
Groundwater Sampling Techniques for Site Characterization and Hydrocarbon Risk Calculations

Technical Background Document and Recommendations

Prepared for
Alaska Statement of Cooperation Working Group

September 2006

Prepared by
Geosphere, Inc.
CH2MHILL

Preface

This document was created under the Alaska Statement of Cooperation (SOC), which is an agreement between the Alaska Department of Environmental Conservation (ADEC), the U.S. Environmental Protection Agency (EPA), the Departments of the Army, Air Force, Navy, Military and Veterans Affairs (Army National Guard), Interior, and the Federal Aviation Administration (FAA) and U.S. Coast Guard. The objective of the agreement is to work cooperatively to identify and resolve issues affecting human health and the environment through promoting compliance with environmental laws, preventing pollution, creating partnerships to identify and cleanup contaminants and pollution, promoting training and coordinating with affected Tribes. A subcommittee or “working group” was formed under the SOC to evaluate the characterization and fate and transport of petroleum hydrocarbons spilled in the environment, and the risks posed by petroleum contamination. FAA contracted with Geosphere and CH2M Hill to research the issues and develop eight technical issue papers. The paper titles are listed below. Staff from ADEC, FAA, the Army and Army Corps of Engineers, and the Army National Guard reviewed and provided feedback on the draft papers. These papers provide sound scientific and technical information along with recommendations for use and/or future consideration.

ADEC Disclaimer

This paper does not constitute ADEC guidance, policy, or rule making, nor does it create any rights or benefits, substantive or procedural, enforceable at law or in equity, by any person. ADEC may take action at variance with this paper.

Statement of Cooperation Working Group Paper Titles

1. Three- and Four-Phase Partitioning of Petroleum Hydrocarbons and Human Health Risk Calculations, Technical Background Report Document and Recommendations
2. Hydrocarbon Characterization for Use in the Hydrocarbon Risk Calculator and Example Characterizations of Selected Alaskan Fuels, Technical Background Document and Recommendations
3. Dilution-Attenuation Factors at Fuel Hydrocarbon Spill Sites, Technical Background Document and Recommendations
4. Maximum Allowable Concentration, Residual Saturation, and Free-Product Mobility, Technical Background Document and Recommendations
5. Groundwater Sampling Techniques for Site Characterization and Hydrocarbon Risk Calculations, Technical Background Document and Recommendations
6. Migration to Indoor Air Calculations for Use in the Hydrocarbon Risk Calculator, Technical Background Document and Recommendations
7. Site Conditions Summary Report for Hydrocarbon Risk Calculations and Site Status Determination, Technical Background Document and Recommendations
8. Proposed Environmental Site Closeout Concepts, Criteria, and Definitions, Technical Background Document and Recommendations

Contents

Section	Page
1 Introduction	1
1.1 Purpose and Objectives	2
2 Background on Groundwater Sample Analysis, Filtration, and Diffusion	
Bag Samplers	3
2.1 Groundwater Sample Analysis	3
2.2 Filtration to Remove NAPL	4
2.3 Diffusion Bag Samplers	4
2.4 Examples of Potential Errors Associated with NAPL Incorporation in Groundwater Samples	5
3 Scope of Work/Laboratory Setup and Analytical Testing	7
3.1 Laboratory Setup	7
3.2 Water Sampling	7
3.3 Analytical Testing	8
4 Testing Results	9
4.1 Diffusion Bag Testing – Objectives and Results	9
4.2 Spiking and Filtration – Objectives and Results	11
4.3 Preliminary Conclusions Concerning Diffusion Bag Samplers and Filtration.....	12
5 Characterization of the Solubility of Alaskan Fuels	13
5.1 BTEX, GRO, VPH, EPH and DRO Data Ranges	13
5.2 Characterization of the Solubility of Alaskan Fuels.....	14
5.3 Correlation of Measured Solubilities with Calculated Effective Solubilities.....	15
5.4 Polar Fraction.....	16
5.5 PAH Concentrations.....	16
6 Dissolved Phase Concentrations – Implications for Risk Calculations	18
6.1 Measured Dissolved Phase Concentrations Compared to Risk-based Criteria.....	19
6.2 Calculated Effective Solubilities (Dissolved Phase) Concentrations Compared to Risk-based Criteria	20
7 SOCWG Conclusions and Recommendations	23
8 References	26

Tables

- 1 BTEX and VPH Laboratory Test Results
- 2 EPH Laboratory Test Results
- 3 Ratio of VPH to EPH in the C8 to C10 and C10 to C12 Aromatic and Aliphatic Fractions in the Carboy Water and Diffusion Bag Samples
- 4 Summary of Hydrocarbon Concentrations in Water Samples from Combined BTEX, VPH & EPH Data
- 5 PAH Concentrations in the Carboy Water Sample
- 6 Measured Fuel Solubilities Compared to Groundwater Risk Criteria
- 7 Calculated Fuel Solubilities Compared to Groundwater Risk Criteria

Figures

- 1 Example 1 Change in DRO Concentration through Time and Estimated Groundwater Cleanup Time
- 2 BioScreen Dissolved Phase Plume Length given a DRO Concentration of 150 mg/L (Example 2A)
- 3 BioScreen Dissolved Phase Plume Length given a DRO Concentration of 3 mg/L (Example 2B)
- 4 Laboratory Setup for Simulating Groundwater in Equilibrium with Oil
- 5 Photograph of Laboratory Carboy Setup for Simulating Groundwater in Equilibrium with Oil
- 6 Close-up Photograph of Laboratory Carboy Setup for Simulating Groundwater in Equilibrium with Oil
- 7 Four Types of Water Samples Collected from Carboy (Approach for Simulating Groundwater Containing NAPL)
- 8 Correlation of Carboy Water & Diffusion Bag BTEX & VPH Test Results
- 9 Correlation of Carboy Water & Diffusion Bag EPH Test Results
- 10 Comparison of Spiked Water and Spiked & Filtered Water
- 11 Comparison of Carboy Water and Spiked & Filtered Water
- 12 Compilation of Laboratory Test Results into Recommended Hydrocarbon Fractions
- 13 Average Dissolved Phase Concentrations from Carboy Water and Diffusion Bag Samples
- 14 Comparison of Calculated and Measured Dissolved Concentrations Sample #3 JP4
- 15 Comparison of Calculated and Measured Dissolved Concentrations Sample #6 Regular Gas
- 16 Comparison of Calculated and Measured Dissolved Concentrations Sample #12 DF2
- 17 Comparison of Calculated and Measured Dissolved Concentrations Sample #10 Diesel Fuel
- 18 Comparison of Calculated and Measured Dissolved Concentrations Sample #9 Jet A
- 19 Comparison of Calculated and Measured Dissolved Concentrations Sample #4 DF1

Acronyms and Abbreviations

ADEC	Alaska Department of Environmental Conservation
AK	Alaska
BTEX	benzene, toluene, ethylbenzene, and total xylenes
DAF	dilution-attenuation factor
DRO	diesel-range organics
EPA	U.S. Environmental Protection Agency
EPH	extended-range petroleum hydrocarbons
GC	gas chromatograph
GRO	gasoline-range organics
μL	micro liters
MCL	maximum contaminant level
mg/kg	milligrams per kilograms
mg/L	milligrams per liter
ml	milliliter
MTBE	methyl tertiary butyl ether
NAPL	nonaqueous-phase liquid
PAH	polycyclic aromatic hydrocarbon
PDB	passive diffusion bag
RPD	relative percent difference
RRO	residual-range organics
SIM	selective ion monitoring
SOCWG	Alaska Statement of Cooperation Working Group
TCLP	toxicity characteristic leaching procedure
TPH	total petroleum hydrocarbon
VPH	volatile petroleum hydrocarbon

SECTION 1

Introduction

To fully characterize petroleum hydrocarbon contaminated sites and the human health and environmental risk associated with them, it is necessary to identify the extent and concentration of the nonaqueous-phase liquid- (NAPL) contaminated soil above and below the water table, the extent and concentration of the dissolved phase hydrocarbon plume, and potentially the extent and concentration of the vapor phase hydrocarbon plume. The collection and handling of soil and groundwater samples is described in numerous U.S. Environmental Protection Agency (EPA) and Alaska Department of Environmental Conservation (ADEC) guidance documents, professional reports, and text books, and is commonly perceived to be relatively simple and well-understood. For example, there are many descriptions of standard sampling techniques involving purging the monitoring wells a given number of well volumes or until water quality parameters such as temperature and conductivity are stabilized, the low flow sampling techniques have been proven to be representative, and sampling groundwater below floating product is commonly avoided so that NAPL is not incorporated into the groundwater sample. However, when collecting groundwater samples in NAPL-contaminated source zones without floating product, it is common to incorporate some non-dissolved hydrocarbon in the water sample without recognizing that NAPL is being sampled. The non-dissolved hydrocarbon includes hydrocarbon sorbed to and adhering to the surface of soil solids, and NAPL droplets and micells mobilized by the sampling effort. The non-dissolved hydrocarbon can result in measured hydrocarbon concentrations above what is dissolved and above what may be calculated by the phase partitioning equations and predicted by transport models. Note that at sites without free product that is mobile at the site scale (i.e., free product on the water table at thicknesses exceeding the Charbeneau thickness), only the dissolved phase is generally considered to be mobile (i.e., to be advected downgradient of the source area by the flowing groundwater).

Different groundwater sampling techniques and different water levels at the time of sampling can influence the amount of NAPL incorporated in a groundwater sample. For example, Waterra foot valve pumps tend to agitate the water column in a monitoring well, produce sediment, and may cause increased NAPL blob incorporation relative to low flow sampling techniques, and sampling during periods of extreme high water may reduce NAPL incorporation relative to sampling during periods of low water. Hence, the measured groundwater concentration may change depending on the season, sampling technique, and person conducting the sampling, even though the dissolved concentration is essentially constant. The high concentrations caused by NAPL incorporation in groundwater samples may result in overestimates of human health risk and may complicate data interpretation. The overestimate of human health risk occurs because maximum concentrations from shallow, poorly developed monitoring wells are commonly used to characterize the groundwater that could be consumed by persons at the contaminated sites, whereas drinking water wells at hydrocarbon spill sites generally do not tap the shallow water sampled by monitoring wells and drinking water wells are typically developed extensively compared to monitoring wells (drinking water well development tends to reduce or eliminate sediment production and NAPL entrainment). Data interpretation problems associated with samples containing NAPL could

include using the NAPL-tainted concentration as the dissolved phase concentration for the source area in fate and transport modeling and/or Mann-Kendall plume stability assessments.

