $C_{13} - C_{15}$ | 4.67 | $2.40 \times 10^4$ | 5.2 | 125 | 0.13 |
| $C_{16} - C_{24}$ | 5.9 | $3.39 \times 10^5$ | 0.12[a] | 40 | 0.04 |

[a] The fraction is not likely toxic because mean $LC_{50}$ exceeds mean aqueous solubility.

## 3.4 Application of Sediment Benchmarks

The sediment benchmark values that are normalized to 0.1 percent organic carbon can be applied to any petroleum contaminated sediment site. However, it should be noted that a 0.1 percent organic carbon content in sediments represents the low range of organic carbon, resulting in the most stringent benchmarks. The equilibrium partitioning approach is appropriate for sediments containing 0.1 percent or more of organic matter (Di Toro et al., 1991). When site-specific organic carbon concentrations are available, it is recommended that an average site-specific organic carbon content be used to derive a site-specific criterion. This can be accomplished by inserting the appropriate fraction of organic carbon ($f_{oc}$) into Equation 4 to obtain a site-specific sediment benchmark for each hydrocarbon fraction. The benchmarks would then be compared to the analytical chemistry results for each hydrocarbon fraction and screened to determine the potential for site risk to aquatic organisms.

As discussed in Section 1.2.3.2, the current MADEP methods use different hydrocarbon fractions that span a wide range of carbon numbers and physical/chemical and toxicological properties. These fractions are currently used for the estimation of risk to human health from petroleum hydrocarbons. Sediment benchmarks were also developed for these fractions as a comparison and are listed in Table 7. The detailed calculation spreadsheet is available in Appendix B (Table B-2).

**Table 7. Sediment Benchmarks for Current MADEP Petroleum Hydrocarbon Fractions**

| Hydrocarbon Fraction | Geometric Mean Log $K_{ow}$ | $K_{oc}$ | Final Chronic Value (µg/L) | Sediment Benchmark (mg/kg oc) | Sediment Benchmark ($f_{oc}$ = 0.001) (mg/kg) |
|---|---|---|---|---|---|
| *Aliphatic Hydrocarbons* | | | | | |
| $C_5 - C_8$ | 4.12 | $7.24 \times 10^3$ | 218 | 1591 | 1.59 |
| $C_9 - C_{18}$ | 7.32 | $7.41 \times 10^6$ | 0.4 | 3167 | 3.17 |
| $C_{19} - C_{36}$ | 11.64 | $8.32 \times 10^{10}$ | 0.0001[a] | 9883 | 9.88 |
| *Aromatic Hydrocarbons* | | | | | |
| $C_9 - C_{10}$ | 3.84 | $3.98 \times 10^3$ | 59.4 | 236 | 0.24 |
| $C_{11} - C_{22}$ | 4.81 | $3.31 \times 10^4$ | 2.8 | 92 | 0.09 |

[a] The fraction is not likely toxic because mean $LC_{50}$ exceeds mean aqueous solubility.

## 3.5 Uncertainties

There are several uncertainties inherent in the use of the equilibrium partitioning method for developing sediment benchmarks for petroleum hydrocarbon fractions, which are accounted for in the method: varying values for Log $K_{ow}$, the appropriate value for the application factor, the limited amount of toxicity data for aliphatic hydrocarbons, the use of toxicity data for both marine and freshwater species, and the use of acute and chronic toxicity data for tests performed over various lengths of time. Each of these uncertainties is further discussed below.

***Log $K_{ow}$***

Several methods have been used over the years to measure or model Log $K_{ow}$ for non-polar organic chemicals, including hydrocarbons. In general, water, octanol, and the chemical of concern are mixed and allowed to equilibrate, allowed to settle, and then the concentration of chemical is measured in both phases. Originally, a shake-flask method was used, until it was discovered that the approach left enough octanol in the water to act as a detergent. Nowadays, slow stir is the method of choice. Gas chromatography is the most common analytical method (Renner, 2002). Other methods include estimating the $K_{ow}$ by the linear relationship between log aqueous solubility and log $K_{ow}$ or by modeling $K_{ow}$ by structure/activity relationships for molecular structure, molecular volume, and various other physical and chemical properties. The different estimation methods produce values that may vary by an order of magnitude or more, particularly for high molecular weight compounds with extremely low aqueous solubilities (Güsten et al., 1991; Mackay et al., 1992; de Maagd et al., 1998). The most representative, most widely used values for Log $K_{ow}$, as recommended by Mackay et al. (1992) in TPHCWG (1997), were used in this report.

***Application Factor***

Because of the small number of toxicity tests available and the small number of taxa of animals used in the tests, an AF of 15 was applied to the estimated mean toxicity values to obtain a conservative final chronic toxicity value, which is protective of most aquatic species. The uncertainty in the geometric mean toxicity values for individual hydrocarbons from the ECOTOX database depends on the number of acute and chronic toxicity tests performed and the number of different major animal taxa (*e.g.*, crustaceans, annelids, mollusks, fish) tested (EC, 2003). If few, mainly acute, tests were performed on just a few taxa, the resulting mean toxicity value is less less certain than mean values based on a large number of acute and chronic tests with several

species representing a wide taxonomic range. There is a paucity of good aquatic toxicity data for higher molecular weight aromatic hydrocarbons and aliphatic hydrocarbons, mainly because of difficulty in getting enough of these low-solubility chemicals into solution to cause biological effects. Thus, high AFs are needed to be sufficiently protective of more sensitive species and life stages, which is the approach taken in this report. To ensure adequate protection of multiple species, the selected AF (15) is higher than that recommended by ECETOC (Länge et al., 1998) and Hansen et al. (2003).

***Limited Toxicity Data for Aliphatic Hydrocarbons***

Toxicity data for aliphatic hydrocarbons were limited, especially for the higher molecular weight fractions. The reason for this lack of data is that the solubility of these hydrocarbons is so low, that it is difficult to get enough hydrocarbons into solution to cause chemical toxicity. As a major fraction of most petroleum products, these hydrocarbons contribute to the physical effects of petroleum contamination in sediments by changing the sediment's texture, porosity, oxygen levels, and redox potential, all of which can cause adverse effects to aquatic and benthic organisms. It is difficult, however, to develop sediment benchmarks for these physical and aesthetic effects in sediments.

***Marine vs. Freshwater Species***

Both marine and freshwater toxicity data were used in this approach to develop sediment benchmarks for petroleum because it is important to use the largest amount of available, reliable aquatic toxicity data to develop appropriate benchmarks. Acute and chronic toxicity data for freshwater and marine species, spanning a wide taxonomic range, are used to derive the most representative mean toxicity values for each hydrocarbon (Di Toro et al., 1991, 2000, 2007; Hansen et al., 2003). Because bioaccumulation of non-polar organic compounds (such as hydrocarbons) is only moderately affected by ambient water salinity, toxicity of these chemicals to freshwater and marine organisms is similar. Sediment benchmarks based on both freshwater and marine data are equally applicable and protective in both marine and freshwater ecosystems.

***Toxicity Test Duration***

The duration of aquatic toxicity tests used to derive sediment benchmarks ranged from 24 hours to months (life cycle tests are often performed for a significant fraction of the normal life-span of the test organism). The 24 hour tests are usually preformed on small, short-lived organisms, such as water fleas, and brine shrimp. These organisms equilibrate rapidly with dissolved chemicals in the ambient water and therefore respond to toxicants more quickly than do larger animals. Inclusion of long term tests in the toxicity dataset is a conservative strategy intended, along with the acute-chronic ratio, to protect more sensitive, untested species. This approach was used by Di Toro et al. (1991, 2000), Hansen et al. (2003), and the EC (2003) to develop benchmarks for non-polar organic chemicals in water and sediments.

Overall, these uncertainties were addressed in an appropriately conservative manner consistent with previous work by Hansen et al. (2003), DiToro et al. (1991), Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) (1997), and the European Community (EC) (2003).

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# Appendix A
# Toxicological Data

**Table A-1. Various Hydrocarbon Names Used to Search ECOTOX Database**

| Aliphatic Hydrocarbons | Aromatic Hydrocarbons |
|---|---|
| n-Pentane | Benzene |
| 2,2-Dimethylbutane | Toluene |
| Cyclopentane | Ethylbenzene |
| 2,3-Dimethylbutane | p-Xylene |
| 2-Methylpentane | o-Xylene |
| 3-Methylpentane | Isopropylbenzene |
| n-Hexane | n-Propylbenzene |
| 2,2-Dimethylpentane | 1-Methyl-4-ethylbenzene |
| Methylcyclopentane | 1,3,5-Trimethylbenzene |
| 2,4-Dimethylpentane | Isobutylbenzene |
| 2,2,3-Trimethylbutane | Sec-Butylbenzene |
| 3,3-Dimethylpentane | 1-Methyl-4-isopropylbenzene |
| Cyclohexane | n-Butylbenzene |
| 2-Methylhexane | 1,2,4,5-Tetramethylbenzene |
| 2,3-Dimethylpentane | Naphthalene |
| 3-Methylhexane | 2-Methylnaphthalene |
| 2,2,4-Trimethylpentane | 1-Methylnaphthalene |
| Heptane | 2-Ethylnaphthalene |
| n-Propylcyclopentane | Biphenyl |
| Methylcyclohexane | 2,6-Dimethylnaphthalene |
| 1,1,3-Trimethylcyclopentane | 2,3-Dimethylnaphthalene |
| 2.3.4-Trimethylpentane | Acenaphthene |
| 2,3-Dimethylhexane | Fluorene |
| 2-Methylheptane | Phenanthrene |
| 3-Methylheptane | Anthracene |
| 1,4-Dimethylcyclohexane | 1-Methylphenanthrene |
| 2,2,5-Trimethylhexane | Pyrene |
| 1,2-Dimethylcyclohexane | Fluoranthene |
| Octane | Benzo(a)fluorene |
| 4-Methyloctane | Benz(a)anthracene |
| 3-Methyloctane | Chrysene |
| Nonane | Benzo(a)pyrene |
| Decane | Coronene |
| Undecane | Benzo(ghi)perylene |
| Dodecane | Dibenz(a,h)anthracene |
| Tetradecane | |
| Pentadecane | |
| Hexadecane | |
| Heptadecane | |
| Octadecane | |
| Nonadecane | |
| Eicosane | |
| Tetracosane | |

**Table A-2. Field Code Descriptions for ECOTOX Data**

| Field Code | Description | Manipulations/Selected Data |
|---|---|---|
| **Test Loc** | Test Location = lab or field | Only lab studies were retained |
| **CAS #** | Chemical Abstracts Service Number | Retained |
| **Chemical Name** | CAS Collective Index Name | Retained |
| **Scientific Name** | Species scientific name | Retained |
| **Common Name** | Species common name | Retained |
| **Endpoint** | The study endpoint - refer to ECOTOX for the full list. | Only $LC_{50}$, $EC_{50}$, $ED_{50}$, $LT_{50}$, NOEC, LOEC were retained. |
| **Effect** | The study effects - refer to ECOTOX for the full list. | For acute data, only mortality was selected; for chronic data survival and reproduction were selected. |
| **Effect Measurement** | Same as effect | For acute data, only mortality was selected; for chronic data survival and reproduction were selected. |
| **Trend** | The observed or measured response trend as compared to the control is coded when textually or graphically reported. | All retained |
| **Media Type** | FW = freshwater; SW = saltwater | Both retained |
| **Test Duration** | Length of study | All studies greater than 24 hours were retained. |
| **Duration Units** | Days or hours | All converted to hours if not reported as such. |
| **Exposure Type** | F = flow through; S = static; R = renewal; L = leachate; I = Injection; D = Diet | I and D rejected; all others retained |
| **Significant** | Statistical analysis as compared to the controls in the test result. | All retained |
| **Level** | The level of significance, if reported. | All retained |
| **Response Site** | A response site or tissue code is used to identify specific body, organ or tissue effect sites for associated effect measurement. | All retained |
| **BCF1 Mean Op** | Bioconcentration factor operation – not applicable | Column not used |
| **BCF1 Mean** | Bioconcentration factor – not applicable | Column not used |
| **BCF1 Min Op** | Bioconcentration factor operation – not applicable | Column not used |
| **BCF1 Min** | Bioconcentration factor – not applicable | Column not used |
| **BCF1 Max Op** | Bioconcentration factor operation – not applicable | Column not used |
| **BCF1 Max** | Bioconcentration factor – not applicable | Column not used |

**Table A-2. Field Code Descriptions for ECOTOX Data (continued)**

| Field Code | Description | Manipulations/Selected Data |
|---|---|---|
| **BCF2 Mean Op** | Bioconcentration factor operation – not applicable | Column not used |
| **BCF2 Mean** | Bioconcentration factor – not applicable | Column not used |
| **BCF2 Min Op** | Bioconcentration factor operation – not applicable | Column not used |
| **BCF2 Min** | Bioconcentration factor – not applicable | Column not used |
| **BCF2 Max Op** | Bioconcentration factor operation – not applicable | Column not used |
| **BCF2 Max** | Bioconcentration factor – not applicable | Column not used |
| **Author** | Author of study | Retained |
| **Year** | Year published | Retained |
| **Title** | Article Title | Retained |
| **Ref Source** | Journal Title | Retained |
| **Concentration1 Mean Op** | Operation signs such as <, >, = | Data associated with <, > values not retained; data associated with = were retained. |
| **Concentration1 Mean** | Mean reported concentration | Retained |
| **Concentration1 Min Op** | Operation signs such as <, >, = | Data associated with <, > values not retained; data associated with = were retained. |
| **Concentration1 Min** | Minimum reported concentration | If the mean and max concentrations were the only two fields reported, the mean of the two was taken. |
| **Concentration1 Max Op** | Operation signs such as <, >, = | Data associated with <, > values not retained; data associated with = were retained. |
| **Concentration1 Max** | Maximum reported concentration | If the mean and max concentrations were the only two fields reported, the mean of the two was taken. |
| **Concentration1 Type** | Concentrations based on the active ingredient (A) or formulation (F) | Both retained |
| **Concentration2 Mean Op** | Not reported (NR) | Column not used |
| **Concentration2 Mean** | Not reported (NR) | Column not used |
| **Concentration2 Min Op** | Not reported (NR) | Column not used |
| **Concentration2 Min** | Not reported (NR) | Column not used |
| **Concentration2 Max Op** | Not reported (NR) | Column not used |
| **Concentration2 Max** | Not reported (NR) | Column not used |
| **Concentration2 Type** | Not reported (NR) | Column not used |
| **Concentration Units** | Concentration units | All converted to µg/L if not reported as such. |
| **Application Rate** | Not applicable | Column not used |
| **Application Units** | Not applicable | Column not used |
| **Application Type** | Not applicable | Column not used |
| **Application Frequency** | Not applicable | Column not used |