Several sampling techniques exist that help minimize or eliminate the false high measures of dissolved phase groundwater concentration caused by the presence of NAPL in water samples. Note that many of the sampling techniques were developed to reduce the handling of purged water. Examples of sampling techniques that may minimize or eliminate NAPL incorporation include the following:

- Low flow techniques (where purging is conducted at low flow levels)
- Sampling with a peristaltic pump in which the suction tube has been filled and covered by a layer of ice (the sampling tube is filled with water and then frozen, and the ice melts after a short time in the monitoring well)
- Filtration of groundwater samples either in the field or laboratory (as reported by Zemo and Foote, 2002)
- Diffusion bag samplers

1.1 Purpose and Objectives

The purpose and objectives of this technical background document are as follows:

- Identify the NAPL incorporation groundwater sampling issue so that responsible parties, consultants, and ADEC are aware of, and have a common understanding of, the impacts of the incorporation of NAPL in groundwater samples
- Characterize the solubility of selected Alaskan fuels to help improve interpretation of field data
- Assess the ability of diffusion bags and filtration to remove NAPL and provide groundwater concentrations representative of the true dissolved phase concentration
 - Regarding the use of filtration, questions to be answered include: Does filtration remove all of the NAPL? Does filtration remove some of the dissolved phase hydrocarbons?
 - Regarding the use of diffusion bag samplers, questions to be answered include: Do diesel range hydrocarbons pass through the walls of the diffusion bag sampler? Will the diffusion bags maintain structural integrity when immersed in NAPL, or will they disintegrate?

This technical background document builds on the information presented in the technical background documents on phase partitioning, hydrocarbon characterization, and site characterization and site closeout.

Background on Groundwater Sample Analysis, Filtration, and Diffusion Bag Samplers

2.1 Groundwater Sample Analysis

Groundwater at fuel hydrocarbon spill sites in Alaska is routinely analyzed for benzene, toluene, ethylbenzene, and total xylenes (BTEX), gasoline-range organics (GRO), and diesel-range organics (DRO). The BTEX and GRO analytical test methods (EPA 8021 and Alaska [AK] 101) are purge and trap gas chromatograph (GC) methods. Purge and trap GC analysis typically involves puncturing the septum of the 40-millimeter sample vial with a needle, removing a small volume of water, bubbling a carrier gas through the water to remove the volatiles (purging), adsorbing or trapping the purged hydrocarbons from the carrier gas in an activated carbon filter, and then heating the carbon filter to drive the hydrocarbon out of the activated carbon and into a carrier gas stream that carries the hydrocarbon through the GC.

The carbon trap is rapidly heated to transfer the hydrocarbon to the GC column. The retention time and temperature in the GC column may be equated to the equivalent carbon number of the hydrocarbon. Most modern GCs are equipped with an “auto sampler” that automatically removes the water from the sample vial and purges and traps the hydrocarbons from a number of sample vials sequentially. The purge and trap method can incorporate NAPL in the water removed from the sample vial primarily as micells (colloidal-sized blobs of hydrocarbon molecules), but in general floating product at the top of the sample and NAPL in sediment at the bottom of the sample would not be included in the water that is removed and purged. Therefore, purge and trap methods are less susceptible to NAPL incorporation than the DRO and residual-range organics (RRO) test (methods as described below). The purge and trap methods are well-suited to soluble and volatile compounds (such as the BTEX and GRO compounds) but not to low solubility and low volatility hydrocarbons such as the DRO and RRO compounds.

The DRO and RRO [and extractable petroleum hydrocarbons (EPH)] test methods are GC methods that use a “total extraction” process. In this extraction process, all of the hydrocarbon in the sample container is extracted by contacting the water sample with a solvent (methylene chloride for the DRO, RRO and EPH tests). In practice the hydrocarbon is transferred from the water to the solvent in a separation funnel as follows: the water sample is poured into the separation funnel; a volume of the solvent is used to rinse the sample jar and is then added to the separation funnel and the separation funnel is shaken for a few minutes to allow contact between the water and the solvent. The solvent is then drained from the separation funnel (methylene chloride is heavier than water). Then a new volume of solvent is added to the water in the separation funnel (after rinsing the sample container with the solvent); the solvent and water is again stirred for a few minutes and the solvent is drained from the separation funnel. Finally, a third volume of solvent is added to the water sample; stirred for a few minutes; and the solvent is drained from the separation funnel. The total volume of solvent from all three

rinses is combined and the extracted hydrocarbon is then concentrated by evaporating or “blowing down” much of the solvent mass (volatile hydrocarbons are also lost in this step; therefore, the DRO and EPH tests are not recommended for volatile hydrocarbons). The concentrated extract is then analyzed in the GC. The entire mass of hydrocarbon in the sample, whether the hydrocarbon is present as NAPL, adsorbed, or dissolved phase, is reported in units of mass per volume of water (e.g., milligrams per liter [mg/L]). The DRO (and RRO and EPH) test methods are susceptible to the incorporation of NAPL in the groundwater sample.

2.2 Filtration to Remove NAPL

Some of the NAPL in the groundwater samples can be removed by filtering the sample (prior to the extraction process) to physically separate the NAPL from the water as documented by Zemo and Foote (2003), and others. The filtration can be conducted in the field or laboratory, although the laboratory affords better working conditions. Zemo and Foote (2003) suggested that the filter be a fiberglass filter so that it does not adsorb organics, and that the opening of the filter be small (0.45 microns). Zemo and Foote (2003) filtered several groundwater samples to demonstrate that much of the mass measured in the total petroleum hydrocarbon (TPH) test (which uses an extraction step) was NAPL and not dissolved hydrocarbon.

2.3 Diffusion Bag Samplers

Diffusion bag samplers or passive diffusion bags (PDBs) consist of low density polyethylene bags filled with distilled water (sandwich bags are typically made of low density polyethylene). When placed in a monitoring well, dissolved phase organic compounds tend to diffuse through the wall of the bag in response to the concentration gradient between the water in the formation and the distilled water in the bag. To keep the bags at the desired elevation in the monitoring well the bottom of the bag is typically weighted and the top of the bag is tied to a string running to the top of the well. The diffusion bags are typically left in the monitoring well for about 2 weeks to allow time for the diffusion bag samplers to equilibrate with the groundwater. After equilibrating the bags are removed from the well, punctured with a straw, and the water is decanted to a standard groundwater sampling container such as a 40-milliliter (milliliter) vial. The diffusion bag samplers eliminate the need to purge the monitoring well and do not require use of pumps on site. The diffusion bags tend to yield an average concentration for the time they are in the well (but would tend to emphasize the more recent concentration trend). Diffusion bags can also be used in surface water environments.

Field tests of the passive diffusion bags have shown very good correlation between samples collected by the traditional bailer method and the diffusion bag for many volatile organic compounds including the BTEX compounds, naphthalene, and the chlorinated alkanes. However, the diffusion bags are not appropriate for all compounds. Methyl tertiary butyl ether (MTBE), acetone, and some semivolatiles appear to be transmitted through the diffusion bag more slowly, resulting in a lower concentration in the bag than in the ambient water. Inorganic metal ions and large organic molecules such as humic acids do not penetrate the diffusion bag walls. The suitability of diffusion bags for monitoring the more soluble DRO fractions has not been fully evaluated and the ability of the bags to maintain their structural integrity during long-term exposure to gasoline NAPL has not been evaluated.

2.4 Examples of Potential Errors Associated with NAPL Incorporation in Groundwater Samples

Groundwater hydrocarbon concentration data may be used for a variety of purposes and therefore many types of conceptual and quantitative errors could result from using groundwater sample data that incorporated NAPL. Hypothetical examples of potential errors are presented below.

- **Example 1.** Sampling data collected at a diesel #2 spill site showed DRO soil concentrations of 7000 milligrams per kilograms (mg/kg) in 1995, and groundwater DRO concentrations decreasing from 200 mg/L, to 99 mg/L, to 64 mg/L, to 31 mg/L over a 4-year period (1996 to 2000). A plot of the existing data showed a significant decrease in concentration and indicated that the groundwater would reach drinking water standards in a few years (Figure 1). The land owner had hoped to develop the property and to use on-site wells as a water source. Based on these data the land owner elected to move forward with the development project without conducting active remediation or removing the source, instead relying on natural attenuation to achieve aquifer remediation.

Fortunately, a reviewer recognized that all of the groundwater test results were above the solubility of diesel fuel and that the groundwater samples contained NAPL and could not be relied upon to indicate the true dissolved phase concentration. The change in concentration observed in the groundwater samples was likely related to variation in the water table elevation and/or sample collection methods. The reviewer modeled the change in source area dissolved phase concentration, given the soil concentration data collected in 1995, and found that there was likely no measurable change in dissolved concentration between 1996 and 2001 and that intrinsic remediation of the source area to drinking water standards could require 50+ years. Subsequent groundwater sampling that excluded NAPL confirmed that the dissolved DRO concentration was about 3.5 mg/L (see Figure 1).

- **Example 2.** A leak along a buried pipeline released several thousand gallons of jet fuel near a drinking water well. During emergency response site assessment work, several groundwater sample analyses showed DRO concentrations of about 150 mg/L. Intrinsic remediation indicator data showed that dissolved oxygen was being consumed but the sulfate and iron concentrations were unchanged by the presence of the hydrocarbon. To predict how far the plume would travel before stabilizing, these groundwater concentrations were used as input to the dissolved phase transport model "BioScreen." Given a source area concentration of 150 mg/L DRO and an upgradient dissolved oxygen concentration of 10 mg/L, the BioScreen model predicted that the plume would be over 1,000 feet long (Figure 2). Given that the drinking water well was only about 700 feet away, extensive emergency response actions were proposed.