**Table A-2. Field Code Descriptions for ECOTOX Data (continued)**

| Field Code | Description | Manipulations/Selected Data |
|---|---|---|
| **Application Date** | Not applicable | Column not used |
| **Application Season** | Not applicable | Column not used |

**Table A-3. Aromatic Hydrocarbon Toxicity Data (pages A-5 through A-27)**

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| [1,1'-Biphenyl]-4-ol | *Daphnia magna* | Water flea | 48 | LC50 | 3660 | Carlson and Caple, 1977 |
| 1,1'-Biphenyl | *Artemia salina* | Brine shrimp | 24 | LC50 | 4009 | Abernethy et al., 1986 |
| 1,1'-Biphenyl | *Artemia salina* | Brine shrimp | 24 | LC50 | 4009 | Abernethy et al., 1986 |
| 1,1'-Biphenyl | *Cyprinodon variegatus* | Sheepshead minnow | 96 | LC50 | 4600 | Dill et al., 1982 |
| 1,1'-Biphenyl | *Daphnia magna* | Water flea | 24 | LC50 | 1300 | Gersich et al., 1989 |
| 1,1'-Biphenyl | *Daphnia magna* | Water flea | 48 | LC50 | 4700 | LeBlanc, 1980 |
| 1,1'-Biphenyl | *Daphnia magna* | Water flea | 48 | LC50 | 2100 | Dill et al., 1982 |
| 1,1'-Biphenyl | *Daphnia magna* | Water flea | 48 | LC50 | 360 | Gersich et al., 1989 |
| 1,1'-Biphenyl | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 4700 | Dill et al., 1982 |
| 1,1'-Biphenyl | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 1500 | Dill et al., 1982 |
| 1,1'-Biphenyl | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 1950 | Brooke, 1991 |
| 1,1'-Biphenyl | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 3500 | Brooke, 1991 |
| 1,1'-Biphenyl | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 2940 | Brooke, 1991 |
| 1,1'-Biphenyl | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 1450 | Brooke, 1991 |
| 1,2,4,5-Tetramethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 470 | Abernethy et al., 1986 |
| 1,2,4-Trimethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 3606 | Abernethy et al., 1986 |
| 1,2,4-Trimethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 7720 | Geiger et al., 1986 |
| 1,2-Dimethylbenzene | *Morone saxatilis* | Striped bass | 96 | LC50 | 9642 | Benville and Korn, 1977 |
| 1,2-Dimethylbenzene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 7600 | Galassi et al., 1988 |
| 1,2-Dimethylbenzene | *Poecilia reticulata* | Guppy | 96 | LC50 | 12000 | Galassi et al., 1988 |
| 1,2-Dimethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 16400 | Geiger et al., 1990 |
| 1,2-Dimethylbenzene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 8050 | Holcombe et al., 1987 |
| 1,2-Dimethylbenzene | *Carassius auratus* | Goldfish | 96 | LC50 | 16100 | Holcombe et al., 1987 |
| 1,2-Dimethylbenzene | *Catostomus commersoni* | White sucker | 96 | LC50 | 16100 | Holcombe et al., 1987 |
| 1,2-Dimethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 16100 | Holcombe et al., 1987 |
| 1,2-Dimethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 16100 | Holcombe et al., 1987 |
| 1,2-Dimethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 3168 | Abernethy et al., 1986 |
| 1,3- Dimethylbenzene | *Morone saxatilis* | Striped bass | 96 | LC50 | 8064 | Benville and Korn, 1977 |
| 1,3,5-Trimethylbenzene | *Carassius auratus* | Goldfish | 96 | LC50 | 12520 | Brenniman et al., 1976 |
| 1,3,5-Trimethylbenzene | *Cancer magister* | Dungeness, Edible crab | 96 | LC50 | 4300 | Caldwell et al., 1977 |
| 1,3,5-Trimethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 6010 | Abernethy et al., 1986 |
| 1,3-Dimethylbenzene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 8400 | Galassi et al., 1988 |
| 1,3-Dimethylbenzene | *Poecilia reticulata* | Guppy | 96 | LC50 | 12900 | Galassi et al., 1988 |
| 1,3-Dimethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 16000 | Geiger et al., 1990 |
| 1,3-Dimethylbenzene | *Ceriodaphnia dubia* | Water flea | 168 | LC50 | 2974 | Niederlehner et al., 1998 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| 1,3-Dimethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 9558 | Abernethy et al., 1986 |
| 1,3-Dimethylnaphthalene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 1700 | Edsall, 1991 |
| 1,3-Dimethylnaphthalene | *Daphnia pulex* | Water flea | 48 | LC50 | 767 | Smith et al., 1988 |
| 1,4-Dimethylbenzene | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 1753 | Benville and Korn, 1977 |
| 1,4-Dimethylbenzene | *Morone saxatilis* | Striped bass | 96 | LC50 | 1753 | Benville and Korn, 1977 |
| 1,4-Dimethylbenzene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 2600 | Galassi et al., 1988 |
| 1,4-Dimethylbenzene | *Poecilia reticulata* | Guppy | 96 | LC50 | 8800 | Galassi et al., 1988 |
| 1-Methylnaphthalene | *Artemia salina* | Brine shrimp | 24 | LC50 | 2560 | Abernethy et al., 1986 |
| 1-Methylnaphthalene | *Cancer magister* | Dungeness or edible crab | 48 | LC50 | 8200 | Caldwell et al., 1977 |
| 1-Methylnaphthalene | *Cancer magister* | Dungeness or edible crab | 96 | LC50 | 1900 | Caldwell et al., 1977 |
| 1-Methylnaphthalene | *Cyprinodon variegatus* | Sheepshead minnow | 24 | LC50 | 3400 | Anderson et al., 1974 |
| 1-Methylnaphthalene | *Nitocra spinipes* | Harpacticoid copepod | 96 | LC50 | 13000 | Bengtsson and Tarkpea, 1983 |
| 1-Methylnaphthalene | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 9000 | Mattson et al., 1976 |
| 1-Methylnaphthalene | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 9000 | Mattson et al., 1976 |
| 1-Methylnaphthalene | *Pimephales promelas* | Fathead minnow | 72 | LC50 | 9000 | Mattson et al., 1976 |
| 1-Methylnaphthalene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 9000 | Mattson et al., 1976 |
| 2,6-Dimethylnaphthalene | *Eurytemora affinis* | Calanoid copepod | 24 | LC50 | 852 | Ott et al., 1978 |
| 2,6-Dimethylnaphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 700 | Neff et al., 1976 |
| 2-Methylnaphthalene | *Artemia salina* | Brine shrimp | 24 | LC50 | 474 | Abernethy et al., 1986 |
| 2-Methylnaphthalene | *Artemia salina* | Brine shrimp | 24 | LC50 | 4735 | Abernethy et al., 1986 |
| 2-Methylnaphthalene | *Cancer magister* | Dungeness or edible crab | 48 | LC50 | 5000 | Caldwell et al., 1977 |
| 2-Methylnaphthalene | *Cancer magister* | Dungeness or edible crab | 96 | LC50 | 1300 | Caldwell et al., 1977 |
| 2-Methylnaphthalene | *Cyprinodon variegatus* | Sheepshead minnow | 24 | LC50 | 2000 | Anderson et al., 1974 |
| 2-Methylnaphthalene | *Eurytemora affinis* | Calanoid copepod | 24 | LC50 | 1499 | Ott et al., 1978 |
| 2-Methylnaphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 24 | LC50 | 2443 | Kennedy, 1990 |
| 2-Methylnaphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 48 | LC50 | 2080 | Kennedy, 1990 |
| 2-Methylnaphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 72 | LC50 | 1694 | Kennedy, 1990 |
| 2-Methylnaphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 1456 | Kennedy, 1990 |
| 2-Methylnaphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 24 | LC50 | 1700 | Anderson et al., 1974 |
| 2-Methylnaphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 24 | LC50 | 1650 | Tatem, 1975 |
| 2-Methylnaphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 48 | LC50 | 1400 | Tatem, 1975 |
| 2-Methylnaphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 1100 | Tatem et al., 1978 |
| 2-Methylnaphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 1100 | Tatem, 1975 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| 2-Methylnaphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 1100 | Neff et al., 1976 |
| 2-Methylnaphthalene | *Penaeus aztecus* | Brown shrimp | 24 | LC50 | 700 | Anderson et al., 1974 |
| 2-Methylnaphthalene | *Penaeus aztecus* | Brown shrimp | 96 | LC50 | 600 | Tatem et al., 1978 |
| Anthracene | *Americamysis bahia* | Opossum shrimp | 48 | LC50 | 3.6 | Pelletier et al., 1997 |
| Anthracene | *Chironomus tentans* | Midge | 240 | LC50 | 6 | Hatch, 1999 |
| Anthracene | *Hyalella azteca* | Scud | 240 | LC50 | 5.6 | Hatch, 1999 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 9.69 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 3.36 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 11.56 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 10.05 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 5.1 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 12.02 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 2.78 | Oris, 1985 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 4.5 | Oris, 1986 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 46 | Oris, 1986 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 7.47 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 1.27 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 7.97 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 6.78 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 3.74 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 8.27 | McCloskey and Oris, 1991 |
| Anthracene | *Lepomis sp.* | Sunfish | 96 | LC50 | 26.47 | Oris, 1986 |
| Anthracene | *Lepomis sp.* | Sunfish | 96 | LC50 | 18.23 | Oris, 1985 |
| Anthracene | *Lepomis sp.* | Sunfish | 96 | LC50 | 11.92 | Oris, 1985 |
| Anthracene | *Lepomis macrochirus* | Bluegill | 202 | LT50 | 15 | Oris, 1986 |
| Benzene | *Ceriodaphnia dubia* | Water flea | 24 | LC50 | 18400 | Marchini et al., 1993 |
| Benzene | *Mugil curema* | White mullet | 48 | LC50 | 22000 | Correa and Garcia, 1990 |
| Benzene | *Pimephales promelas* | Fathead minnow | 168 | LC50 | 14010 | Marchini et al., 1992 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 24600 | Geiger et al., 1990 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 12600 | Geiger et al., 1990 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 15590 | Marchini et al., 1992 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 24600 | Marchini et al., 1992 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Benzene | *Platichthys flesus* | Starry, european flounder | 97 | LC50 | 10864 | Furay and Smith, 1995 |
| Benzene | *Ambystoma mexicanum* | Mexican axolotl | 24 | LC50 | 440000 | Slooff, 1982 |
| Benzene | *Ambystoma mexicanum* | Mexican axolotl | 48 | LC50 | 370000 | Slooff and Baerselman, 1980 |
| Benzene | *Ambystoma mexicanum* | Mexican axolotl | 48 | LC50 | 370000 | Slooff, 1982 |
| Benzene | *Artemia salina* | Brine shrimp | 24 | LC50 | 127325 | Abernethy et al., 1986 |
| Benzene | *Artemia sp.* | Brine shrimp | 48 | LC50 | 97800 | MacLean and Doe, 1989 |
| Benzene | *Artemia sp.* | Brine shrimp | 48 | LC50 | 139000 | MacLean and Doe, 1989 |
| Benzene | *Asellus aquaticus* | Aquatic sowbug | 48 | LC50 | 120000 | Slooff, 1983 |
| Benzene | *Chironomus thummi* | Midge | 48 | LC50 | 100000 | Slooff, 1983 |
| Benzene | *Corixa punctata* | Water boatman | 48 | LC50 | 48000 | Slooff, 1983 |
| Benzene | *Daphnia magna* | Water flea | 24 | LC50 | 250000 | LeBlanc, 1980 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 200000 | LeBlanc, 1980 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 682000 | Eastmond et al., 1984 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 96200 | MacLean and Doe, 1989 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 99200 | MacLean and Doe, 1989 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 76900 | MacLean and Doe, 1989 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 59600 | MacLean and Doe, 1989 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 156600 | MacLean and Doe, 1989 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 135700 | MacLean and Doe, 1989 |
| Benzene | *Daphnia pulex* | Water flea | 96 | LC50 | 15000 | Trucco et al., 1983 |
| Benzene | *Diaptomus forbesi* | Calanoid copepod | 96 | LC50 | 710000 | Saha and Konar, 1983 |
| Benzene | *Gammarus pseudolimnaeus* | Scud | 96 | LC50 | 12100 | Brooke, 1987 |
| Benzene | *Gammarus pulex* | Scud | 48 | LC50 | 42000 | Slooff, 1983 |
| Benzene | *Hydra oligactis* | Hydra | 48 | LC50 | 34000 | Slooff et al., 1983 |
| Benzene | *Hydra oligactis* | Hydra | 48 | LC50 | 34000 | Slooff, 1983 |
| Benzene | *Ictalurus punctatus* | Channel catfish | 24 | LC50 | 425000 | Mayer and Ellersieck, 1986 |
| Benzene | *Ictalurus punctatus* | Channel catfish | 96 | LC50 | 425000 | Mayer and Ellersieck, 1986 |
| Benzene | *Katelysia opima* | Marine bivalve | 24 | LC50 | 225000 | Dange and Masurekar, 1984 |
| Benzene | *Katelysia opima* | Marine bivalve | 48 | LC50 | 205000 | Dange and Masurekar, 1984 |
| Benzene | *Katelysia opima* | Marine bivalve | 72 | LC50 | 195000 | Dange and Masurekar, 1984 |
| Benzene | *Katelysia opima* | Marine bivalve | 96 | LC50 | 190000 | Dange and Masurekar, 1984 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 400000 | Mayer and Ellersieck, 1986 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 140000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 910000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 740000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 580000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 370000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 260000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 102000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 165000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 230000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 100000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 600000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 450000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 290000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 370000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 260000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 102000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 165000 | Mayer and Ellersieck, 1986 |
| Benzene | *Lymnaea stagnalis* | Great pond snail | 24 | LC50 | 440000 | Slooff, 1982 |
| Benzene | *Lymnaea stagnalis* | Great pond snail | 48 | LC50 | 230000 | Slooff et al., 1983 |
| Benzene | *Lymnaea stagnalis* | Great pond snail | 48 | LC50 | 230000 | Slooff, 1983 |
| Benzene | *Lymnaea stagnalis* | Great pond snail | 48 | LC50 | 230000 | Slooff, 1982 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 24 | LC50 | 9200 | Mayer and Ellersieck, 1986 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 48 | LC50 | 56000 | Slooff et al., 1983 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 21637 | Hodson et al., 1984 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 5900 | Galassi et al., 1988 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 5300 | Degraeve et al., 1982 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 9200 | Mayer and Ellersieck, 1986 |
| Benzene | *Oryzias latipes* | Medaka, high-eyes | 24 | LC50 | 74000 | Tsuji et al., 1986 |
| Benzene | *Oryzias latipes* | Medaka, high-eyes | 24 | LC50 | 70000 | Tsuji et al., 1986 |
| Benzene | *Oryzias latipes* | Medaka, high-eyes | 24 | LC50 | 54000 | Tsuji et al., 1986 |
| Benzene | *Oryzias latipes* | Medaka, high-eyes | 48 | LC50 | 250000 | Slooff et al., 1983 |
| Benzene | *Oryzias latipes* | Medaka, high-eyes | 48 | LC50 | 74000 | Tsuji et al., 1986 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Benzene | *Oryzias latipes* | Medaka, high-eyes | 48 | LC50 | 70000 | Tsuji et al., 1986 |
| Benzene | *Oryzias latipes* | Medaka, high-eyes | 48 | LC50 | 54000 | Tsuji et al., 1986 |
| Benzene | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 78000 | Slooff, 1982 |
| Benzene | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 84000 | Slooff et al., 1983 |
| Benzene | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 84000 | Slooff, 1982 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 12500 | Brooke, 1987 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 35700 | Brooke, 1987 |