Fortunately, a reviewer recognized that the groundwater test results were above the solubility of jet fuel and that the high DRO concentrations were the result of NAPL in the groundwater samples and that the NAPL was not mobile. Groundwater samples not containing NAPL were collected and the results indicated that dissolved phase concentrations in the source area were only 3 mg/L. When these dissolved phase concentrations were used as input, the BioScreen model predicted that the dissolved phase plume would meet drinking water standards about 100 feet downgradient of the NAPL

source zone and 600 feet upgradient of the drinking water well (Figure 3). A less-extensive remediation effort, monitoring program, and contingency plan were implemented to address the site conditions.

Scope of Work/Laboratory Setup and Analytical Testing

To assess the solubilities of the selected Alaskan fuels and to test the ability of the diffusion sample bags and filtering to remove NAPL from groundwater samples, laboratory testing was conducted.

3.1 Laboratory Setup

The tests involved simulating groundwater in equilibrium with the NAPL of six typical Alaskan fuels. The 6 fuels used in this demonstration were selected from the 12 fuels used in the NAPL characterization study and included: Sample #3 a JP-4 jet fuel, Sample #4 DF1 diesel fuel, Sample #6 regular gasoline, Sample #9 Jet A, Sample #10 diesel fuel, and Sample #12 DF2 diesel fuel. (The NAPL characterization study involved assessing the mass fraction in different aromatic and aliphatic equivalent carbon groups for samples of 12 Alaskan fuels (Geosphere and CH2M HILL, 2006)).

The test apparatus is pictured in Figures 4 through 6, and consisted of a 6-gallon carboy glass bottle containing about 2.5 to 3.0 gallons of Anchorage tap water, a stainless steel racking cane (hollow tube) used to extract the water sample, and one or two diffusion bag samplers. The diffusion bag samplers were purchased from “Eon Products” and were pre-filled with distilled water. The diffusion bags were about 1.25-inches in diameter, 36 to 40 inches long, and contained about 1.1 liters of water. The diffusion bags were slightly under-filled with water so they could be folded when they were in the carboy bottle. The diffusion bags were tied to a string to allow retrieval from the carboy bottle. The racking cane and string were held in place and volatilization was minimized by a rubber stopper in the mouth of the carboy.

After preparing the carboy bottles as described above, about 2 liters of selected Alaskan fuels were poured into the carboy bottles through a funnel and tube (the tubing caused the fuel to flow against the wall of the carboy and not penetrate the water surface to the depth of the racking cane). When the fuel was in the carboy the diffusion bag sampler was in contact with both the water and NAPL in the carboy bottle. A magnetic stir bar was dropped into the carboy and the carboy was placed on a stirring table. The carboys containing the water and fuel were continuously stirred for about 14 to 16 days while the fuel and water came into phase equilibrium. While equilibrating, the carboys and stirring tables were located under a room temperature, vented hood at the University of Alaska, Anchorage, School of Engineering.

3.2 Water Sampling

After the fuel and water had equilibrated, 4 types of water samples were collected from the carboys as depicted on Figure 7 and described below.

1. **Carboy water in equilibrium with the NAPL (but not containing NAPL).** Water in equilibrium with the NAPL, but not containing NAPL, was pumped from the bottom of the carboy bottles using the racking cane and a peristaltic pump. The water was pumped into in 40-milliliter vials and a minimum of four each, 1-liter amber jars (in most cases duplicates were also collected). The 40- milliliter vial samples were submitted for BTEX and volatile petroleum hydrocarbon (VPH) analysis; one of the four each, 1-liter bottles was submitted for EPH analysis; and one of the 1-liter jars was submitted for polycyclic aromatic hydrocarbon (PAH) analysis (the other two 1-liter bottles were spiked with NAPL as described below). The carboy water in equilibrium with the NAPL was the first type of sample.
2. **Carboy water spiked with the NAPL.** The two remaining 1-liter jars were spiked with NAPL from the carboy jar to simulate groundwater samples containing NAPL. The NAPL was drawn from the carboy using the peristaltic pump and placed in a 50-milliliter beaker. A gas-tight syringe was used to extract NAPL from the beaker and inject 1-milliliter of the NAPL into each of the two 1-liter sample bottles. The spiked bottles were both sent to the laboratory, where one of the spiked samples was analyzed for EPH. The carboy water spiked with NAPL was the second type of sample.
3. **Carboy water spiked with the NAPL and filtered.** The second spiked sample sent to the analytical laboratory where the water was filtered through a 0.45-micron fiberglass filter (a toxicity characteristic leaching procedure [TCLP] filter) and the filtered water was analyzed for EPH. The carboy water spiked with NAPL and then filtered was the third type of sample.
4. **Diffusion Bag Water.** The diffusion bags were removed from the carboy bottles and the exterior surface of the bags was wiped with a cloth to remove NAPL from the surface of the bags. Then the bags were punctured with a sampling straw and the water in the bags was decanted into 40-milliliter vials and 1-liter amber jars. The 40-milliliter vial samples were submitted for BTEX and VPH analysis and the 1-liter bottles were submitted for EPH analysis. The diffusion bag water was the fourth type of sample.

3.3 Analytical Testing

The water samples were submitted to North Creek Analytical in Portland, Oregon, for analysis. The un-spiked water samples from the carboy and the diffusion bag samples were analyzed for BTEX, VPH, and EPH. The spiked water and spiked and filtered water samples were analyzed for EPH. Note that the impact of NAPL incorporation on the BTEX and VPH results was not evaluated because the impact of NAPL incorporation on the BTEX and VPH was not expected to be as significant as the effect of NAPL incorporation on the EPH results (as described in the background section), and because the filtering process was expected to cause unacceptable mass loss in the BTEX and VPH ranges.

Testing Results

The results of the BTEX, VPH, and EPH testing are presented in Tables 1 and 2. In the following sections these laboratory test results are used to assess the ability of diffusion bag samplers and NAPL to yield dissolved phase concentrations in NAPL source areas and to characterize the solubility of selected Alaskan fuels.

4.1 Diffusion Bag Testing—Objectives and Results

The objective of the diffusion bag testing was to assess the ability of diffusion bags to simultaneously eliminate NAPL from groundwater samples and provide groundwater concentrations representative of the true dissolved phase concentration. Questions to be answered include: (1) Will the diffusion bags maintain structural integrity when immersed in NAPL (or will the bags disintegrate?), and (2) Do diesel-range aromatic and aliphatic hydrocarbons pass through the walls of the diffusion bag sampler at the same concentrations that the diesel-range aromatic and aliphatic fractions dissolve in water?

As described previously, the test approach consisted of placing diffusion bags filled with distilled water in carboy bottles containing water and NAPL for a period of 14 to 16 days. Portions of the diffusion bags were in contact with the water and NAPL as pictured in Figure 6. The diffusion bags were suspended in the carboy and retrieved from the carboy by a string tied around the diffusion bag. The diffusion bags had a diameter of 1.25 inches and were slightly under-filled so that the bags could be folded back on themselves in the carboy and pulled through the 1-inch-diameter mouth of the carboy bottle. The diffusion bags were in contact with regular gasoline, JP4 jet fuel, Jet A, diesel fuel #1, diesel fuel (a wide cut diesel), and diesel fuel #2. After allowing time for the carboy water and diffusion bag water to equilibrate with the NAPL, the carboy water and diffusion bag water were sampled and tested.

The answer to question 1, “will the diffusion bags maintain structural integrity when immersed in NAPL or will the bags disintegrate?” may be assessed based on the performance (i.e., the integrity) of the bags during the test. All of the diffusion bags maintained structural integrity for the 14- to 16-day NAPL contact period. At the conclusion of the NAPL contact period, the diffusion bags were removed from the carboy bottles by pulling the 1.25-inch-diameter bags through the 1-inch-diameter mouth of the carboy bottle. The diffusion bags were then wiped with a cloth to remove NAPL from the surface of the bag and sampled by puncturing the bags with a sampling straw. None of the bags ruptured and no slow leaks were observed during removal from the carboy, wiping to remove NAPL, or water sampling. Based on this evidence it appears that the diffusion bags can maintain structural integrity for at least 2 weeks while in contact with the NAPL of the Alaskan fuels used in the demonstration.

The answer to question 2, “do diesel-range aromatic and aliphatic hydrocarbons pass through the walls of the diffusion bag sampler at the same concentrations that the diesel- range aromatic and aliphatic fractions dissolve in water” may be assessed by comparing the laboratory test results from the carboy water with the test results from the diffusion bags (the carboy and

diffusion bag samples constitute paired samples). The BTEX and VPH results are presented in Table 1 and graphed in Figure 8. Figure 8A displays all BTEX and VPH equivalent carbon groups while Figure 8B displays only the VPH results in the DRO range. In both Figure 8A and Figure 8B, the carboy water concentrations are graphed on the x-axis and the corresponding diffusion bag concentrations are graphed on the y-axis. Note that on both Figures 8A and 8B results reported at less than 1 percent of the reporting limit are not graphed or included in the calculation of the trend line. This screening of lab data only eliminated the C12 to C13 aromatics fraction from the gasoline sample and the C5 to C6 aliphatics fraction from the diesel fuel #1 sample. As shown on both figures the paired data values fall along a 1:1 correlation line showing that essentially the same concentrations were measured in the water from the carboy as in the water from the diffusion bags. The results in Figure 8A for all BTEX and VPH equivalent carbon groups has a slope of 1.04 ($R^2 = .999$). The results in Figure 8B which include only the VPH results in the DRO range equivalent carbon groups has a slope of 1.03 ($R^2 = .990$). The correlation of the BTEX results was expected because the diffusion bags have been repeatedly tested and shown to accurately represent dissolved BTEX concentrations. The correlation of the C10 to C12 aromatics, C12 to C13 aromatics, and C10 to C12 aliphatics may be considered new data indicating that hydrocarbons in the most soluble portions of the DRO range pass through the walls of the diffusion bags and are present in the diffusion bag at the same concentration as they are in the surrounding water. This result should not be surprising because the diffusion bags had previously been shown to accurately measure dissolved naphthalene which has an equivalent carbon number of 11.69 (Vrobesky, 2001a).

The EPH results are presented in Table 2 and selected EPH data are graphed in Figure 9. Figure 9 displays DRO range aromatic and aliphatic equivalent carbon groups from the EPH test (not the C8 to C10 fraction), total EPH data (which includes the C8 to C10 fraction) and DRO values (which are calculated as the sum of the EPH data in the C10 to C21 range). In addition, Figure 9 does not include data from Sample #10 diesel fuel because the diffusion bag sample appears to have been impacted by NAPL as indicated by C12 to C16 aliphatic and C16 to C21 aliphatic concentrations above solubility limits. The incorporation of NAPL into the diffusion bag sample is interpreted to be due to sampling techniques (e.g., not completely wiping NAPL off the bag before drawing a sample from the bag) and not to NAPL penetrating the LDPE walls of the bag. In Figure 9, the carboy water concentrations are graphed on the x-axis and the corresponding diffusion bag concentrations are graphed on the y-axis. Note that when duplicate samples existed, the duplicate carboy water samples and duplicate diffusion bag samples were averaged and the average carboy water and average diffusion bags values were compared. Although the EPH results show more variability than the VPH results, they still fall along a line representing a 1:1.165 correlation ($R^2 = .967$), showing that similar concentrations were measured in the water from the carboy as in the water from the diffusion bags. The correlation of the C10 to C12 aromatics, C12 to C16 aromatics, and C16 to C21 aromatics indicates that aromatic and aliphatic hydrocarbons in the DRO range pass through the walls of the diffusion bags and are present in the diffusion bag at approximately the same concentration as they are in the surrounding water (note that the results that do not correlate well suggest that the diffusion bag has higher concentration than in the carboy water).

4.2 Spiking and Filtration—Objectives and Results

The objective of the filtration testing was to assess the ability of filtering to simultaneously eliminate NAPL from groundwater samples and provide groundwater concentrations representative of the true dissolved phase concentration. Questions to be answered include: (1) Does the filtration remove all of the NAPL, and 2) Does the filtration remove any of the dissolved phase hydrocarbons?

As described previously, testing of the filtration method for removing NAPL involved collecting multiple 1-liter samples from the carboy bottle after the water had equilibrated with NAPL in the carboy bottles (14 to 16 days). Pairs of the 1-liter samples were spiked with NAPL from the carboy and sent to the analytical laboratory. In the laboratory one of each pair of spiked samples was analyzed for EPH without filtering while the other was filtered and then analyzed (recall that the high hydrocarbon concentrations associated with NAPL incorporation are more significant for the EPH/DRO tests than for the VPH/GRO tests). The sample of spiked water that was not filtered was expected to show relatively high hydrocarbon concentrations and to have many constituents present at concentrations exceeding the effective solubility of the fraction. If the filtering was successful at removing NAPL and not removing dissolved phase hydrocarbon, then the filtered sample would match the concentrations measured in the carboy water samples.

The answer to questions 1 does the filtration remove the all of the NAPL and question 2 does the filtration remove any of the dissolved phase hydrocarbons may be answered by comparing the spiked and filtered water with the water from the carboy. The EPH results are presented in Table 2 and graphed in Figures 10 and 11. In Figure 10 the spiked water concentrations are graphed on the x-axis and the corresponding spiked and filtered concentrations are graphed on the y-axis. The results show that the spiked water had much higher concentrations than the spiked and filtered water (the majority of the data points fall to the right of the 1:1 correlation line). This indicates that the filtering was able to remove much of the NAPL mass.

In Figure 11 the carboy water concentrations are graphed on the x-axis and the corresponding spiked and filtered water concentrations are graphed on the y-axis. The results show that the data are scattered, but that in general the spiked and filtered water had higher concentrations than the carboy water. That is, the majority of the data points fall to the left of the 1:1 correlation line, and a best fit line for the pairs of data indicate that the spiked and filtered water samples have a concentration about 1.58 times the carboy water concentration ($R^2 = .70$). This comparison suggests that the filtering was able to remove much, but not all, of the NAPL. Comparison of the total EPH concentration of the filtered samples to the spiked samples and the carboy water samples suggests that the filtering removed about 85 to 100 percent of the NAPL (in the five samples in the data set). The carboy water samples and the spiked and filtered water samples do not clearly show the loss of any single hydrocarbon fraction as a result of volatilization during filtration. The only fraction that appears to be present at a higher concentration in the carboy water than the filtered water is the C12 to C16 aromatics.

4.3 Preliminary Conclusions Concerning Diffusion Bag Samplers and Filtration

Diffusion Bags Samplers. The limited quantity of data presented here suggests that diffusion bag samplers have the potential to:

- Measure true dissolved phase DRO concentrations
- Eliminate NAPL incorporation in EPH and DRO samples when sampling in NAPL-contaminated source zones (provided the surface of the bags are wiped properly)
- Maintain their structural integrity when in contact with NAPL for at least 2 weeks

Filtration of DRO and EPH Samples. The data presented here suggests that filtration of samples containing NAPL may eliminate the majority, but not likely all, of the NAPL in a water sample containing NAPL. Filtration appears capable of yielding more realistic measures of the dissolved phase concentration in samples known to contain diesel or jet fuel NAPL, but likely does not characterize the true dissolved phase concentration as accurately as diffusion bag samplers or carefully collected, low flow groundwater samples.

Characterization of the Solubility of Alaskan Fuels

The laboratory test results from the diffusion bag and filtration study can provide a characterization of the solubility of the fuels used in the tests. This fuel solubility characterization is valuable because it helps document and demonstrate basic concepts related to phase partitioning, site characterization, dissolved phase transport and human health and environmental risk calculations.

Individually, the results of the BTEX, PAH, VPH and EPH laboratory tests present a partial or incomplete picture of the dissolved phase hydrocarbons in equilibrium with the NAPL of the Alaskan fuels. For example, although Alaskan jet and diesel fuels appear to have dissolved constituents ranging from about C6 to C20, the VPH test results do not present data on the BTEX concentrations or on fractions above equivalent carbon number 13. Similarly, the EPH test does not include information on hydrocarbon fractions below equivalent carbon number 8. Full characterization of the dissolved phase hydrocarbons resulting from releases of Alaskan fuels will likely require several different laboratory tests (for example, BTEX, VPH, DRO and PAH) and decisions on how to use the overlapping data.

5.1 BTEX, GRO, VPH, EPH and DRO Data Ranges

Figure 12 shows the hydrocarbon equivalent carbon ranges provided by the different laboratory test methods, the desired or recommended aromatic and aliphatic equivalent carbon ranges, and summarizes guidelines for combining data from the different test methods. Figure 12 shows the GRO, DRO, RRO, VPH, EPH, and BTEX aromatic and aliphatic equivalent carbon ranges from left to right across the page, and the desired or recommended fractions on the far right side of the page. Red arrows are used to highlight how the BTEX, VPH, and EPH data may be used to characterize the concentrations in the recommended aromatic and aliphatic equivalent carbon groups. Figure 12 highlights the following:

- The BTEX test provides concentrations of the individual BTEX compounds (in addition, p-, m-, and o-xylenes are often differentiated). Note that benzene is the only aromatic compound in the C6 to C7 range, toluene is the only aromatic in the C7 to C8 range, and ethylbenzene and the p-, m-, and o-xylenes are the only aromatics in the C8 to C9 range. There are no aromatics with equivalent carbon numbers below C6.5 (benzene), and above C9 there are many aromatic isomers (with slightly different equivalent carbon numbers).
- The VPH test presents concentrations for the following aromatic fractions: C8 to C10; C10 to 12, and C12 to C13; and the following aliphatic fractions: C5 to C6, C6 to C8, C8 to C10, and C10 to C12.

- The EPH test presents concentrations in the following aromatic fractions: C8 to C10; C10 to 12, and C12 to C16, C16 to C21, and C21 to C35; and the following aliphatic fractions: C8 to C10; C10 to 12, and C12 to C16, C16 to C21, and C21 to C35.

To derive the dissolved concentrations in the desired or recommended hydrocarbon fractions, the data from several tests should be combined. General rules for combining the data are illustrated on Figure 12 and listed as follows:

- Within the GRO range, use the VPH aliphatic results as the concentration in the recommended aliphatic ranges
- Use the BTEX results as the BTEX concentrations
- The C9 to C10 aromatics should be calculated as the VPH C8 to C10 aromatic value (or the EPH value, whichever is greater, as described below) minus the sum of the ethylbenzene and xylene from the BTEX test. If the sum of the ethylbenzene and xylene results is greater than the VPH C8 to C10 concentration, then the aromatic C9 to C10 fraction should be assigned a concentration of zero (not a negative value).
- Within the DRO range, both the VPH and EPH tests provide data on the C8 to C10 and C10 to C12 aromatic and aliphatic fractions. In general, the higher of the VPH or EPH test results should be used as the concentration in the C8 to C10 and C10 to C12 aromatic and aliphatic fractions. Note that the VPH test is a purge and trap method, while the EPH test uses an extraction and blow-down concentration step. Hence, the VPH test may be expected to have less loss of volatiles in both the C8 to C10 and C10 to C12 aromatic and aliphatic fractions than the EPH test. Therefore, when both VPH and EPH results are available, the VPH results may frequently yield higher concentrations in the C8 to C10 and C10 to C12 aromatic and aliphatic fractions than the EPH test results. Table 3 presents the VPH to EPH ratio for the testing performed for this project. As shown, the VPH C8 to C10 aromatics test results from the carboy water and diffusion bag samples were higher than the EPH C8 to C10 aromatics results by a factor of about 3 to 30 and averaging about 9.5; and the VPH C10 to C12 aliphatics test results from the carboy water and diffusion bag samples were higher than the EPH C10 to C12 aliphatics results by a factor of 1 to 95 and averaging about 13 (also note that most of the difference between the VPH and EPH measures of the C10 to C12 aliphatics was attributable to one sample).
- The C12 to C16, C16 to C21, and C21 to C35 aromatic and aliphatic fractions must be derived from the EPH test results. Note that the AK102 and AK103 methods divide the DRO from the RRO fraction at C25, while the EPH test has an equivalent carbon break at C21, but not at C25. The proposed characterization considers the RRO range to be from C21 to C25. The effect of using C21 as the dividing line between DRO and RRO will have little effect on the characterization of risk because most refined Alaskan fuels have little mass in the C21 to C35 range.