| Benzene | *Poecilia reticulata* | Guppy | 96 | LC50 | 28600 | Galassi et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 24 | LC50 | 7146 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 24 | LC50 | 9117 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 24 | LC50 | 11299 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 24 | LC50 | 7146 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 24 | LC50 | 5614 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 48 | LC50 | 5799 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 48 | LC50 | 8052 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 48 | LC50 | 10014 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 48 | LC50 | 5799 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 48 | LC50 | 4418 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 72 | LC50 | 4629 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 72 | LC50 | 7339 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 72 | LC50 | 8941 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 72 | LC50 | 4629 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 72 | LC50 | 3291 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 96 | LC50 | 3678 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 96 | LC50 | 6090 | Rao et al., 1988 |
| Benzene | *Scylla serrata* | Crab | 96 | LC50 | 7682 | Rao et al., 1988 |
| Benzene | *Therapon jarbua* | Tigerfish, crescent perch | 24 | LC50 | 96000 | Dange and Masurekar, 1984 |
| Benzene | *Therapon jarbua* | Tigerfish, crescent perch | 48 | LC50 | 94000 | Dange and Masurekar, 1984 |
| Benzene | *Therapon jarbua* | Tigerfish, crescent perch | 72 | LC50 | 88000 | Dange and Masurekar, 1984 |
| Benzene | *Therapon jarbua* | Tigerfish, crescent perch | 96 | LC50 | 84000 | Dange and Masurekar, 1984 |
| Benzene | *Morone saxatilis* | Striped bass | 96 | LC50 | 5084 | Benville and Korn, 1977 |
| Benzene | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 17500 | Benville and Korn, 1977 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Benzene | *Cancer magister* | Dungeness crab, edible | 96 | LC50 | 108000 | Caldwell et al., 1977 |
| Benzene | *Daphnia pulex* | Water flea | 48 | LC50 | 265000 | Canton and Adema, 1978 |
| Benzene | *Daphnia pulex* | Water flea | 48 | LC50 | 345000 | Canton and Adema, 1978 |
| Benzene | *Daphnia cucullata* | Water flea | 48 | LC50 | 356000 | Canton and Adema, 1978 |
| Benzene | *Daphnia cucullata* | Water flea | 48 | LC50 | 390000 | Canton and Adema, 1978 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 400000 | Canton and Adema, 1978 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 412000 | Canton and Adema, 1978 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 620000 | Canton and Adema, 1978 |
| Benzene | *Ceriodaphnia dubia* | Water flea | 168 | LC50 | 12419 | Niederlehner et al., 1998 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 5300 | Degraeve et al., 1982 |
| Benzene | *Daphnia magna* | Water flea | 48 | LC50 | 682000 | Eastmond et al., 1984 |
| Benzene | *Gammarus fossarum* | Scud | 120 | LC50 | 58000 | Erben and Pisl, 1993 |
| Benzene | *Gammarus fossarum* | Scud | 96 | LC50 | 6000 | Erben and Pisl, 1993 |
| Benzene | *Asellus aquaticus* | Aquatic sowbug | 96 | LC50 | 290000 | Erben and Pisl, 1993 |
| Benzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 9200 | Johnson and Finley, 1980 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 100000 | Johnson and Finley, 1980 |
| Benzene | *Ictalurus punctatus* | Channel catfish | 96 | LC50 | 425000 | Johnson and Finley, 1980 |
| Benzene | *Morone saxatilis* | Striped bass | 96 | LC50 | 9554 | Meyeroff, 1975 |
| Benzene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 4628 | Moles et al., 1979 |
| Benzene | *Oncorhynchus nerka* | Sockeye salmon | 96 | LC50 | 4865 | Moles et al., 1979 |
| Benzene | *Salvelinus malma* | Dolly varden | 96 | LC50 | 5522 | Moles et al., 1979 |
| Benzene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 7424 | Moles et al., 1979 |
| Benzene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 8590 | Moles et al., 1979 |
| Benzene | *Oncorhynchus nerka* | Sockeye salmon | 96 | LC50 | 9431 | Moles et al., 1979 |
| Benzene | *Oncorhynchus tshawytscha* | Chinook salmon | 96 | LC50 | 10281 | Moles et al., 1979 |
| Benzene | *Salvelinus malma* | Dolly varden | 96 | LC50 | 10430 | Moles et al., 1979 |
| Benzene | *Salvelinus malma* | Dolly varden | 96 | LC50 | 10482 | Moles et al., 1979 |
| Benzene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 12350 | Moles et al., 1979 |
| Benzene | *Thymallus arcticus* | Arctic grayling | 96 | LC50 | 12894 | Moles et al., 1979 |
| Benzene | *Cottus cognatus* | Slimy sculpin | 96 | LC50 | 13507 | Moles et al., 1979 |
| Benzene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 14980 | Moles et al., 1979 |
| Benzene | *Gasterosteus aculeatus* | Threespine stickleback | 96 | LC50 | 21763 | Moles et al., 1979 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Benzene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 297000 | Moles et al., 1979 |
| Benzene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 475000 | Moles et al., 1979 |
| Benzene | *Solea solea* | Dover sole | 96 | LC50 | 10070 | Pickering and Henderson, 1966 |
| Benzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 22490 | Pickering and Henderson, 1966 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 32000 | Pickering and Henderson, 1966 |
| Benzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 33470 | Pickering and Henderson, 1966 |
| Benzene | *Carrasius auratus* | Goldfish | 96 | LC50 | 34420 | Pickering and Henderson, 1966 |
| Benzene | *Poecilia reticulata* | Guppy | 96 | LC50 | 36600 | Pickering and Henderson, 1966 |
| Benzene | *Clupea harengus pallasi* | Pacific herring | 96 | LC50 | 40000 | Struhsaker et al., 1974 |
| Benzene | *Palaemonetes pugio* | Grass shrimp | 96 | LC50 | 27000 | Tatem et al., 1978 |
| Benzene | *Daphnia pulex* | Water flea | 96 | LC50 | 15000 | Trucco et al., 1983 |
| Benzene | *Gambusia affinis* | Western mosquitofish | 96 | LC50 | 386000 | Wallen et al., 1957 |
| Benzene | *Pimephales promelas* | Fathead minnow | 168 | LOEC | 17200 | Marchini et al., 1992 |
| Benzene | *Pimephales promelas* | Fathead minnow | 168 | NOEC | 10200 | Marchini et al., 1992 |
| Benzo(a)pyrene | *Daphnia pulex* | Water flea | 96 | LC50 | 5 | Trucco et al., 1983 |
| Benzo(a)pyrene | *Pimephales promelas* | Fathead minnow | 40 | LT50 | 6 | Oris, 1987 |
| Chrysene | *Daphnia magna* | Water flea | 24 | LT50 | 0.7 | Newsted and Giesy, 1987 |
| Dibenzothiophene | *Palaemonetes pugio* | Grass shrimp | 48 | LC50 | 280 | Wofford and Neff, 1978 |
| Ethenylbenzene | *Ceriodaphnia dubia* | Water flea | 168 | LOEC | 0.13 | Tatarazako et al., 2002 |
| Ethenylbenzene | *Ceriodaphnia dubia* | Water flea | 168 | NOEC | 0.06 | Tatarazako et al., 2002 |
| Ethylbenzene | *Americamysis bahia* | Opossum shrimp | 72 | LC50 | 4000 | Masten et al., 1994 |
| Ethylbenzene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 2600 | Masten et al., 1994 |
| Ethylbenzene | *Menidia menidia* | Atlantic silverside | 24 | LC50 | 7000 | Masten et al., 1994 |
| Ethylbenzene | *Menidia menidia* | Atlantic silverside | 48 | LC50 | 6400 | Masten et al., 1994 |
| Ethylbenzene | *Menidia menidia* | Atlantic silverside | 72 | LC50 | 5800 | Masten et al., 1994 |
| Ethylbenzene | *Menidia menidia* | Atlantic silverside | 96 | LC50 | 5100 | Masten et al., 1994 |
| Ethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 9090 | Geiger et al., 1990 |
| Ethylbenzene | *Artemia salina* | Brine shrimp | 24 | LC50 | 11326 | Abernethy et al., 1986 |
| Ethylbenzene | *Artemia sp.* | Brine shrimp | 48 | LC50 | 8780 | MacLean and Doe, 1989 |
| Ethylbenzene | *Artemia sp.* | Brine shrimp | 48 | LC50 | 13300 | MacLean and Doe, 1989 |
| Ethylbenzene | *Daphnia magna* | Water flea | 24 | LC50 | 77000 | LeBlanc, 1980 |
| Ethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 75000 | LeBlanc, 1980 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Ethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 18400 | MacLean and Doe, 1989 |
| Ethylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 13900 | MacLean and Doe, 1989 |
| Ethylbenzene | *Gammarus pseudolimnaeus* | Scud | 96 | LC50 | 1940 | Brooke, 1987 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 169000 | Buccafusco et al., 1981 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 90000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 100000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 160000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 135000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 134000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 80000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 135000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 150000 | Buccafusco et al., 1981 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 88000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 84000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 140000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 56000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 86000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 135000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 134000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 80000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 135000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 24 | LC50 | 14000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 4200 | Galassi et al., 1988 |
| Ethylbenzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 14000 | Mayer and Ellersieck, 1986 |
| Ethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 12100 | Geiger et al., 1986 |
| Ethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 11900 | Brooke, 1987 |
| Ethylbenzene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 9100 | Brooke, 1987 |
| Ethylbenzene | *Poecilia reticulata* | Guppy | 96 | LC50 | 9600 | Galassi et al., 1988 |
| Ethylbenzene | *Morone saxatilis* | Striped bass | 96 | LC50 | 3769 | Benville and Korn, 1977 |
| Ethylbenzene | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 429 | Benville and Korn, 1977 |
| Ethylbenzene | *Cancer magister* | Dungeness crab, edible | 96 | LC50 | 13000 | Caldwell et al., 1977 |
| Ethylbenzene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 14000 | Johnson and Finley, 1980 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 88000 | Johnson and Finley, 1980 |
| Ethylbenzene | *Ceriodaphnia dubia* | Water flea | 168 | LC50 | 3611 | Neiderlehner et al., 1998 |
| Ethylbenzene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 32000 | Pickering and Henderson, 1966 |
| Ethylbenzene | *Pimpelas promelas* | Fathead minnow | 96 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Ethylbenzene | *Pimpelas promelas* | Fathead minnow | 96 | LC50 | 48510 | Pickering and Henderson, 1966 |
| Ethylbenzene | *Carassius auratus* | Goldfish | 96 | LC50 | 94440 | Pickering and Henderson, 1966 |
| Ethylbenzene | *Poecilia reticulata* | Guppy | 96 | LC50 | 97100 | Pickering and Henderson, 1966 |
| Ethylbenzene | *Mypsidopsis bahia* | Opossum shrimp | 96 | LC50 | 87600 | USEPA, 1978 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 48 | LC50 | 5.32 | Pelletier et al., 1997 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 48 | LC50 | 63.8 | Pelletier et al., 1997 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 40 | USEPA, 1978 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 22 | Spehar et al., 1999 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 1.4 | Spehar et al., 1999 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 31 | Spehar et al., 1999 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 58 | Spehar et al., 1999 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 12 | Spehar et al., 1999 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 12 | Spehar et al., 1999 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 2.8 | Spehar et al., 1999 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 96 | LC50 | 0.8 | Spehar et al., 1999 |
| Fluoranthene | *Ampelisca abdita* | Amphipod | 96 | LC50 | 67 | Spehar et al., 1999 |
| Fluoranthene | *Arbacia punctulata* | Purple-spined sea urchin | 48 | LC50 | 3.9 | Spehar et al., 1999 |
| Fluoranthene | *Arbacia punctulata* | Purple-spined sea urchin | 96 | LC50 | 1 | Spehar et al., 1999 |
| Fluoranthene | *Ceriodaphnia dubia* | Water flea | 48 | LC50 | 45 | Oris et al., 1991 |
| Fluoranthene | *Chironomus riparius* | Midge | 264 | LC50 | 64.1 | Stewart and Thompson, 1995 |
| Fluoranthene | *Chironomus riparius* | Midge | 264 | LC50 | 70.5 | Stewart and Thompson, 1995 |
| Fluoranthene | *Chironomus riparius* | Midge | 264 | LC50 | 61.5 | Stewart and Thompson, 1995 |
| Fluoranthene | *Chironomus riparius* | Midge | 264 | LC50 | 86.1 | Stewart and Thompson, 1995 |
| Fluoranthene | *Chironomus tentans* | Midge | 240 | LC50 | 37.8 | Suedel, 1996 |
| Fluoranthene | *Chironomus tentans* | Midge | 240 | LC50 | 23.6 | Suedel, 1996 |
| Fluoranthene | *Chironomus tentans* | Midge | 240 | LC50 | 12.6 | Hatch, 1999 |
| Fluoranthene | *Chironomus thummi* | Midge | 48 | LC50 | 44 | Horne and Oblad, 1983 |
| Fluoranthene | *Corophium insidiosum* | Scud | 96 | LC50 | 85 | Boese et al., 1997 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Fluoranthene | *Corophium spinicorne* | Corophiid amphipod | 240 | LC50 | 23.9 | Swartz et al., 1990 |
| Fluoranthene | *Corophium spinicorne* | Corophiid amphipod | 240 | LC50 | 37.9 | Swartz et al., 1990 |
| Fluoranthene | *Cyprinodon variegatus* | Sheepshead minnow | 96 | LC50 | 159 | Spehar et al., 1999 |
| Fluoranthene | *Cyprinodon variegatus* | Sheepshead minnow | 96 | LC50 | 0.9 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 240 | LC50 | 102.6 | Suedel, 1996 |
| Fluoranthene | *Daphnia magna* | Water flea | 240 | LC50 | 110.5 | Suedel, 1996 |
| Fluoranthene | *Daphnia magna* | Water flea | 72 | LC50 | 75.22 | Barata and Baird, 2000 |
| Fluoranthene | *Daphnia magna* | Water flea | 72 | LC50 | 73.7 | Barata and Baird, 2000 |
| Fluoranthene | *Daphnia magna* | Water flea | 48 | LC50 | 105.7 | Suedel, 1996 |
| Fluoranthene | *Daphnia magna* | Water flea | 48 | LC50 | 117 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 48 | LC50 | 1.6 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 48 | LC50 | 78 | Spehar et al., 1999 |
| Fluoranthene | *Emerita analoga* | Pacific sand crab | 96 | LC50 | 74 | Boese et al., 1997 |
| Fluoranthene | *Gammarus minus* | Scud | 96 | LC50 | 32 | Horne and Oblad, 1983 |
| Fluoranthene | *Gammarus pseudolimnaeus* | Scud | 96 | LC50 | 108 | Spehar et al., 1999 |
| Fluoranthene | *Grandidierella japonica* | Scud | 96 | LC50 | 36 | Boese et al., 1997 |
| Fluoranthene | *Homarus americanus* | American lobster | 96 | LC50 | 24 | Spehar et al., 1999 |
| Fluoranthene | *Homarus americanus* | American lobster | 96 | LC50 | 13 | Spehar et al., 1999 |
| Fluoranthene | *Homarus americanus* | American lobster | 96 | LC50 | 0.6 | Spehar et al., 1999 |
| Fluoranthene | *Hyalella azteca* | Scud | 240 | LC50 | 30.3 | Suedel, 1996 |
| Fluoranthene | *Hyalella azteca* | Scud | 240 | LC50 | 60.6 | Suedel, 1996 |
| Fluoranthene | *Hyalella azteca* | Scud | 240 | LC50 | 7.3 | Hatch, 1999 |
| Fluoranthene | *Hyalella azteca* | Scud | 48 | LC50 | 92.2 | Suedel, 1996 |
| Fluoranthene | *Hyalella azteca* | Scud | 96 | LC50 | 44 | Spehar et al., 1999 |
| Fluoranthene | *Hydra americana* | Hydra | 96 | LC50 | 70 | Spehar et al., 1999 |
| Fluoranthene | *Hydra americana* | Hydra | 96 | LC50 | 2.2 | Spehar et al., 1999 |
| Fluoranthene | *Hydra americana* | Hydra | 96 | LC50 | 32 | Spehar et al., 1999 |
| Fluoranthene | *Ictalurus punctatus* | Channel catfish | 96 | LC50 | 36 | Gendusa, 1990 |
| Fluoranthene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 12.3 | Spehar et al., 1999 |
| Fluoranthene | *Lumbriculus variegatus* | Oligochaete, worm | 96 | LC50 | 1.2 | Spehar et al., 1999 |
| Fluoranthene | *Menidia beryllina* | Inland silverside | 96 | LC50 | 21 | Spehar et al., 1999 |
| Fluoranthene | *Menidia beryllina* | Inland silverside | 96 | LC50 | 30 | Spehar et al., 1999 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Fluoranthene | *Menidia beryllina* | Inland silverside | 96 | LC50 | 103 | Spehar et al., 1999 |
| Fluoranthene | *Menidia beryllina* | Inland silverside | 96 | LC50 | 49 | Spehar et al., 1999 |
| Fluoranthene | *Menidia beryllina* | Inland silverside | 96 | LC50 | 30 | Spehar et al., 1999 |