5.2 Characterization of the Solubility of Alaskan Fuels

The BTEX, VPH, and EPH test results from the carboy and diffusion bag water samples (those which do not contain NAPL) have been combined in Table 4 following the general rules provided above. The carboy water samples and the diffusion bag samples are interpreted to be

in phase equilibrium with the NAPL of the example fuels and to characterize the solubility of the fresh fuels used in the demonstration. Note that for each of the 6 fuels used in the carboy and diffusion bag testing, there are several measurements of the dissolved concentration in equilibrium with the NAPL (e.g., for Sample #6 regular gasoline, Sample #9 Jet A, Sample #3 JP4, and Sample #4 diesel fuel 1, there are 2 carboy water samples and 2 diffusion bag samples). The average measured dissolved phase concentrations of the 6 fuel types are summarized and graphed in Figure 13. The measured solubility data show the following:

- Measured TPH solubilities ranged from about 354 mg/L for the gasoline sample to 5.24 mg/L for the Sample #12 diesel fuel 2
- Measured GRO solubilities ranged from about 350 mg/L for the gasoline sample to 3.28 mg/L for the Sample #12 diesel fuel 2
- Measured DRO solubilities ranged from about 1.12 mg/L for the JP4 sample to 4.85 mg/L for the Sample #9 Jet A
- In all of the samples the dissolved GRO concentration was greater than the dissolved DRO concentration, and the majority of the dissolved GRO was composed of the BTEX compounds

5.3 Correlation of Measured Solubilities with Calculated Effective Solubilities

Figures 14 through 19 provide tabulated data and a graph comparing the measured dissolved phase concentrations with the calculated dissolved phase concentrations for each of the 6 fuel types used in the study (the calculated dissolved phase concentrations are based on the oil analyses described in the Alaska Statement of Cooperation Working Group (SOCWG) paper on fuel characterization (Geosphere and CH2M HILL, 2006). The tabular data on each figure lists the ratio of the average measured solubilities and the calculated solubilities (average measured concentration/calculated dissolved concentration). The results generally show a good correlation between the measured and calculated solubilities for the aromatics fractions, with the measured solubilities being commonly being between about 0.5 and 2 times the calculated solubilities. This correlation is acceptable because Raoult's Law is only accurate to a factor of about 2, and both the measured water concentrations and the analysis of the oil have repeatability acceptance criteria of ± 50 percent. For the aliphatic fractions the correlation is not as good, with the measured concentrations commonly being an order of magnitude above the calculated solubility (however the aliphatic solubilities are several orders of magnitude below the aromatic solubilities and the aliphatics typically contribute a minor fraction of the total solubility within a given equivalent carbon range). Despite the differences between the measured and calculated solubility values, both the measured and calculated solubility data are very instructive and useful. From the data we are able to conclude the following:

- Fresh Alaskan gasolines may have GRO solubilities between about 150 and 350 mg/L
- Fresh Alaskan diesel and jet A fuels may have GRO solubilities between about 3 and 8 mg/L, and DRO solubilities between about 1 and 5 mg/L

As fresh fuels weather, the solubilities of the BTEX and GRO fractions would tend to be reduced relatively quickly by volatilization, dissolution and biodegradation, while the DRO aromatic and aliphatic concentrations would remain relatively stable for a sustained time (decades). Hence, when groundwater samples from diesel and jet fuel spill sites show DRO aromatic and aliphatic concentrations in the 10 to 100+ mg/L range, we can readily conclude that the sample contained NAPL and that the true dissolved phase DRO aromatic and aliphatic concentrations are lower. We can therefore adjust our understanding of the site conditions and our use of the DRO aromatic and aliphatic groundwater sample data.

5.4 Polar Fraction

The biodegradation of aromatic and aliphatic fuel hydrocarbons tends to produce polar biodegradation byproducts, such as organic acids, alcohols, and phenols. These polar biodegradation byproducts are very soluble compared to the aromatic and aliphatic compounds; therefore, a small mass fraction of the polar compounds in the NAPL will tend to result in a relatively high dissolved concentration of polar compounds. The polar biodegradation byproducts are detected by and reported as DRO and RRO in the AK102 and AK103 tests. This creates problems in that results derived from the AK102 and AK103 tests at old spill sites where the fuel has been subject to biodegradation may show:

- DRO and RRO concentrations above the diesel fuel and jet A solubilities presented here, but it is likely that the results include polar compounds and that the true aromatic and aliphatic hydrocarbon concentrations are lower than the diesel and jet A solubilities reported here.
- Groundwater samples analyzed only for DRO maybe exceed risk-based groundwater ingestion concentrations, when in reality DRO aromatic and aliphatic concentrations meet risk-based criteria and much of the mass being quantified as DRO is composed of polar compounds.

To assess the risks associated with DRO aromatic and aliphatics in groundwater and eliminate the incorporation of polar fraction in the DRO test result, the DRO and RRO analysis should include a silica gel cleanup step or the VPH and EPH test methods may be used. As an alternative, it is likely that diffusion bags would preclude the polar fraction from being incorporated in the water sample (polar molecules do not diffuse through the walls of the bag); therefore, DRO analysis of diffusion bag samples should tend to report only DRO aromatics and aliphatics (field trails are recommended).

5.5 PAH Concentrations

The carboy water samples were tested by EPA method 8270 with selective ion monitoring (SIM) to assess the effective solubility of the PAH compounds (i.e., the solubility in water in equilibrium with the NAPL of the selected Alaskan fuels). The results (Table 5) show that only 4 of the 13 PAH compounds were detected in the carboy water: naphthalene, acenaphthene, fluorene, and phenanthrene; and that only naphthalene was detected at concentrations above 10 micro liters (μL). As shown at the bottom of Table 5, all of the detected compounds were below the ADEC 18AAC75 Table C groundwater ingestion risk levels, and only naphthalene was present in the water at more than about 1 percent of its risk-based concentration. These

measured PAH concentrations indicate that releases of fresh diesel and jet A will not result in groundwater that exceeds risk-based concentrations for the PAH compounds even when there is NAPL trapped below the water table and product floating on the water table.

SECTION 6

Dissolved Phase Concentrations—Implications for Risk Calculations

The measured dissolved concentration data from the carboy and diffusion bag water samples and the calculated effective solubilities from the oil analysis (Geosphere and CH2MHill, 2006) can be used to learn about the potential risks posed by spilled hydrocarbons via the groundwater ingestion and migration-to-groundwater routes. The following discussion assumes that the carboy water, diffusion bag, and oil sample analyses performed for the SOCWG are representative of the dissolved concentrations of the example fuels and that dilution and attenuation that occur as described by the EPA and ADEC dilution/attenuation factor (DAF) equation. The discussion is intended to help understand what fuel constituents are most likely to drive risk at fuel hydrocarbon contaminated sites and does not suggest that monitoring or risk characterization is unnecessary for the hydrocarbon fractions that do not appear to drive risk.

The groundwater ingestion route assumes that the groundwater at the site is the primary drinking water source for people at the site. Under a reasonably expected worst-case scenario, spilled fuel hydrocarbon would migrate to the saturated zone and be immobilized below the water table and smeared through the zone of seasonal water table fluctuation. Under these conditions, hydrocarbon constituents would partition from the fuel NAPL into the groundwater at the fuel constituent's effective solubility, and the groundwater in phase equilibrium with the NAPL could be consumed without dilution or attenuation. (It is possible for the drinking water well to also extract NAPL, but long-term consumption of water containing NAPL is not likely because the water would smell like fuel, taste like fuel, and have a sheen that would alert the user to the presence of the contamination. In contrast, dissolved phase contamination above risk-based levels may not exhibit a smell or taste and would not have a sheen to alert the consumer to the presence of the contaminant; hence, long-term consumption of the tainted water could persist undetected).

Assessing the potential risk posed by ingesting groundwater in phase equilibrium with the fuel NAPLs used in this study involves comparing the measured carboy and diffusion bag water concentrations and the calculated effective solubilities of the oil samples (analyzed in the technical background document on fuel characterization) to risk-based groundwater levels or to maximum contaminant levels (MCLs). A groundwater ingestion "fraction of risk" calculation is used to make this comparison. The groundwater ingestion fraction of risk is calculated by dividing the measured or calculated dissolved phase concentrations by the risk-based groundwater ingestion concentration for each hydrocarbon fraction. Fraction of risk values less than 1 present acceptable risks, while fraction of risk values greater than 1 present unacceptable risks. Note that some of the 18AAC75 Table C groundwater cleanup levels are risk-based groundwater ingestion concentrations, and some are not risk-based concentrations. Those Table C groundwater standards that are not risk-based include concentrations that are capped at solubility limits (e.g., GRO and DRO aliphatics), or use MCLs (e.g., the BTEX compounds), which are sometimes lower than the risk-based groundwater ingestion levels (the lower MCL

values are intended to simultaneously account for risk from water ingestion, dermal contact, and inhalation).

The migration-to-groundwater route is similar to the groundwater ingestion route, but the migration-to-groundwater route, as described by ADEC and EPA, involves transporting the dissolved phase contaminants from a vadose zone source to the saturated zone at the downgradient edge of the site. In concept, while the dissolved contaminants are being transported they are subject to dilution and attenuation. The ADEC default assumption is that dissolved contaminants are subject to a dilution-attenuation factor of 13.3 (that is, the “target concentration” in the vadose soil moisture concentration may be 13.3 times the risk-based concentration). The “fraction of risk” for the migration-to-groundwater route may be assessed by dividing the measured or calculated dissolved concentration by the risk-based groundwater standard multiplied by the dilution attenuation factor (migration to groundwater fraction of risk = equilibrium concentration / (groundwater ingestion risk-based concentration * DAF). Fraction of risk values less than 1 represent acceptable risks, while fraction of risk values greater than 1 represent unacceptable risks. Recall that the migration-to-groundwater route is not used in cumulative risk calculations but has been used to help set cleanup levels for contaminated sites.

6.1 Measured Dissolved Phase Concentrations Compared to Risk-based Criteria

Table 6 compares the measured dissolved phase equilibrium concentrations for the fuels used in these studies to the risk-based drinking water standards and the migration-to-groundwater “target concentrations.” The left side of Table 6 provides data used in the assessment of risk for each petroleum hydrocarbon fraction, including the hydrocarbon fraction pure phase solubility, the drinking water MCL and groundwater ingestion risk-based concentration, the vadose zone soil moisture target concentration, and a comparison of the groundwater ingestion risk-based concentration to the pure phase solubility of the fraction. Note that the comparison of the groundwater ingestion risk-based concentration to the pure phase solubility of the fraction shows that only the BTEX, GRO aromatics, and DRO aromatics have solubilities above the risk-based concentration for the fraction; that is, only these hydrocarbon fractions have the potential to pose a dissolved phase groundwater ingestion risk. The RRO aromatic and the GRO, DRO, and RRO aliphatics cannot dissolve into groundwater at concentrations that would cause a groundwater ingestion risk (but these fractions could cause a risk if NAPL were consumed). Following these data in Table 6 are the average dissolved phase concentrations measured in each fuel used in the carboy water and diffusion bag study and the potential fraction of risk values for the groundwater ingestion route and the migration- to-groundwater route. Table 6 shows the following:

- In Sample #6 regular gasoline, the groundwater ingestion potential fraction of risk for benzene, toluene, ethylbenzene and GRO aromatics exceeds 1, indicating that benzene, toluene, ethylbenzene and GRO aromatics can partition into groundwater above the drinking water standards when the gasoline NAPL is in contact with the groundwater (dilution-attenuation factor= 1). However, the GRO aliphatics and DRO aromatic and aliphatic constituents in gasoline would not partition into groundwater at concentrations exceeding the groundwater criteria for these fractions even when NAPL contamination

extends below the water table and floating product is present on the water table. Given that the default dilution-attenuation factor represents the processes occurring at the site, the migration to groundwater fraction of risk calculation shows that benzene, and GRO aromatics have the potential to migrate to groundwater at concentrations above groundwater risk-based levels but that the ethylbenzene, xylene, GRO aliphatics, and the DRO aromatic constituents in gasoline would not be transported into the groundwater mixing zone at concentrations exceeding the groundwater ingestion criteria for these fractions. (In addition, RRO aromatics, GRO aliphatics, and DRO aromatics and aliphatics would not be transported into the groundwater mixing zone at concentrations exceeding the groundwater ingestion criteria for these fractions).

- The JP4 fuel sample has similar results, showing that if JP4 NAPL is in contact with groundwater, then only benzene, toluene and the GRO aromatics would partition into the water at concentrations exceeding the groundwater risk-based levels (xylene, GRO aliphatics, and the DRO and RRO aromatic and aliphatic constituents did not partition into the water at concentrations exceeding the groundwater standard), and given that the default dilution-attenuation factor represents the processes occurring at the site, benzene is the only hydrocarbon fraction that would migrate to groundwater at concentrations above the groundwater ingestion criteria.
- Sample #4 DF#1, Sample #9 Jet A , and Sample #10 diesel fuel results indicate that only benzene and DRO aromatics (and GRO aromatics in the Sample #4 DF#1) will partition into groundwater at concentrations above the groundwater ingestion risk-based level when there is diesel or jet NAPL in contact with the groundwater. When the diesel or jet NAPL is confined to the vadose zone, as assumed in the migration-to-groundwater route, only benzene has the potential to be transported into the groundwater mixing zone at concentrations exceeding the groundwater ingestion risk-based level (given that the default dilution-attenuation factor represents the processes occurring at the site).
- Sample #12 DF#2 dissolved phase data indicate only benzene would be expected to partition into groundwater above risk-based concentrations, even when the DF#2 NAPL is present below and floating on the water table. The groundwater in contact with the DF#2 NAPL would be expected to have dissolved phase concentrations below the risk-based standards for the toluene, ethylbenzene, xylenes, GRO, DRO, and RRO aromatic and aliphatic fractions. The migration to groundwater fraction of risk value shows that benzene would be expected to migrate from vadose zone soils into the groundwater mixing zone at concentrations above the benzene groundwater ingestion (given the default dilution-attenuation factor), but that toluene, ethylbenzene, xylenes, GRO aromatics, and DRO aromatics would not exceed risk-based levels in groundwater because of a vadose zone source.

6.2 Calculated Effective Solubilities (Dissolved Phase) Concentrations Compared to Risk-based Criteria

Table 7 compares the calculated effective solubilities from the oil analysis data (Geosphere and CH2MHill, 2006) to the drinking water standards and the migration-to-groundwater “target concentrations.” Table 7 is very similar to Table 6 in that it provides the effective solubilities

(dissolved phase concentrations) calculated for each fuel used in the oil analysis study and the potential fraction of risk values for the groundwater ingestion route and the migration-to-groundwater route. Table 7 shows the following:

- Groundwater in contact with fresh gasoline NAPL would be expected to exceed the groundwater risk-based levels for benzene, toluene, ethylbenzene, and GRO aromatics. In addition, the Sample 2 #1 and Sample #2 gasolines could be expected to cause groundwater to exceed groundwater ingestion levels for DRO aromatics. Given the oil analysis results derived in the SOCWG study, xylene, the GRO aliphatics, and DRO aliphatic constituents in gasoline are not expected to partition into groundwater at concentrations exceeding the groundwater ingestion risk-based criteria for these fractions even when NAPL contamination extends below the water table and floating product is present on the water table. (Note that the gasolines have little or no mass in the RRO range).
- Fresh gasoline NAPL in the vadose zone has the potential to cause groundwater in the mixing zone to exceed groundwater ingestion risk-based criteria for benzene and GRO aromatics (given that the default dilution-attenuation factor represents the processes occurring at the site). In addition, toluene from the aviation gasoline sample could be expected to be transported to the groundwater mixing zone at concentrations exceeding the toluene groundwater ingestion risk-based level.
- Groundwater in contact with the example fresh JP4 NAPL would be expected to exceed the groundwater risk-based levels for benzene, toluene, and GRO aromatics. Fresh JP4 NAPL in the vadose zone has the potential to cause groundwater in the mixing zone to exceed groundwater ingestion risk-based criteria for benzene (given that the default dilution-attenuation factor represents the processes occurring at the site).
- Groundwater in contact with the Sample #4 DF1 diesel fuel and Sample #11 Jet A fuel would be expected to exceed the groundwater ingestion risk-based levels for benzene and DRO aromatics (and GRO aromatics for the Sample #11 Jet A). Given the oil analysis results derived in the SOCWG study, toluene, ethylbenzene, xylene and the GRO aliphatics, and DRO aliphatic constituents in the DF1 and Jet A are not expected to partition into groundwater at concentrations exceeding the groundwater ingestion risk-based criteria for these fractions even when NAPL contamination extends below the water table and floating product is present on the water table. Fresh Sample #4 DF1 diesel fuel and Sample #11 Jet A fuel NAPL in the vadose zone has the potential to cause groundwater in the mixing zone to exceed groundwater ingestion risk-based criteria for benzene (given that the default dilution-attenuation factor represents the processes occurring at the site).
- Groundwater in contact with the Sample #9 Jet A, Sample #10 DF, Sample #5 DF2, and Sample #12 DF2 fuels would be expected to exceed the groundwater ingestion risk-based levels only for benzene. Given the analytical results presented in the SOCWG fuel characterization report all other fuel fractions, including the DRO aromatics are not expected to partition into groundwater at concentrations exceeding the groundwater ingestion risk-based criteria for these fractions even when NAPL contamination extends below the water table and floating product is present on the water table. (Diesel fuels with higher aromatic mass fractions would be expected to partition into groundwater at concentrations exceeding the groundwater ingestion risk-based level for DRO aromatics).

- When the Sample #9 Jet A, Sample #10 DF, Sample #5 DF2, and Sample #12 DF2 fuels NAPL is confined to the vadose zone (as assumed in the migration-to-groundwater route), benzene would be expected to be transported into the groundwater mixing zone at concentrations exceeding the groundwater MCL (given that the default dilution-attenuation factor represents the processes occurring at the site).

The comparison of the risk-based groundwater standards to the pure phase solubilities of the hydrocarbon fractions shows that RRO aromatics and GRO, DRO, and RRO aliphatics cannot partition into water above their risk-based concentrations. This means that there is not a critical soil concentration above which RRO aromatics or GRO, DRO, and RRO aliphatics can cause groundwater to exceed groundwater standards, and there is not a risk-based migration to groundwater soil cleanup level for RRO aromatics or for GRO, DRO, and RRO aliphatics (that is, no matter how high the soil concentration was in these hydrocarbon fractions, the soil could not cause the groundwater to exceed the risk-based levels given the ADEC DAF assumptions). The calculated effective solubilities and the measured carboy and diffusion bag water samples for the Alaskan gasolines and diesel and jet fuels confirm that RRO aromatics and GRO, DRO, and RRO aliphatics do not partition into water above risk-based levels.

In addition, the calculated effective solubilities and the measured carboy and diffusion bag water solubilities for the Alaskan gasolines and diesel and jet fuels show that the DRO aromatics would only be expected to cause groundwater to exceed the groundwater standard when the fuel NAPL is in contact with the groundwater (the NAPL is below the water table). When diesel and jet fuels are in the vadose zone they would not be expected to cause groundwater contamination above risk-based levels regardless of the concentration in the vadose zone soils; that is, there is not a risk-based migration to groundwater soil cleanup level for DRO aromatics, given the current groundwater mixing zone and dilution attenuation assumptions (in addition to there not being a migration to groundwater cleanup level for RRO aromatics or GRO, DRO, and RRO aliphatics). Note that the fixed mixing depth DAF equation proposed by the SOCWG (Geosphere and CH2MHill, 2005) calculates that DRO aromatics can present a migration to groundwater risk when source zones are relatively large and/or when a portion of the source is in the saturated zone.

SOCWG Conclusions and Recommendations

Groundwater sampling in NAPL-contaminated soil source areas can sometimes incorporate NAPL and adsorbed hydrocarbons in the water samples. When DRO, RRO, and EPH water samples contain adsorbed hydrocarbons or NAPL, the reported water concentrations will likely be well above the true dissolved phase concentration of DRO-, RRO-, and EPH-range hydrocarbons. BTEX, GRO, and VPH samples containing NAPL can also have reported values above the true dissolved phase concentrations, but these test methods are less susceptible to false high readings than the DRO and EPH tests. The false high measures of the dissolved phase concentration can be used to help define the NAPL- contaminated source area, if the user of the data is aware of the solubilities of diesel and jet fuels. However, if the user of the data is not aware, the false high measures of the dissolved phase concentration can lead to conceptual misinterpretations of the data, which in turn can lead to remedial action where none is warranted, or to not undertaking a corrective action where corrective action is needed. This technical background document highlights the issue of NAPL incorporation in groundwater samples, provides information on the solubilities of several Alaskan fuels, characterizes the groundwater ingestion and migration to groundwater risks associated with the fuels, and reports on two sampling techniques intended to eliminate the incorporation of NAPL in groundwater samples.