| Fluoranthene | *Menidia beryllina* | Inland silverside | 96 | LC50 | 2.3 | Spehar et al., 1999 |
| Fluoranthene | *Mulinia lateralis* | Clam | 48 | LC50 | 2.8 | Spehar et al., 1999 |
| Fluoranthene | *Mulinia lateralis* | Clam | 96 | LC50 | 1.8 | Pelletier et al., 1997 |
| Fluoranthene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 500 | Rossi and Neff, 1978 |
| Fluoranthene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 500 | Neff et al., 1976 |
| Fluoranthene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 187 | Horne and Oblad, 1983 |
| Fluoranthene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 7.7 | Spehar et al., 1999 |
| Fluoranthene | *Palaemonetes sp.* | Grass shrimp,freshwater prawn | 96 | LC50 | 6.5 | Spehar et al., 1999 |
| Fluoranthene | *Palaemonetes sp.* | Grass shrimp,freshwater prawn | 96 | LC50 | 142 | Spehar et al., 1999 |
| Fluoranthene | *Palaemonetes sp.* | Grass shrimp,freshwater prawn | 96 | LC50 | 22 | Spehar et al., 1999 |
| Fluoranthene | *Palaemonetes sp.* | Grass shrimp,freshwater prawn | 96 | LC50 | 3.3 | Spehar et al., 1999 |
| Fluoranthene | *Physa heterostropha* | Pond snail, pneumonate snail | 96 | LC50 | 137 | Horne and Oblad, 1983 |
| Fluoranthene | *Physella virgata* | Snail | 96 | LC50 | 82 | Spehar et al., 1999 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 720 | LC50 | 7.1 | Gendusa, 1990 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 144 | LC50 | 6.83 | Diamond et al., 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 95 | Horne and Oblad, 1983 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 6.83 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 12.2 | Spehar et al., 1999 |
| Fluoranthene | *Pleuronectes americanus* | Winter flounder | 96 | LC50 | 0.1 | Spehar et al., 1999 |
| Fluoranthene | *Rhepoxynius abronius* | Amphipod | 240 | LC50 | 22.7 | Swartz et al., 1990 |
| Fluoranthene | *Rhepoxynius abronius* | Amphipod | 240 | LC50 | 29.4 | Swartz et al., 1990 |
| Fluoranthene | *Rhepoxynius abronius* | Amphipod | 240 | LC50 | 24.2 | Swartz et al., 1990 |
| Fluoranthene | *Rhepoxynius abronius* | Amphipod | 240 | LC50 | 11.1 | Swartz et al., 1990 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 744 | LOEC | 18.8 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | LOEC | 35.3 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | LOEC | 35.3 | Brooke, 1993 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | LOEC | 1.5 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | LOEC | 73.2 | Brooke, 1993 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 768 | LOEC | 21.7 | Spehar et al., 1999 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 768 | LOEC | 21.7 | Spehar et al., 1999 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 113 | LT50 | 4.8 | Weinstein and Oris, 1999 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 45 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 46 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 49 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 52 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 55 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 56 | LT50 | 27.6 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 61 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 64 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 64 | LT50 | 28.2 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 65 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 67 | LT50 | 27.85 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 73 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 73 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 76 | LT50 | 69.75 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 91 | LT50 | 28.2 | Diamond, 1995 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 95 | LT50 | 9.7 | Weinstein and Oris, 1999 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 97 | LT50 | 28.2 | Diamond, 1995 |
| Fluoranthene | *Americamysis bahia* | Opossum shrimp | 744 | NOEC | 11.1 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | NOEC | 17 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | NOEC | 17 | Brooke, 1993 |
| Fluoranthene | *Daphnia magna* | Water flea | 72 | NOEC | 20 | Barata and Baird, 2000 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | NOEC | 1.4 | Spehar et al., 1999 |
| Fluoranthene | *Daphnia magna* | Water flea | 504 | NOEC | 35.3 | Brooke, 1993 |
| Fluoranthene | *Daphnia magna* | Water flea | 72 | NOEC | 30 | Barata and Baird, 2000 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 768 | NOEC | 10.4 | Spehar et al., 1999 |
| Fluoranthene | *Pimephales promelas* | Fathead minnow | 768 | NOEC | 10.4 | Spehar et al., 1999 |
| Isopropylbenzene | *Daphnia magna* | Water flea | 48 | LC50 | 601 | Abernethy et al., 1986 |
| Naphthalene | *Artemia salina* | Brine shrimp | 24 | LC50 | 10638 | Abernethy et al., 1986 |
| Naphthalene | *Artemia salina* | Brine shrimp | 24 | LC50 | 10638 | Abernethy et al., 1986 |
| Naphthalene | *Artemia sp.* | Brine shrimp | 48 | LC50 | 12500 | MacLean and Doe, 1989 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Naphthalene | *Artemia sp.* | Brine shrimp | 48 | LC50 | 9820 | MacLean and Doe, 1989 |
| Naphthalene | *Callinectes sapidus* | Blue crab | 24 | LC50 | 1980 | Sabourin, 1982 |
| Naphthalene | *Callinectes sapidus* | Blue crab | 24 | LC50 | 2250 | Sabourin, 1982 |
| Naphthalene | *Callinectes sapidus* | Blue crab | 24 | LC50 | 3120 | Sabourin, 1982 |
| Naphthalene | *Chironomus attenuatus* | Midge | 24 | LC50 | 13100 | Darville and Wilhm, 1984 |
| Naphthalene | *Chironomus attenuatus* | Midge | 24 | LC50 | 13000 | Darville and Wilhm, 1984 |
| Naphthalene | *Chironomus attenuatus* | Midge | 24 | LC50 | 13900 | Darville, 1982 |
| Naphthalene | *Chironomus attenuatus* | Midge | 24 | LC50 | 13300 | Darville, 1982 |
| Naphthalene | *Chironomus tentans* | Midge | 48 | LC50 | 2810 | Millemann et al., 1984 |
| Naphthalene | *Cyprinodon variegatus* | Sheepshead minnow | 24 | LC50 | 2400 | Anderson et al., 1974 |
| Naphthalene | *Daphnia magna* | Water flea | 24 | LC50 | 17000 | LeBlanc, 1980 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 8600 | LeBlanc, 1980 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 2160 | Millemann et al., 1984 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 22600 | Eastmond et al., 1984 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 12300 | MacLean and Doe, 1989 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 11400 | MacLean and Doe, 1989 |
| Naphthalene | *Daphnia magna* | Water flea | 24 | LC50 | 13200 | Crider et al., 1982 |
| Naphthalene | *Daphnia magna* | Water flea | 24 | LC50 | 6600 | Crider et al., 1982 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 3400 | Crider et al., 1982 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 4100 | Crider et al., 1982 |
| Naphthalene | *Daphnia pulex* | Water flea | 48 | LC50 | 3405 | Geiger, 1982 |
| Naphthalene | *Daphnia pulex* | Water flea | 96 | LC50 | 1000 | Trucco et al., 1983 |
| Naphthalene | *Elasmopus pectinicrus* | Scud | 24 | LC50 | 3650 | Lee and Nicol, 1978 |
| Naphthalene | *Elasmopus pectinicrus* | Scud | 48 | LC50 | 2800 | Lee and Nicol, 1978 |
| Naphthalene | *Elasmopus pectinicrus* | Scud | 96 | LC50 | 2680 | Lee and Nicol, 1978 |
| Naphthalene | *Eualus suckleyi* | Shortscale eualid | 96 | LC50 | 1390 | Rice and Thomas, 1989 |
| Naphthalene | *Eurytemora affinis* | Calanoid copepod | 24 | LC50 | 3798 | Ott et al., 1978 |
| Naphthalene | *Gammarus minus* | Scud | 48 | LC50 | 3930 | Millemann et al., 1984 |
| Naphthalene | *Hemigrapsus nudus* | Shore crab | 192 | LC50 | 1950 | Gharrett and Rice, 1987 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 24 | LC50 | 5000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 24 | LC50 | 5000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 24 | LC50 | 5000 | Jaiswal et al., 1989 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 24 | LC50 | 5000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 24 | LC50 | 5000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 24 | LC50 | 5000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 48 | LC50 | 5000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 48 | LC50 | 5000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 48 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 48 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 48 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 72 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 72 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 72 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 72 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 72 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 96 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 96 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Macrobrachium kistnensis* | Shrimp | 96 | LC50 | 3000 | Jaiswal et al., 1989 |
| Naphthalene | *Micropterus salmoides* | Largemouth bass | 168 | LC50 | 510 | Black et al., 1983 |
| Naphthalene | *Micropterus salmoides* | Largemouth bass | 168 | LC50 | 680 | Millemann et al., 1984 |
| Naphthalene | *Neomysis americana* | Opossum shrimp | 96 | LC50 | 1280 | Smith and Hargreaves, 1983 |
| Naphthalene | *Neomysis americana* | Opossum shrimp | 96 | LC50 | 850 | Smith and Hargreaves, 1983 |
| Naphthalene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 3800 | Rossi and Neff, 1978 |
| Naphthalene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 3800 | Neff et al., 1976 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 24 | LC50 | 920 | Thomas and Rice, 1978 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 960 | LC50 | 1200 | Moles and Rice, 1983 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 48 | LC50 | 960 | Rice and Thomas, 1989 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 48 | LC50 | 900 | Rice and Thomas, 1989 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 48 | LC50 | 990 | Rice and Thomas, 1989 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 48 | LC50 | 1010 | Rice and Thomas, 1989 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 48 | LC50 | 890 | Rice and Thomas, 1989 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 1370 | Korn et al., 1979 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 1840 | Korn et al., 1979 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 1240 | Korn et al., 1979 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 1200 | Moles and Rice, 1983 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 24 | LC50 | 1560 | Korn et al., 1979 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 24 | LC50 | 1840 | Korn et al., 1979 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 24 | LC50 | 1380 | Korn et al., 1979 |
| Naphthalene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 3220 | Moles, 1980 |
| Naphthalene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 2100 | Moles et al., 1981 |
| Naphthalene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 5600 | Korn and Rice, 1981 |
| Naphthalene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 2100 | USEPA, 2000 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 552 | LC50 | 120 | Black et al., 1983 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 648 | LC50 | 110 | Black et al., 1983 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 1800 | Edsall, 1991 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 6100 | Edsall, 1991 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 2600 | Edsall, 1991 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 4400 | Edsall, 1991 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 5500 | Edsall, 1991 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 4500 | Edsall, 1991 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 1600 | Degraeve et al., 1982 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 2250 | Bergman and Anderson, 1977 |
| Naphthalene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 648 | LC50 | 120 | Millemann et al., 1984 |
| Naphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 24 | LC50 | 2600 | Anderson et al., 1974 |
| Naphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 24 | LC50 | 2600 | Tatem, 1975 |
| Naphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 48 | LC50 | 2600 | Tatem, 1975 |
| Naphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 2350 | Tatem et al., 1978 |
| Naphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 2350 | Tatem, 1975 |
| Naphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 2400 | Neff et al., 1976 |
| Naphthalene | *Palaemonetes pugio* | Daggerblade grass shrimp | 48 | LC50 | 2350 | Tatem and Anderson, 1973 |
| Naphthalene | *Pandalus goniurus* | Humpy shrimp | 96 | LC50 | 2160 | Korn et al., 1979 |
| Naphthalene | *Pandalus goniurus* | Humpy shrimp | 96 | LC50 | 1020 | Korn et al., 1979 |
| Naphthalene | *Pandalus goniurus* | Humpy shrimp | 96 | LC50 | 971 | Korn et al., 1979 |
| Naphthalene | *Pandalus goniurus* | Humpy shrimp | 24 | LC50 | 2210 | Korn et al., 1979 |
| Naphthalene | *Pandalus goniurus* | Humpy shrimp | 24 | LC50 | 2060 | Korn et al., 1979 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Naphthalene | *Pandalus goniurus* | Humpy shrimp | 24 | LC50 | 1290 | Korn et al., 1979 |
| Naphthalene | *Penaeus aztecus* | Brown shrimp | 24 | LC50 | 2500 | Anderson et al., 1974 |
| Naphthalene | *Penaeus aztecus* | Brown shrimp | 96 | LC50 | 2500 | Tatem et al., 1978 |
| Naphthalene | *Physa gyrina* | Pouch snail | 48 | LC50 | 5020 | Millemann et al., 1984 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 7760 | Holcombe et al., 1984 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 6350 | Holcombe et al., 1984 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 72 | LC50 | 6080 | Holcombe et al., 1984 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 6080 | Holcombe et al., 1984 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 1990 | Millemann et al., 1984 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 6140 | Geiger et al., 1985 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 6140 | Broderius et al., 1995 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 7900 | Degraeve et al., 1982 |
| Naphthalene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 4900 | Bergman and Anderson, 1977 |
| Naphthalene | *Tanytarsus dissimilis* | Midge | 48 | LC50 | 20700 | Darville and Wilhm, 1984 |
| Naphthalene | *Tanytarsus dissimilis* | Midge | 48 | LC50 | 12600 | Darville and Wilhm, 1984 |
| Naphthalene | *Tanytarsus dissimilis* | Midge | 48 | LC50 | 13700 | Darville, 1982 |
| Naphthalene | *Tanytarsus dissimilis* | Midge | 48 | LC50 | 12200 | Darville, 1982 |
| Naphthalene | *Therapon jarbua* | Tigerfish, crescent perch | 24 | LC50 | 22500 | Dange and Masurekar, 1984 |
| Naphthalene | *Therapon jarbua* | Tigerfish, crescent perch | 48 | LC50 | 20000 | Dange and Masurekar, 1984 |
| Naphthalene | *Therapon jarbua* | Tigerfish, crescent perch | 72 | LC50 | 18000 | Dange and Masurekar, 1984 |
| Naphthalene | *Therapon jarbua* | Tigerfish, crescent perch | 96 | LC50 | 15500 | Dange and Masurekar, 1984 |
| Naphthalene | *Tilapia mossambica* | Mozambique tilapia | 96 | LC50 | 7900 | Dange, 1986 |
| Naphthalene | *Daphnia pulex* | Water flea | 48 | LC50 | 2920 | Geiger and Buikema, 1981 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 4730 | Abernethy et al., 1986 |
| Naphthalene | *Neomysis americana* | Mysid | 96 | LC50 | 850 | Smith and Hargreaves, 1984 |
| Naphthalene | *Neomysis americana* | Mysid | 96 | LC50 | 1280 | Smith and Hargreaves, 1984 |
| Naphthalene | *Daphnia pulex* | Water flea | 96 | LC50 | 1000 | Trucco et al., 1983 |
| Naphthalene | *Oncorhynchus kisutch* | Coho salmon,silver salmon | 96 | LC50 | 2100 | USEPA, 1995 |
| Naphthalene | *Daphnia magna* | Water flea | 48 | LC50 | 8570 | USEPA, 1978 |
| Naphthalene | *Oncorhynchus gorbuscha* | Pink salmon | 24 | LC50 | 920 | Thomas and Rice, 1978 |
| Phenanthrene | *Daphnia magna* | Water flea | 24 | EC50 | 302 | Brooke, 1994 |