Water samples in equilibrium with the NAPL of six Alaskan gasoline, diesel, and jet fuels, and calculations of the effective solubility of 12 oil samples, shows the following:

- Water in phase equilibrium with Alaskan gasolines may be expected to have GRO concentrations about 150 to 350 mg/L; benzene concentrations of 10 to 100+ mg/L; toluene concentrations of 10 to 100 mg/L; and ethylbenzene, GRO aromatics, and possibly even DRO aromatics above groundwater ingestion risk-based levels.
- Water in phase equilibrium with Alaskan diesel #1 and jet A fuels may be expected to have GRO concentrations about 3 to 10 mg/L; benzene concentrations generally less than 1 mg/L; toluene concentrations of about 0.5 to 2 mg/L; DRO aromatic concentrations of 2 to 5 mg/L; and GRO aromatics up to 8 mg/L (which is above groundwater ingestion risk-based levels).
- DRO concentrations in water in equilibrium with diesel #1 and jet A fuels may be expected to have DRO concentrations of about 2 to 5 mg/L. DRO concentrations exceeding this range likely indicate the presence of NAPL or the presence of partially degraded polar compounds in the sample (not dissolved phase DRO aromatics or aliphatics).
- Water in phase equilibrium with Alaskan diesel #2 may be expected to have benzene, and potentially toluene and DRO aromatic concentrations, exceeding their respective risk-based groundwater ingestion levels (1 to 2 mg/L DRO).

The comparison of the groundwater ingestion risk-based levels to the pure phase solubilities of the hydrocarbon fractions shows that RRO aromatics and GRO, DRO, and RRO aliphatics cannot partition into water above their risk-based concentrations. This means that there is not a

critical soil concentration above which RRO aromatics or GRO, DRO, and RRO aliphatics can cause groundwater to exceed groundwater standards, and there is not a risk-based migration to groundwater soil cleanup level for RRO aromatics or for GRO, DRO, and RRO aliphatics. That is, no matter how high the soil concentration was in these hydrocarbon fractions, the soil could not cause the groundwater to exceed the risk-based levels. In addition, the calculated effective solubilities and the measured carboy and diffusion bag water solubilities for the Alaskan gasolines and diesel and jet fuels show that the DRO aromatics can only cause groundwater to exceed risk-based levels when the fuel NAPL is in contact with the groundwater (the NAPL is below the water table). Given the current groundwater mixing zone and DAF assumptions, diesel and jet fuels in the vadose zone should not be expected to cause DRO groundwater contamination above risk-based levels regardless of the concentration in the vadose zone soils. That is, there is not a risk-based migration to groundwater soil cleanup level for DRO aromatics or aliphatics. Note that the fixed mixing depth DAF equation proposed by the SOCWG (Geosphere and CH2MHill, 2006) calculates that DRO aromatics can present a migration to groundwater risk when source zones are relatively large and/or when a portion of the source is in the saturated zone.

Measurement of true dissolved phase DRO concentrations in the NAPL-contaminated soil source area is desirable to help assess risk, as input for fate and transport models, and to assess remedial progress. Tests were performed to assess if diffusion bag samplers and filtration could remove NAPL from water samples and yield representative dissolved phase concentrations. Testing to assess the performance of diffusion bag samplers showed that DRO aromatics and aliphatic concentrations measured in water in equilibrium with NAPL and in diffusion bag samplers correlated very closely. This suggests that the diffusion bag samplers may be a valuable tool to collect true dissolved phase DRO data in NAPL source areas. In addition, the diffusion bags maintained their structural integrity for at least 2 weeks when in contact with floating gasoline, JP4, and diesel and jet fuels, suggesting that diffusion bag samplers may be a valuable tool for collecting true dissolved phase concentration data even when substantial floating free product is present.

Filtration of groundwater samples to remove DRO-, RRO-, and EPH-range NAPL indicates that most but not all of the NAPL present in the water samples could be removed by filtering, but that the diffusion bag samplers likely yielded better measures of the true dissolved phase concentration in the GRO, DRO, and RRO ranges.

Based on the information presented in this report, the SOCWG recommends that the ADEC consider the following:

- Repeating the oil analyses and carboy water analyses to further document the character and seasonal variability of Alaskan fuels.
- Accepting the use of diffusion bags as a supplement to traditional groundwater samples for measuring dissolved BTEX, GRO, and DRO concentrations when NAPL is present in monitoring wells. (The SOCWG understands that filtering may not completely remove NAPL from water samples containing NAPL).
- Continued evaluation of diffusion bags for measuring dissolved DRO or EPH concentrations when NAPL is present in monitoring wells to more fully document (build a data base regarding) the quality of the DRO and EPH data from the diffusion bags.

- Acknowledging that RRO aromatics and GRO, DRO, and RRO aliphatics cannot partition in to groundwater above risk-based levels (hence, there is not a groundwater ingestion cleanup level or migration to groundwater soil cleanup level for these compounds). The SOCWG understands that water containing NAPL may exceed risk-based groundwater ingestion levels for GRO, DRO and RRO aliphatics and that GRO, DRO and RRO aliphatics contribute to cumulative risk.
- Acknowledging that given the current calculation of the migration-to- groundwater route, DRO aromatics do not pose a risk via the migration-to-groundwater route; therefore, there is not a migration to groundwater soil cleanup level driven by the existing migration to groundwater calculation.
- Changing the DAF equation to provide a better representation of the potential risks associated with the migration-to-groundwater route.

SECTION 8

References

Alaska Department of Environmental Conservation. 1998. *Guidance on Cleanup Standards Equations and Input Parameters*. September 16, 1998.

Alaska Department of Environmental Conservation. 1999. "Oil Spill and Hazardous Substances Pollution Control Regulations." *Alaska Administrative Code*. Title 18, Chapter 75. January 22, 1999.

Geosphere and CH2M HILL. 2006. Hydrocarbon Characterization for Use in the Hydrocarbon Risk Calculator and Example Characterizations of Selected Alaskan Fuels, Technical Background Document. Draft report prepared for the Alaska Statement of Cooperation Working Group (SOCWG).

Geosphere and CH2M HILL . 2006. Three- and Four-Phase Partitioning & Human Health Risk Calculations Technical Background Report. Draft report prepared for the SOCWG.

Geosphere and CH2M HILL . 2006. Dilution-Attenuation Factors at Fuel Hydrocarbon Spill Sites Technical Background Report. Draft report prepared for the SOCWG.

Hers, Ian, R. Zapf-Gilje, P. Johnson, and L. Li. 2003 Evaluation of the Johnson and Ettinger Model of Indoor Air Quality . *Groundwater Monitoring and Remediation*, vol. 23, no. 2, pages 119-133.

TPH Criteria Working Group. 1996. *Selection of Representative TPH Fractions Based on Fate and Transport Considerations*. Volume 3. Amherst Scientific Publishing.

U.S. Environmental Protection Agency. 1996. *Soil Screening Guidance: Technical Background Document*.

U.S. Geological Survey. 2000. *Use of Passive Diffusion Samplers for Monitoring Volatile Organic Compounds in Groundwater*. USGS Fact Sheet 088-00.

Vroblesky, D.A. 2001a. *User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells, Part 1: Deployment, Recovery, Data Interpretation, and Quality Control and Assurance*. U.S. Geological Survey Water Resources Investigation Report 01-4060.

Vroblesky, D.A. 2001b. *User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells, Part 2: Field Tests*, U.S. Geological Survey Water Resources Investigation Report 01-4061.

Zemo, D. and G. R. Foote. 2003. The Technical Case for Eliminating the Use of the TPH Analysis and Regulating Dissolved Hydrocarbons in Groundwater. *Groundwater Monitoring and Remediation*, vol. 23, no. 2, pages 119-133.