| Phenanthrene | *Daphnia magna* | Water flea | 48 | EC50 | 212 | Brooke, 1994 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Phenanthrene | *Daphnia magna* | Water flea | 48 | EC50 | 230 | Brooke, 1994 |
| Phenanthrene | *Artemia salina* | Brine shrimp | 24 | LC50 | 677 | Abernethy et al., 1986 |
| Phenanthrene | *Artemia salina* | Brine shrimp | 24 | LC50 | 677 | Abernethy et al., 1986 |
| Phenanthrene | *Chironomus tentans* | Midge | 48 | LC50 | 490 | Millemann et al., 1984 |
| Phenanthrene | *Cyprinodon variegatus* | Sheepshead minnow | 96 | LC50 | 478 | Moreau et al., 1999 |
| Phenanthrene | *Daphnia magna* | Water flea | 48 | LC50 | 700 | Millemann et al., 1984 |
| Phenanthrene | *Daphnia magna* | Water flea | 48 | LC50 | 843 | Eastmond et al., 1984 |
| Phenanthrene | *Daphnia pulex* | Water flea | 48 | LC50 | 1120 | Geiger, 1982 |
| Phenanthrene | *Daphnia pulex* | Water flea | 96 | LC50 | 100 | Trucco et al., 1983 |
| Phenanthrene | *Eohaustorius estuarius* | Amphipod | 240 | LC50 | 158 | Swartz et al., 1995 |
| Phenanthrene | *Gammarus minus* | Scud | 48 | LC50 | 460 | Millemann et al., 1984 |
| Phenanthrene | *Leptocheirus plumulosus* | Amphipod | 240 | LC50 | 180 | Dewitt et al., 1992 |
| Phenanthrene | *Micropterus salmoides* | Largemouth bass | 168 | LC50 | 180 | Black et al., 1983 |
| Phenanthrene | *Micropterus salmoides* | Largemouth bass | 168 | LC50 | 250 | Millemann et al., 1984 |
| Phenanthrene | *Nereis arenaceodentata* | Polychaete worm | 336 | LC50 | 501 | Emery and Dillon, 1996 |
| Phenanthrene | *Nereis arenaceodentata* | Polychaete worm | 336 | LC50 | 501 | Emery and Dillon, 1996 |
| Phenanthrene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 51 | Emery and Dillon, 1996 |
| Phenanthrene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 51 | Emery and Dillon, 1996 |
| Phenanthrene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 600 | Rossi and Neff, 1978 |
| Phenanthrene | *Nereis arenaceodentata* | Polychaete worm | 96 | LC50 | 600 | Neff et al., 1976 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 552 | LC50 | 40 | Black et al., 1983 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 648 | LC50 | 40 | Black et al., 1983 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | LC50 | 0.0002 | Passino-Reader, 1993 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 648 | LC50 | 30 | Millemann et al., 1984 |
| Phenanthrene | *Daphnia magna* | Water flea | 504 | LOEC | 93 | Brooke, 1993 |
| Phenanthrene | *Daphnia magna* | Water flea | 504 | LOEC | 345 | Brooke, 1993 |
| Phenanthrene | *Daphnia pulex* | Water flea | 384 | LOEC | 60 | Savino and Tanabe, 1989 |
| Phenanthrene | *Daphnia pulex* | Water flea | 384 | LOEC | 60 | Savino and Tanabe, 1989 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | LOEC | 44 | Passino-Reader et al., 1995 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | LOEC | 88 | Passino-Reader et al., 1995 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | LOEC | 75 | Passino-Reader et al., 1995 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | LOEC | 75 | Passino-Reader et al., 1995 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Phenanthrene | *Daphnia magna* | Water flea | 504 | NOEC | 48 | Brooke, 1993 |
| Phenanthrene | *Daphnia magna* | Water flea | 504 | NOEC | 183 | Brooke, 1993 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | NOEC | 44 | Passino-Reader et al., 1995 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | NOEC | 19 | Passino-Reader et al., 1995 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | NOEC | 38 | Passino-Reader et al., 1995 |
| Phenanthrene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 1440 | NOEC | 38 | Passino-Reader et al., 1995 |
| Propyl benzene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 1550 | Galassi et al., 1988 |
| Pyrene | *Americamysis bahia* | Opossum shrimp | 48 | LC50 | 0.89 | Pelletier et al., 1997 |
| Pyrene | *Americamysis bahia* | Opossum shrimp | 48 | LC50 | 24.8 | Pelletier et al., 1997 |
| Pyrene | *Mulinia lateralis* | Clam | 96 | LC50 | 1.68 | Pelletier et al., 1997 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 25000 | Devlin, 1983 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 55000 | Devlin, 1983 |
| Toluene | *Morone saxatilis* | Striped bass | 96 | LC50 | 6398 | Benville and Korn, 1977 |
| Toluene | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 3769 | Benville and Korn, 1977 |
| Toluene | *Carrisius auratus* | Goldfish | 96 | LC50 | 22800 | Brenniman et al., 1976 |
| Toluene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 6780 | Brooke et al., 1986 |
| Toluene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 13000 | Buccafusco et al., 1981 |
| Toluene | *Cancer magister* | Dungeness, Edible crab | 96 | LC50 | 28000 | Caldwell et al., 1977 |
| Toluene | *Therapon jarbua* | Tigerfish crescent perch | 96 | LC50 | 128000 | Dange and Masurekar, 1984 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 18000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 25000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 26000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 27000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 28000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 30000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 31000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 36000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 55000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 59000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 66000 | Devlin et al., 1982 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 72000 | Devlin et al., 1982 |
| Toluene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 5800 | Galassi et al., 1988 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Toluene | *Poecilia reticulata* | Guppy | 96 | LC50 | 28200 | Galassi et al., 1988 |
| Toluene | *Pimpelas promelas* | Fathead minnow | 96 | LC50 | 36200 | Geiger et al., 1986 |
| Toluene | *Pimpelas promelas* | Fathead minnow | 96 | LC50 | 31700 | Geiger et al., 1990 |
| Toluene | *Clarias lazera* | Catfish | 96 | LC50 | 26200 | Ghazaly, 1991 |
| Toluene | *Oncorhynchus mykiss* | Rainbow trout | 96 | LC50 | 24000 | Johnson and Finley, 1980 |
| Toluene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 170000 | Johnson and Finley, 1980 |
| Toluene | *Ictalurus punctatus* | Channel catfish | 96 | LC50 | 240000 | Johnson and Finley, 1980 |
| Toluene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 6410 | Korn et al., 1979 |
| Toluene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 7630 | Korn et al., 1979 |
| Toluene | *Oncorhynchus gorbuscha* | Pink salmon | 96 | LC50 | 8090 | Korn et al., 1979 |
| Toluene | *Oncorhynchus kiustch* | Coho salmon | 96 | LC50 | 9360 | Korn et al., 1979 |
| Toluene | *Eualus sp.* | Shrimp | 96 | LC50 | 14700 | Korn et al., 1979 |
| Toluene | *Eualus sp.* | Shrimp | 96 | LC50 | 20200 | Korn et al., 1979 |
| Toluene | *Eualus sp.* | Shrimp | 96 | LC50 | 21400 | Korn et al., 1979 |
| Toluene | *Daphnia magna* | Water flea | 48 | LC50 | 310000 | LeBlanc, 1980 |
| Toluene | *Ceriodaphnia dubia* | Water flea | 168 | LC50 | 3409 | Niederlehner et al., 1998 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 9390 | Marchini et al, 1992 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 17030 | Marchini et al., 1992 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 36200 | Marchini et al., 1992 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 54000 | Mayes et al., 1983 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 56400 | Mayes et al., 1983 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 77400 | Mayes et al., 1983 |
| Toluene | *Oncorhynchus kiustch* | Coho Salmon | 96 | LC50 | 5500 | Moles et al., 1981 |
| Toluene | *Oncorhynchus kiustch* | Coho Salmon | 96 | LC50 | 8110 | Moles, 1980 |
| Toluene | *Cyclops viridis* | Cyclopoid copepod | 96 | LC50 | 215000 | Panigrahi and Konar, 1989 |
| Toluene | *Pimpelas promelas* | Fathead minnow | 96 | LC50 | 12600 | Pearson et al., 1979 |
| Toluene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 24000 | Pickering and Henderson, 1966 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 34270 | Pickering and Henderson, 1966 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Toluene | *Carrisius auratus* | Goldfish | 96 | LC50 | 57680 | Pickering and Henderson, 1966 |
| Toluene | *Poecilia reticulata* | Guppy | 96 | LC50 | 59300 | Pickering and Henderson, 1966 |
| Toluene | *Eualus suckleyi* | Shrimp | 96 | LC50 | 19750 | Rice and Thomas, 1989 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Toluene | *Diaptomus forbesi* | Calanoid copepod | 96 | LC50 | 447000 | Saha and Konar, 1983 |
| Toluene | *Oryzias latipes* | Medaka, high eyes | 96 | LC50 | 54000 | Stoss and Haines, 1979 |
| Toluene | *Palaemonetes pugio* | Grass shrimp | 96 | LC50 | 9500 | Tatem et al., 1978 |
| Toluene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 18000 | Devlin, 1983 |
| Xylene | *Artemia salina* | Brine shrimp | 24 | LC50 | 5.7 | Calleja et al., 1994 |
| Xylene | *Brachionus calyciflorus* | Rotifer | 24 | LC50 | 9.2 | Calleja et al., 1994 |
| Xylene | *Carassius auratus* | Goldfish | 24 | LC50 | 75000 | Jensen, 1978 |
| Xylene | *Carassius auratus* | Goldfish | 24 | LC50 | 30550 | Brenniman et al., 1976 |
| Xylene | *Carassius auratus* | Goldfish | 24 | LC50 | 36810 | Pickering and Henderson, 1966 |
| Xylene | *Carassius auratus* | Goldfish | 48 | LC50 | 25100 | Brenniman et al., 1976 |
| Xylene | *Carassius auratus* | Goldfish | 48 | LC50 | 36810 | Pickering and Henderson, 1966 |
| Xylene | *Carassius auratus* | Goldfish | 72 | LC50 | 20720 | Brenniman et al., 1976 |
| Xylene | *Carassius auratus* | Goldfish | 96 | LC50 | 16940 | Brenniman et al., 1976 |
| Xylene | *Carassius auratus* | Goldfish | 96 | LC50 | 36810 | Pickering and Henderson, 1966 |
| Xylene | *Danio rerio* | Zebra danio | 48 | LC50 | 20000 | Slooff, 1979 |
| Xylene | *Danio rerio* | Zebra danio | 48 | LC50 | 20000 | Slooff, 1978 |
| Xylene | *Diaptomus forbesi* | Calanoid copepod | 96 | LC50 | 99500 | Saha and Konar, 1983 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 25600 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 16800 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 10400 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 24000 | Pickering and Henderson, 1966 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 36000 | Cope, 1965 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 14000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 12500 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 16500 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 14000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 12000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 12000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 16300 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 17400 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 15000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 15600 | Mayer and Ellersieck, 1986 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 13500 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 15600 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 25600 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 16500 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 24000 | Pickering and Henderson, 1966 |
| Xylene | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 19000 | Cope, 1965 |
| Xylene | *Lepomis macrochirus* | Bluegill | 72 | LC50 | 25600 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 72 | LC50 | 16500 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 24500 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 15700 | Bailey et al., 1985 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 20870 | Pickering and Henderson, 1966 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 19000 | Cope, 1965 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 13500 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 8600 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 12000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 13300 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 12000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 12000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 16100 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 17400 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 15000 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 14400 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 13500 | Mayer and Ellersieck, 1986 |
| Xylene | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 15000 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 24 | LC50 | 8300 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 24 | LC50 | 3300 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 24 | LC50 | 13500 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 24 | LC50 | 17300 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 8200 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 3300 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 13500 | Mayer and Ellersieck, 1986 |
| Xylene | *Oncorhynchus mykiss* | Rainbow trout,donaldson trout | 96 | LC50 | 17300 | Mayer and Ellersieck, 1986 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Xylene | *Palaemonetes pugio* | Daggerblade grass shrimp | 24 | LC50 | 14000 | Tatem et al., 1978 |
| Xylene | *Palaemonetes pugio* | Daggerblade grass shrimp | 24 | LC50 | 14000 | Tatem, 1975 |
| Xylene | *Palaemonetes pugio* | Daggerblade grass shrimp | 48 | LC50 | 8500 | Tatem et al., 1978 |
| Xylene | *Palaemonetes pugio* | Daggerblade grass shrimp | 48 | LC50 | 8500 | Tatem, 1975 |
| Xylene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 7400 | Tatem et al., 1978 |
| Xylene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 7400 | Tatem, 1975 |
| Xylene | *Palaemonetes pugio* | Daggerblade grass shrimp | 96 | LC50 | 7400 | Neff et al., 1976 |
| Xylene | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 28770 | Pickering and Henderson, 1966 |
| Xylene | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 28770 | Pickering and Henderson, 1966 |
| Xylene | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 42000 | Mattson et al., 1976 |
| Xylene | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 27710 | Pickering and Henderson, 1966 |
| Xylene | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 28770 | Pickering and Henderson, 1966 |
| Xylene | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 42000 | Mattson et al., 1976 |
| Xylene | *Pimephales promelas* | Fathead minnow | 72 | LC50 | 42000 | Mattson et al., 1976 |
| Xylene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 13400 | Geiger et al., 1990 |
| Xylene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 26700 | Pickering and Henderson, 1966 |
| Xylene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 28770 | Pickering and Henderson, 1966 |
| Xylene | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 42000 | Mattson et al., 1976 |
| Xylene | *Poecilia reticulata* | Guppy | 24 | LC50 | 34730 | Pickering and Henderson, 1966 |
| Xylene | *Poecilia reticulata* | Guppy | 48 | LC50 | 34730 | Pickering and Henderson, 1966 |
| Xylene | *Poecilia reticulata* | Guppy | 96 | LC50 | 34730 | Pickering and Henderson, 1966 |
| Xylene | *Streptocephalus proboscideus* | Fairy shrimp | 24 | LC50 | 2.6 | Calleja et al., 1994 |
| Xylene | *Therapon jarbua* | Tigerfish, crescent perch | 24 | LC50 | 102000 | Dange and Masurekar, 1984 |
| Xylene | *Therapon jarbua* | Tigerfish, crescent perch | 48 | LC50 | 95000 | Dange and Masurekar, 1984 |
| Xylene | *Therapon jarbua* | Tigerfish, crescent perch | 72 | LC50 | 92000 | Dange and Masurekar, 1984 |
| Xylene | *Therapon jarbua* | Tigerfish, crescent perch | 96 | LC50 | 89000 | Dange and Masurekar, 1984 |
| Xylene | *Brachionus calyciflorus* | Rotifer | 48 | LOEC | 40000 | Snell and Moffat, 1992 |
| Xylene | *Moina macrocopa* | Water flea | 180 | LT50 | 10 | Wong et al., 1995 |
| Xylene | *Brachionus calyciflorus* | Rotifer | 48 | NOEC | 20000 | Snell and Moffat, 1992 |

**Table A-4. Aliphatic Hydrocarbon Toxicity Data (pages A-28 and A-29)**

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| 1,1-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 5200 | Benville et al., 1985 |
| 1,1-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 5200 | Benville et al., 1985 |
| 1,1-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 6900 | Benville et al., 1985 |
| 1,1-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 6900 | Benville et al., 1985 |
| 1,2-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 1500 | Benville et al., 1985 |
| 1,2-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 1000 | Benville et al., 1985 |
| 1,2-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 1500 | Benville et al., 1985 |
| 1,2-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 1000 | Benville et al., 1985 |
| 1,2-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 3200 | Benville et al., 1985 |
| 1,2-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 3200 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 6200 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 6200 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 6200 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 6200 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 24 | LC50 | 9900 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 9300 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 24 | LC50 | 9900 | Benville et al., 1985 |
| 1,3-Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 9300 | Benville et al., 1985 |
| 1,4-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 2800 | Benville et al., 1985 |
| 1,4-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 1500 | Benville et al., 1985 |
| 1,4-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 2800 | Benville et al., 1985 |
| 1,4-Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 1500 | Benville et al., 1985 |
| Cyclohexane | *Artemia salina* | Brine shrimp | 24 | LC50 | 7322 | Abernathy et al., 1986 |
| Cyclohexane | *Carassius auratus* | Goldfish | 24 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Cyclohexane | *Carassius auratus* | Goldfish | 48 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Cyclohexane | *Carassius auratus* | Goldfish | 96 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Cyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 3400 | Benville et al., 1985 |
| Cyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 2400 | Benville et al., 1985 |
| Cyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 2400 | Benville and Korn, 1977 |

| Chemical Name | Species Scientific Name | Species Common Name | Test Duration (hours) | Endpoint | Concentration (µg/L) | Reference |
|---|---|---|---|---|---|---|
| Cyclohexane | *Lepomis macrochirus* | Bluegill | 24 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Cyclohexane | *Lepomis macrochirus* | Bluegill | 48 | LC50 | 40600 | Pickering and Henderson, 1966 |
| Cyclohexane | *Lepomis macrochirus* | Bluegill | 96 | LC50 | 34720 | Pickering and Henderson, 1966 |
| Cyclohexane | *Morone saxatilis* | Striped bass | 24 | LC50 | 8300 | Benville et al., 1985 |
| Cyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 8300 | Benville et al., 1985 |
| Cyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 8300 | Benville and Korn, 1977 |
| Cyclohexane | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 35080 | Pickering and Henderson, 1966 |
| Cyclohexane | *Pimephales promelas* | Fathead minnow | 24 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Cyclohexane | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 35080 | Pickering and Henderson, 1966 |
| Cyclohexane | *Pimephales promelas* | Fathead minnow | 48 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Cyclohexane | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 4530 | Geiger et al., 1990 |
| Cyclohexane | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 32710 | Pickering and Henderson, 1966 |
| Cyclohexane | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 42330 | Pickering and Henderson, 1966 |
| Cyclopentane | *Artemia salina* | Brine shrimp | 24 | LC50 | 19638 | Abernathy et al., 1986 |
| Dimethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 1500 | Benville and Korn, 1977 |
| Dimethylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 3200 | Benville and Korn, 1977 |
| Ethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 3700 | Benville et al., 1985 |
| Ethylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 3100 | Benville et al., 1985 |
| Hexane | *Artemia salina* | Brine shrimp | 24 | LC50 | 3533 | Abernathy et al., 1986 |
| Hexane | *Pimephales promelas* | Fathead minnow | 96 | LC50 | 2500 | Geiger et al., 1990 |
| Methylcyclohexane | *Artemia salina* | Brine shrimp | 24 | LC50 | 3682 | Abernathy et al., 1986 |
| Methylcyclohexane | *Crangon franciscorum* | Bay shrimp | 24 | LC50 | 3500 | Benville et al., 1985 |
| Methylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 3300 | Benville et al., 1985 |
| Methylcyclohexane | *Crangon franciscorum* | Bay shrimp | 96 | LC50 | 3500 | Benville and Korn, 1977 |
| Methylcyclohexane | *Morone saxatilis* | Striped bass | 24 | LC50 | 7000 | Benville et al., 1985 |
| Methylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 5800 | Benville et al., 1985 |
| Methylcyclohexane | *Morone saxatilis* | Striped bass | 96 | LC50 | 5800 | Benville and Korn, 1977 |
| Octane | *Artemia salina* | Brine shrimp | 24 | LC50 | 400 | Abernathy et al., 1986 |
| Pentane | *Artemia salina* | Brine shrimp | 24 | LC50 | 11905 | Abernathy et al., 1986 |

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# Appendix B
# Calculation Spreadsheets

**Table B-1. Spreadsheet for Derivation of Risk-based Sediment Benchmarks for Petroleum Hydrocarbons**

| Fraction | Hydrocarbons | Solubility, 25°C (mg/L) | Log $K_{ow}$ | Geomean Log $K_{ow}$ | Log LC50[a] (mM/L) | LC50 (mM/L) | Molecular Weight | LC50 (mg/L) | >Solubility (y/n) | Geomean LC50 (mg/L) | FCV[b] (mg/L) | FCV (ug/L) | Log $K_{oc}$[c] | Sediment Benchmark (ug/g oc)[d] | Sediment Benchmark (f=0.001) (ug/g)[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Aliphatics** | | | | | | | | | | | | | | |
| $C_5$-$C_8$ | n-Pentane | 38 | 3.45 | 4.12 | -0.85 | 1.42E-01 | 72.15 | 10.24 | n | 3.2654 | 0.2177 | 218 | 3.86 | 1591 | 1.59 |
| | 2,2-Dimethylbutane | 18.4 | 3.82 | | -1.18 | 6.62E-02 | 86.18 | 5.71 | n | | | | | | |
| | Cyclopentane | 156 | 3 | | -0.44 | 3.59E-01 | 70.14 | 25.18 | n | | | | | | |
| | 2,3-Dimethylbutane | 19.1 | 3.85 | | -1.21 | 6.22E-02 | 86.18 | 5.36 | n | | | | | | |
| | 2-Methylpentane | 13.8 | 3.74 | | -1.11 | 7.81E-02 | 86.18 | 6.73 | n | | | | | | |
| | 3-Methylpentane | 12.8 | 3.6 | | -0.98 | 1.04E-01 | 86.18 | 8.98 | n | | | | | | |
| | n-Hexane | 9.5 | 4.11 | | -1.44 | 3.64E-02 | 86.18 | 3.14 | n | | | | | | |
| | cycloheptane | 30 | 4 | | -1.34 | 4.57E-02 | 98.19 | 4.49 | n | | | | | | |
| | 2,2-Dimethylpentane | 4.4 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | Methylcyclopentane | 42 | 3.37 | | -0.78 | 1.67E-01 | 84.16 | 14.09 | n | | | | | | |
| | 2,4-Dimethylpentane | 4.06 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | 2,2,3-Trimethylbutane | 4.38 | 4.03 | | -1.37 | 4.29E-02 | 100.2 | 4.30 | n | | | | | | |
| | 3,3-Dimethylpentane | 5.94 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | Cyclohexane | 55 | 3.44 | | -0.84 | 1.45E-01 | 84.16 | 12.20 | n | | | | | | |
| | 2,3-Dimethylpentane | 5.25 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | 3-Methylhexane | 3.3 | 4.27 | | -1.58 | 2.62E-02 | 100.2 | 2.62 | n | | | | | | |
| | 2,2,4-Trimethylpentane | 2.44 | 4.54 | | -1.82 | 1.50E-02 | 114.2 | 1.71 | n | | | | | | |
| | Heptane | 2.9 | 5 | | -2.24 | 5.81E-03 | 100.2 | 0.58 | n | | | | | | |
| | Methylcyclohexane | 14 | 3.88 | | -1.23 | 5.85E-02 | 98.19 | 5.75 | n | | | | | | |
| | 1,1,3-Trimethylcyclopentane | 3.73 | 4.35 | | -1.65 | 2.22E-02 | 112.2 | 2.49 | n | | | | | | |
| | 2,3,4-Trimethylpentane | 2 | 4.54 | | -1.82 | 1.50E-02 | 114.2 | 1.71 | n | | | | | | |
| | 2-Methylheptane | 0.85 | 4.8 | | -2.06 | 8.78E-03 | 114.2 | 1.00 | y | | | | | | |
| | 3-Methylheptane | 0.79 | 4.8 | | -2.06 | 8.78E-03 | 114.2 | 1.00 | y | | | | | | |
| | 1,4-Dimethylcyclohexane | 3.84 | 4.39 | | -1.69 | 2.04E-02 | 112.2 | 2.29 | n | | | | | | |
| | 2,2,5-Trimethylhexane | 1.15 | 5.06 | | -2.29 | 5.14E-03 | 128.3 | 0.66 | n | | | | | | |
| | 1,2-Dimethylcyclohexane | 6 | 4.39 | | -1.69 | 2.04E-02 | 112.2 | 2.29 | n | | | | | | |
| | Octane | 0.66 | 5.15 | | -2.37 | 4.27E-03 | 114.2 | 0.49 | n | | | | | | |
| $C_9$-$C_{12}$ | 3-Methyloctane | 1.42 | 5.32 | 6.01 | -2.52 | 3.01E-03 | 128.3 | 0.39 | n | 0.09425 | 0.006 | 6.3 | 5.64 | 2722 | 2.72 |
| | Nonane | 0.22 | 5.65 | | -2.82 | 1.52E-03 | 128.3 | 0.20 | n | | | | | | |
| | Decane | 0.052 | 6.25 | | -3.35 | 4.42E-04 | 142.3 | 0.06 | y | | | | | | |
| | Undecane | 0.04 | 6.94 | | -3.97 | 1.07E-04 | 156.3 | 0.02 | n | | | | | | |
| $C_{13}$-$C_{18}$ | Tetradecane | 7.00E-04 | 7.2 | 8.75 | -4.21 | 6.24E-05 | 198.4 | 0.0124 | y | 0.0007561 | 5.04E-05 | 0.05 | 8.04 | 5543 | 5.54 |
| | Pentadecane | 8.00E-05 | 8.63 | | -5.49 | 3.27E-06 | 212.4 | 0.0007 | y | | | | | | |
| | Hexadecane | 5.00E-05 | 8.25 | | -5.15 | 7.16E-06 | 226.4 | 0.0016 | y | | | | | | |
| | Heptadecane | 6.00E-06 | 9.69 | | -6.43 | 3.68E-07 | 240.5 | 0.0001 | y | | | | | | |
| | Octadecane | 4.00E-06 | 9.32 | | -6.10 | 7.89E-07 | 254.5 | 0.0002 | y | | | | | | |

| Fraction | Hydrocarbons | Solubility, 25°C (mg/L) | Log $K_{ow}$ | Geomean Log $K_{ow}$ | Log LC50[a] (mM/L) | LC50 (mM/L) | Molecular Weight | LC50 (mg/L) | >Solubility (y/n) | Geomean LC50 (mg/L) | FCV[b] (mg/L) | FCV (ug/L) | Log $K_{oc}$[c] | Sediment Benchmark (ug/g oc)[d] | Sediment Benchmark (f=0.001) (ug/g)[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $C_{19}$-$C_{36}$ | Nonadecane | 4.00E-07 | 10.72 | 11.64 | -7.36 | 4.40E-08 | 268.5 | 1.18E-05 | y | 1.77E-06 | 1.18E-07 | 0.0001 | 10.92 | 9883 | 9.88 |
| | Eicosane | 3.00E-07 | 11.27 | | -7.85 | 1.42E-08 | 282.6 | 4.00E-06 | y | | | | | | |
| | Tetracosane | 6.00E-10 | 13.07 | | -9.46 | 3.46E-10 | 338.7 | 1.17E-07 | y | | | | | | |
| $C_6$-$C_8$ | Benzene | 1770 | 2.13 | 2.82 | 0.31 | 2.03 | 78.1 | 158.18 | n | 17.863 | 1.19 | 1191 | 2.65 | 531 | 0.53 |
| | Toluene | 530 | 2.69 | | -0.50 | 0.318 | 92.1 | 29.33 | n | | | | | | |
| | Ethylbenzene | 169 | 3.13 | | -1.13 | 7.44E-02 | 106.2 | 7.91 | n | | | | | | |
| | p-Xylene | 180 | 3.18 | | -1.20 | 6.31E-02 | 106.2 | 6.7 | n | | | | | | |
| | o-Xylene | 220 | 3.15 | | -1.16 | 6.97E-02 | 106.2 | 7.4 | n | | | | | | |
| $C_9$-$C_{12}$ | Isopropylbenzene | 56 | 3.63 | 3.94 | -1.85 | 1.43E-02 | 120.2 | 1.72 | n | 0.6923 | 0.0462 | 46.2 | 3.69 | 228 | 0.23 |
| | n-Propylbenzene | 55 | 3.69 | | -1.93 | 1.17E-02 | 120.2 | 1.41 | n | | | | | | |
| | 1-Methyl-4-ethylbenzene | 95 | 3.63 | | -1.85 | 1.43E-02 | 120.2 | 1.72 | n | | | | | | |
| | 1,3,5-Trimethylbenzene | 48.9 | 3.58 | | -1.77 | 1.68E-02 | 120.2 | 2.02 | n | | | | | | |
| | Naphthalene | 31 | 3.37 | | -1.47 | 3.37E-02 | 128.2 | 4.32 | n | | | | | | |
| | 2-Methylnaphthalene | 25 | 3.86 | | -2.18 | 6.68E-03 | 142.2 | 0.95 | n | | | | | | |
| | 1-Methylnaphthalene | 28 | 3.87 | | -2.19 | 6.46E-03 | 142.2 | 0.92 | n | | | | | | |
| | 1-Methyl-4-isopropylbenzene | 34 | 4.1 | | -2.52 | 3.02E-03 | 134.2 | 0.41 | n | | | | | | |
| | 2-Ethylnaphthalene | 8 | 4.4 | | -2.95 | 1.12E-03 | 156.2 | 0.18 | n | | | | | | |
| | Biphenyl | 7.2 | 3.69 | | -1.93 | 1.17E-02 | 154.2 | 1.80 | n | | | | | | |
| | Isobutylbenzene | 10.1 | 4.01 | | -2.39 | 4.07E-03 | 134.2 | 0.55 | n | | | | | | |
| | n-Butylbenzene | 15 | 4.26 | | -2.75 | 1.78E-03 | 134.2 | 0.24 | n | | | | | | |
| | Sec-Butylbenzene | 14 | 4.1 | | -2.52 | 3.02E-03 | 134.2 | 0.41 | n | | | | | | |
| | 1,2,4,5-Tetramethylbenzene | 3.48 | 4.1 | | -2.52 | 3.02E-03 | 134.2 | 0.41 | n | | | | | | |
| | 2,6-Dimethylnaphthalene | 1.7 | 4.1 | | -2.52 | 3.02E-03 | 156.2 | 0.47 | n | | | | | | |
| | 2,3-Dimethylnaphthalene | 2.5 | 4.4 | | -2.95 | 1.12E-03 | 156.2 | 0.18 | n | | | | | | |
| | Dibenzothiophene | 1.47 | 4.38 | | -2.92 | 1.20E-03 | 184.3 | 0.22 | n | | | | | | |
| | Acenaphthene | 3.8 | 3.92 | | -2.26 | 5.47E-03 | 154.2 | 0.84 | n | | | | | | |
| $C_{13}$-$C_{15}$ | Fluorene | 1.9 | 3.97 | 4.67 | -2.33 | 4.64E-03 | 166.2 | 0.77 | n | 0.07758 | 0.0052 | 5.2 | 4.38 | 125 | 0.13 |
| | Phenanthrene | 1.1 | 4.36 | | -2.89 | 1.28E-03 | 178.2 | 0.23 | n | | | | | | |
| | 2-Methylanthracene | 0.03 | 5.15 | | -4.03 | 9.41E-05 | 192.3 | 0.02 | n | | | | | | |
| | 9-Methylanthracene | 0.261 | 5.07 | | -3.91 | 1.23E-04 | 192.3 | 0.02 | n | | | | | | |
| | 1-Methylphenanthrene | 0.27 | 4.93 | | -3.71 | 1.95E-04 | 192.3 | 0.04 | n | | | | | | |
| $C_{16}$-$C_{24}$ | Benzo(a)fluorene | 0.045 | 5.4 | 5.9 | -4.38 | 4.12E-05 | 216.3 | 0.0089 | n | 0.001746 | 0.00012 | 0.12 | 5.53 | 40 | 0.04 |
| | Benz(a)anthracene | 0.011 | 5.91 | | -5.12 | 7.64E-06 | 228.3 | 0.0017 | n | | | | | | |
| | Chrysene | 1.90E-03 | 5.79 | | -4.94 | 1.14E-05 | 228.3 | 0.0026 | y | | | | | | |
| | Benzo(a)pyrene | 1.00E-03 | 6.04 | | -5.30 | 4.98E-06 | 252.3 | 0.0013 | y | | | | | | |
| | Pyrene | 0.13 | 5.18 | | -4.07 | 8.52E-05 | 202.3 | 0.02 | n | | | | | | |
| | Fluoranthene | 0.24 | 5.22 | | -4.13 | 7.47E-05 | 202.3 | 0.02 | n | | | | | | |

| Fraction | Hydrocarbons | Solubility, 25°C (mg/L) | Log $K_{ow}$ | Geomean Log $K_{ow}$ | Log LC50[a] (mM/L) | LC50 (mM/L) | Molecular Weight | LC50 (mg/L) | >Solubility (y/n) | Geomean LC50 (mg/L) | FCV[b] (mg/L) | FCV (ug/L) | Log $K_{oc}$[c] | Sediment Benchmark (ug/g oc)[d] | Sediment Benchmark (f=0.001) (ug/g)[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coronene | 1.4E-04 | 6.75 | | -6.32 | 4.77E-07 | 300.4 | 0.0001 | y | | | | | | |
| | Benzo(ghi)perylene | 1.40E-04 | 6.29 | | -5.66 | 2.18E-06 | 276.3 | 0.0006 | y | | | | | | |
| | Dibenz(a,h)anthracene | 5.80E-04 | 6.75 | | -6.32 | 4.77E-07 | 278.4 | 0.0001 | n | | | | | | |

[a] Values obtained from regression equation and corresponding log $K_{ow}$

[b] To obtain the final chronic aquatic value, the mean LC50 was divided by an ACR of 15

[c] Calculated from the equation: Log $K_{oc}$ = 0.00028 + 0.938Log $K_{ow}$

[d] µg/g is equivalent to mg/kg or parts per million (ppm)

**Table B-2. Spreadsheet for Derivation of Sediment Benchmarks for Petroleum Hydrocarbons – Current MADEP Fractions**

| Fraction | Hydrocarbons | Solubility, 25°C (mg/L) | Log $K_{ow}$ | Geomean Log $K_{ow}$ | Log LC50[a] (mM/L) | LC50 (mM/L) | Molecular Weight | LC50 (mg/L) | >Solubility (y/n) | Geomean LC50 (mg/L) | FCV[b] (mg/L) | FCV (ug/L) | Log $K_{oc}$[c] | Sediment Benchmark (ug/g oc)[d] | Sediment Benchmark (f=0.001) (ug/g)[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Aliphatics** | | | | | | | | | | | | | | |
| $C_5$-$C_8$ | n-Pentane | 38 | 3.45 | 4.12 | -0.85 | 1.42E-01 | 72.15 | 10.24 | n | 3.2654 | 0.2177 | 218 | 3.86 | 1591 | 1.59 |
| | 2,2-Dimethylbutane | 18.4 | 3.82 | | -1.18 | 6.62E-02 | 86.18 | 5.71 | n | | | | | | |
| | Cyclopentane | 156 | 3 | | -0.44 | 3.59E-01 | 70.14 | 25.18 | n | | | | | | |
| | 2,3-Dimethylbutane | 19.1 | 3.85 | | -1.21 | 6.22E-02 | 86.18 | 5.36 | n | | | | | | |
| | 2-Methylpentane | 13.8 | 3.74 | | -1.11 | 7.81E-02 | 86.18 | 6.73 | n | | | | | | |
| | 3-Methylpentane | 12.8 | 3.6 | | -0.98 | 1.04E-01 | 86.18 | 8.98 | n | | | | | | |
| | n-Hexane | 9.5 | 4.11 | | -1.44 | 3.64E-02 | 86.18 | 3.14 | n | | | | | | |
| | cycloheptane | 30 | 4 | | -1.34 | 4.57E-02 | 98.19 | 4.49 | n | | | | | | |
| | 2,2-Dimethylpentane | 4.4 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | Methylcyclopentane | 42 | 3.37 | | -0.78 | 1.67E-01 | 84.16 | 14.09 | n | | | | | | |
| | 2,4-Dimethylpentane | 4.06 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | 2,2,3-Trimethylbutane | 4.38 | 4.03 | | -1.37 | 4.29E-02 | 100.2 | 4.30 | n | | | | | | |
| | 3,3-Dimethylpentane | 5.94 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | Cyclohexane | 55 | 3.44 | | -0.84 | 1.45E-01 | 84.16 | 12.20 | n | | | | | | |
| | 2,3-Dimethylpentane | 5.25 | 4.14 | | -1.47 | 3.42E-02 | 100.2 | 3.43 | n | | | | | | |
| | 3-Methylhexane | 3.3 | 4.27 | | -1.58 | 2.62E-02 | 100.2 | 2.62 | n | | | | | | |
| | 2,2,4-Trimethylpentane | 2.44 | 4.54 | | -1.82 | 1.50E-02 | 114.2 | 1.71 | n | | | | | | |
| | Heptane | 2.9 | 5 | | -2.24 | 5.81E-03 | 100.2 | 0.58 | n | | | | | | |
| | Methylcyclohexane | 14 | 3.88 | | -1.23 | 5.85E-02 | 98.19 | 5.75 | n | | | | | | |
| | 1,1,3-Trimethylcyclopentane | 3.73 | 4.35 | | -1.65 | 2.22E-02 | 112.2 | 2.49 | n | | | | | | |
| | 2,3,4-Trimethylpentane | 2 | 4.54 | | -1.82 | 1.50E-02 | 114.2 | 1.71 | n | | | | | | |
| | 2-Methylheptane | 0.85 | 4.8 | | -2.06 | 8.78E-03 | 114.2 | 1.00 | y | | | | | | |
| | 3-Methylheptane | 0.79 | 4.8 | | -2.06 | 8.78E-03 | 114.2 | 1.00 | y | | | | | | |
| | 1,4-Dimethylcyclohexane | 3.84 | 4.39 | | -1.69 | 2.04E-02 | 112.2 | 2.29 | n | | | | | | |
| | 2,2,5-Trimethylhexane | 1.15 | 5.06 | | -2.29 | 5.14E-03 | 128.3 | 0.66 | n | | | | | | |
| | 1,2-Dimethylcyclohexane | 6 | 4.39 | | -1.69 | 2.04E-02 | 112.2 | 2.29 | n | | | | | | |
| | Octane | 0.66 | 5.15 | | -2.37 | 4.27E-03 | 114.2 | 0.49 | n | | | | | | |
| $C_9$-$C_{18}$ | 3-Methyloctane | 1.42 | 5.32 | 7.32 | -2.52 | 3.01E-03 | 128.3 | 0.39 | n | 0.00646 | 0.0004 | 0.4 | 6.87 | 3167 | 3.17 |
| | Nonane | 0.22 | 5.65 | | -2.82 | 1.52E-03 | 128.3 | 0.20 | n | | | | | | |
| | Decane | 0.052 | 6.25 | | -3.35 | 4.42E-04 | 142.3 | 0.06 | y | | | | | | |
| | Undecane | 0.04 | 6.94 | | -3.97 | 1.07E-04 | 156.3 | 0.02 | n | | | | | | |
| | Tetradecane | 7.00E-04 | 7.2 | | -4.21 | 6.24E-05 | 198.4 | 0.0124 | y | | | | | | |
| | Pentadecane | 8.00E-05 | 8.63 | | -5.49 | 3.27E-06 | 212.4 | 0.0007 | y | | | | | | |
| | Hexadecane | 5.00E-05 | 8.25 | | -5.15 | 7.16E-06 | 226.4 | 0.0016 | y | | | | | | |
| | Heptadecane | 6.00E-06 | 9.69 | | -6.43 | 3.68E-07 | 240.5 | 0.0001 | y | | | | | | |
| | Octadecane | 4.00E-06 | 9.32 | | -6.10 | 7.89E-07 | 254.5 | 0.0002 | y | | | | | | |

| Fraction | Hydrocarbons | Solubility, 25°C (mg/L) | Log $K_{ow}$ | Geomean Log $K_{ow}$ | Log LC50[a] (mM/L) | LC50 (mM/L) | Molecular Weight | LC50 (mg/L) | >Solubility (y/n) | Geomean LC50 (mg/L) | FCV[b] (mg/L) | FCV (ug/L) | Log $K_{oc}$[c] | Sediment Benchmark (ug/g oc)[d] | Sediment Benchmark (f=0.001) (ug/g)[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $C_{19}$-$C_{36}$ | Nonadecane | 4.00E-07 | 10.72 | 11.64 | -7.36 | 4.40E-08 | 268.5 | 1.18E-05 | y | 1.77E-06 | 1.18E-07 | 0.0001 | 10.92 | 9883 | 9.88 |
| | Eicosane | 3.00E-07 | 11.27 | | -7.85 | 1.42E-08 | 282.6 | 4.00E-06 | y | | | | | | |
| | Tetracosane | 6.00E-10 | 13.07 | | -9.46 | 3.46E-10 | 338.7 | 1.17E-07 | y | | | | | | |
| $C_9$-$C_{10}$ | Isopropylbenzene | 56 | 3.63 | 3.84 | -1.85 | 1.43E-02 | 120.2 | 1.72 | n | 0.8907 | 0.0594 | 59.4 | 3.60 | 236 | 0.24 |
| | n-Propylbenzene | 55 | 3.69 | | -1.93 | 1.17E-02 | 120.2 | 1.41 | n | | | | | | |
| | 1-Methyl-4-ethylbenzene | 95 | 3.63 | | -1.85 | 1.43E-02 | 120.2 | 1.72 | n | | | | | | |
| | 1,3,5-Trimethylbenzene | 48.9 | 3.58 | | -1.77 | 1.68E-02 | 120.2 | 2.02 | n | | | | | | |
| | Naphthalene | 31 | 3.37 | | -1.47 | 3.37E-02 | 128.2 | 4.32 | n | | | | | | |
| | 1-Methyl-4-isopropylbenzene | 34 | 4.1 | | -2.52 | 3.02E-03 | 134.2 | 0.41 | n | | | | | | |
| | Isobutylbenzene | 10.1 | 4.01 | | -2.39 | 4.07E-03 | 134.2 | 0.55 | n | | | | | | |
| | n-Butylbenzene | 15 | 4.26 | | -2.75 | 1.78E-03 | 134.2 | 0.24 | n | | | | | | |
| | Sec-Butylbenzene | 14 | 4.1 | | -2.52 | 3.02E-03 | 134.2 | 0.41 | n | | | | | | |
| | 1,2,4,5-Tetramethylbenzene | 3.48 | 4.1 | | -2.52 | 3.02E-03 | 134.2 | 0.41 | n | | | | | | |
| $C_{11}$-$C_{22}$ | 2-Methylnaphthalene | 25 | 3.86 | 4.81 | -2.18 | 6.68E-03 | 142.2 | 0.95 | n | 0.0421 | 0.0028 | 2.8 | 4.52 | 92 | 0.09 |
| | 1-Methylnaphthalene | 28 | 3.87 | | -2.19 | 6.46E-03 | 142.2 | 0.92 | n | | | | | | |
| | 2-Ethylnaphthalene | 8 | 4.4 | | -2.95 | 1.12E-03 | 156.2 | 0.18 | n | | | | | | |
| | Biphenyl | 7.2 | 3.69 | | -1.93 | 1.17E-02 | 154.2 | 1.80 | n | | | | | | |
| | 2,6-Dimethylnaphthalene | 1.7 | 4.1 | | -2.52 | 3.02E-03 | 156.2 | 0.47 | n | | | | | | |
| | 2,3-Dimethylnaphthalene | 2.5 | 4.4 | | -2.95 | 1.12E-03 | 156.2 | 0.18 | n | | | | | | |
| | Dibenzothiophene | 1.47 | 4.38 | | -2.92 | 1.20E-03 | 184.3 | 0.22 | n | | | | | | |
| | Acenaphthene | 3.8 | 3.92 | | -2.26 | 5.47E-03 | 154.2 | 0.84 | n | | | | | | |
| | Fluorene | 1.9 | 3.97 | | -2.33 | 4.64E-03 | 166.2 | 0.77 | n | | | | | | |
| | Phenanthrene | 1.1 | 4.36 | | -2.89 | 1.28E-03 | 178.2 | 0.23 | n | | | | | | |
| | 2-Methylanthracene | 0.03 | 5.15 | | -4.03 | 9.41E-05 | 192.3 | 0.02 | n | | | | | | |
| | 9-Methylanthracene | 0.261 | 5.07 | | -3.91 | 1.23E-04 | 192.3 | 0.02 | n | | | | | | |
| | 1-Methylphenanthrene | 0.27 | 4.93 | | -3.71 | 1.95E-04 | 192.3 | 0.04 | n | | | | | | |
| | Benzo(a)fluorene | 0.045 | 5.4 | | -4.38 | 4.12E-05 | 216.3 | 0.0089 | n | | | | | | |
| | Benz(a)anthracene | 0.011 | 5.91 | | -5.12 | 7.64E-06 | 228.3 | 0.0017 | n | | | | | | |
| | Chrysene | 1.90E-03 | 5.79 | | -4.94 | 1.14E-05 | 228.3 | 0.0026 | y | | | | | | |
| | Benzo(a)pyrene | 1.00E-03 | 6.04 | | -5.30 | 4.98E-06 | 252.3 | 0.0013 | y | | | | | | |
| | Pyrene | 0.13 | 5.18 | | -4.07 | 8.52E-05 | 202.3 | 0.02 | n | | | | | | |
| | Fluoranthene | 0.24 | 5.22 | | -4.13 | 7.47E-05 | 202.3 | 0.02 | n | | | | | | |
| | Benzo(ghi)perylene | 1.40E-04 | 6.29 | | -5.66 | 2.18E-06 | 276.3 | 0.0006 | y | | | | | | |
| | Dibenz(a,h)anthracene | 5.80E-04 | 6.75 | | -6.32 | 4.77E-07 | 278.4 | 0.0001 | n | | | | | | |

[a] Values obtained from regression equation and corresponding log $K_{ow}$

[b] To obtain the final chronic aquatic value, the mean LC50 was divided by an ACR of 15

[c] Calculated from the equation: Log $K_{oc}$ = 0.00028 + 0.938Log $K_{ow}$

[d] µg/g is equivalent to mg/kg or parts per million (ppm)