Tables

Table 1 BTEX and VPH Laboratory Test Results

Sample # & Product Type	description of sample	Benzene			Toluene			Ethylbenzene			Xylenes (total)			C8-C10 Aromatics			C9-C10 aromatics	C10-C12 Aromatics			C12-C13 Aromatics			C5-C6 Aliphatics			C6-C8 Aliphatics			C8-C10 Aliphatics			C10-C12 Aliphatics			Total VPH		
		Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L	Calculated Result mg/L (C8 to C10 aromatics - (xylene + toluene))	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Reporting Limit ug/L	Stat Value ug/L
#6 Regular Gas W 1A	carboy water	107,000.0	100.0	107000	90,400.0	170.0	90400	3,570.0	100.0	3570	18,800.0	252.0	18800	24,400.0	50,000.0	24400	2,030.0	2,130.0	50,000.0	2130	1,930.0	50,000.0	1930	3040	50,000.0	3040	110000	50,000.0	110000	0.0	50,000.0	0	3,240.0	50,000.0	3240	144,740	50,000.0	144,740
#6 Regular Gas W 1B	diffusion bag	113,000.0	100.0	113000	96,000.0	170.0	96000	3,760.0	100.0	3760	20,000.0	252.0	20000	25,500.0	50,000.0	25500	1,740.0	611.0	50,000.0	611	247.0	50,000.0	247	2860	50,000.0	2860	114000	50,000.0	114000	0.0	50,000.0	0	2,370.0	50,000.0	2370	145,588	50,000.0	145,588
#6 Regular Gas DB 1C	carboy water	111,000.0	100.0	111000	100,000.0	170.0	100000	4,070.0	100.0	4070	21,700.0	252.0	21700	27,800.0	50,000.0	27800	2,030.0	278.0	50,000.0	278	50.0	50,000.0	50	2850	50,000.0	2850	116000	50,000.0	116000	0.0	50,000.0	0	2,360.0	50,000.0	2360	149,338	50,000.0	149,338
#6 Regular Gas DB 1D	diffusion bag	111,000.0	100.0	111000	100,000.0	170.0	100000	4,090.0	100.0	4090	21,800.0	252.0	21800	27,900.0	50,000.0	27900	2,010.0	479.0	50,000.0	479	36.0	50,000.0	36	3210	50,000.0	3210	117000	50,000.0	117000	0.0	50,000.0	0	2,440.0	50,000.0	2440	151,065	50,000.0	151,065
#3 JP4 Jet Fuel W 6A	carboy water	18,300.0	10.0	18300	13,600.0	17.0	13600	823.0	10.0	823	4,060.0	25.2	4060	5,270.0	5,000.0	5270	387.0	496.0	5,000.0	496	287.0	5,000.0	287	3090	5,000.0	3090	24200	5,000.0	24200	0.0	5,000.0	0	165.0	5,000.0	165	33,508	5,000.0	33,508
#3 JP4 Jet Fuel DB 6B	diffusion bag	18,100.0	10.0	18100	13,700.0	17.0	13700	848.0	10.0	848	4,160.0	25.2	4160	5,480.0	5,000.0	5480	472.0	424.0	5,000.0	424	210.0	5,000.0	210	3560	5,000.0	3560	25500	5,000.0	25500	0.0	5,000.0	0	169.0	5,000.0	169	35,343	5,000.0	35,343
#3 JP4 Jet Fuel W 6E	carboy water	18,100.0	10.0	18100	13,500.0	17.0	13500	810.0	10.0	810	3,970.0	25.2	3970	5,160.0	5,000.0	5160	380.0	382.0	5,000.0	382	173.0	5,000.0	173	2940	5,000.0	2940	24400	5,000.0	24400	0.0	5,000.0	0	146.0	5,000.0	146	33,201	5,000.0	33,201
#3 JP4 Jet Fuel DB 6F	diffusion bag	18,000.0	10.0	18000	13,500.0	17.0	13500	834.0	10.0	834	4,090.0	25.2	4090	5,320.0	5,000.0	5320	396.0	360.0	5,000.0	360	160.0	5,000.0	160	3140	5,000.0	3140	24700	5,000.0	24700	0.0	5,000.0	0	158.0	5,000.0	158	33,838	5,000.0	33,838
#12 DF2 diesel fuel W 2A	carboy water	562.0	1.0	562	825.0	1.7	825	80.6	1.0	80.6	434.0	2.5	434	668.0	500.0	668	153.4	178.0	500.0	178	189.0	500.0	189	8.05	500.0	8.05	868	500.0	868	0.0	500.0	0	103.0	500.0	103	2,014	500.0	2,014
#12 DF2 diesel fuel DB 2B	diffusion bag	593.0	1.0	593	888.0	1.7	888	91.3	1.0	91.3	497.0	2.5	497	779.0	500.0	779	190.7	210.0	500.0	210	239.0	500.0	239	9.23	500.0	9.23	917	500.0	917	0.0	500.0	0	119.0	500.0	119	2,273	500.0	2,273
#10 DF diesel fuel W 3A	carboy water	492.0	1.0	492	1,390.0	1.7	1390	315.0	1.0	315	1,820.0	2.5	1820	3,320.0	500.0	3320	1,185.0	922.0	500.0	922	410.0	500.0	410	11.2	500.0	11.2	1170	500.0	1170	0.0	500.0	0	1,190.0	500.0	1190	7,023	500.0	7,023
#10 DF diesel fuel DB 3B	diffusion bag	492.0	1.0	492	1,420.0	1.7	1420	335.0	1.0	335	1,930.0	2.5	1930	3,590.0	500.0	3590	1,325.0	981.0	500.0	981	407.0	500.0	407	14.9	500.0	14.9	1240	500.0	1240	0.0	500.0	0	1,320.0	500.0	1320	7,553	500.0	7,553
#9 Jet A W 4A	carboy water	444.0	2.0	444	1,420.0	3.4	1420	371.0	2.0	371	2,230.0	5.0	2230	4,770.0	1,000.0	4770	2,169.0	1,520.0	1,000.0	1520	419.0	1,000.0	419	12	1,000.0	12	1140	1,000.0	1140	0.0	1,000.0	0	2,430.0	1,000.0	2430	10,291	1,000.0	10,291
#9 Jet A DB 4B	diffusion bag	435.0	2.0	435	1,410.0	3.4	1410	376.0	2.0	376	2,260.0	5.0	2260	4,890.0	1,000.0	4890	2,254.0	1,620.0	1,000.0	1620	469.0	1,000.0	469	18.7	1,000.0	18.7	1130	1,000.0	1130	0.0	1,000.0	0	2,530.0	1,000.0	2530	10,658	1,000.0	10,658
#9 Jet A W 4E	carboy water	430.0	2.0	430	1,350.0	3.4	1350	343.0	2.0	343	2,090.0	5.0	2090	4,400.0	1,000.0	4400	1,967.0	1,380.0	1,000.0	1380	353.0	1,000.0	353	4	1,000.0	4	1080	1,000.0	1080	0.0	1,000.0	0	2,260.0	1,000.0	2260	9,477	1,000.0	9,477
#9 Jet A DB 4F	diffusion bag	433.0	2.0	433	1,390.0	3.4	1390	366.0	2.0	366	2,210.0	5.0	2210	4,720.0	1,000.0	4720	2,144.0	1,480.0	1,000.0	1480	424.0	1,000.0	424	10	1,000.0	10	1130	1,000.0	1130	0.0	1,000.0	0	2,400.0	1,000.0	2400	10,164	1,000.0	10,164
#4 DF1 diesel fuel W 5A	carboy water	795.0	2.0	795	1,920.0	3.4	1920	440.0	2.0	440	2,780.0	5.0	2780	4,960.0	1,000.0	4960	1,740.0	1,080.0	1,000.0	1080	462.0	1,000.0	462	6.2	1,000.0	6.2	1580	1,000.0	1580	0.0	1,000.0	0	1,540.0	1,000.0	1540	9,628	1,000.0	9,628
#4 DF1 diesel fuel DB 5B	diffusion bag	767.0	2.0	767	1,900.0	3.4	1900	456.0	2.0	456	2,880.0	5.0	2880	5,300.0	1,000.0	5300	1,964.0	1,230.0	1,000.0	1230	518.0	1,000.0	518	5.24	1,000.0	5.24	1640	1,000.0	1640	0.0	1,000.0	0	1,710.0	1,000.0	1710	10,403	1,000.0	10,403
#4 DF1 diesel fuel W 5E	carboy water	779.0	2.0	779	1,870.0	3.4	1870	427.0	2.0	427	2,690.0	5.0	2690	4,790.0	1,000.0	4790	1,673.0	1,050.0	1,000.0	1050	450.0	1,000.0	450	4.72	1,000.0	4.72	1530	1,000.0	1530	0.0	1,000.0	0	1,450.0	1,000.0	1450	9,275	1,000.0	9,275
#4 DF1 diesel fuel DB 5F	diffusion bag	800.0	2.0	800	1,980.0	3.4	1980	471.0	2.0	471	2,960.0	5.0	2960	5,390.0	1,000.0	5390	1,959.0	1,220.0	1,000.0	1220	528.0	1,000.0	528	0.6	1,000.0	0.6	1650	1,000.0	1650	0.0	1,000.0	0	1,680.0	1,000.0	1680	10,469	1,000.0	10,469

Table 2 EPH Laboratory Test Results

Sample # & Product Type	description of sample	C8-C10 Aromatics			C8-C10 Aliphatics			C10-C12 Aromatics			C10-C12 Aliphatics			C12-C16 Aromatics			C12-C16 Aliphatics			C16-C21 Aromatics			C16-C21 Aliphatics			C21-C34 Aromatics			C21-C34 Aliphatics			Total EPH				
		Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L	Lab Result mg/L	Method Detection Limit mg/L	Stat Value mg/L					
#3 JP4 Jet Fuel W 6A	carboy water	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	0.14	0.025	0.14	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	0.14	
#3 JP4 Jet Fuel DB 6B	diffusion bag	0.291	0.025	0.291	2.15	0.025	2.15	0.327	0.025	0.327	0.333	0.025	0.333	0.487	0.025	0.487	0.24	0.025	0.24	0.0332	0.025	0.0332	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	3.83	
#3 JP4 Jet Fuel SW 6C	spiked water	0.258	0.05	0.258	3.96	0.05	3.96	0.384	0.05	0.384	3.15	0.05	3.15	0.866	0.05	0.866	5.27	0.05	5.27	0.235	0.05	0.235	0.284	0.05	0.284	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	14.4	
#3 JP4 Jet Fuel FW 6D	spiked & filtered water	0.118	0.025	0.118	0.72	0.025	0.72	0.24	0.025	0.24	0.201	0.025	0.201	0.448	0.025	0.448	0.142	0.025	0.142	0.0433	0.025	0.0433	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	1.87	
#3 JP4 Jet Fuel W 6E	carboy water	0.209	0.025	0.209	1.39	0.025	1.39	0.284	0.025	0.284	0.177	0.025	0.177	0.471	0.025	0.471	0.0654	0.025	0.0654	0.0332	0.025	0.0332	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	2.59	
#3 JP4 Jet Fuel DB 6F	diffusion bag	0.0662	0.025	0.0662	0.0921	0.025	0.0921	0.304	0.025	0.304	0.0889	0.025	0.0889	0.545	0.025	0.545	0.065	0.025	0.065	0.0374	0.025	0.0374	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	1.16	
#12 DF2 diesel fuel W 2A	carboy water	0.0996	0.025	0.0996	0.183	0.025	0.183	0.153	0.025	0.153	0.0713	0.025	0.0713	0.612	0.025	0.612	0.0682	0.025	0.0682	0.416	0.025	0.416	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	1.6	
#12 DF2 diesel fuel DB 2B	diffusion bag	0.076	0.025	0.076	0.261	0.025	0.261	0.134	0.025	0.134	0.123	0.025	0.123	0.518	0.025	0.518	0.504	0.025	0.504	0.478	0.025	0.478	0.659	0.025	0.659	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	2.75	
#12 DF2 diesel fuel SW 2C	spiked water	0.271	0.25	0.271	0.55	0.25	0.55	0.509	0.25	0.509	2.88	0.25	2.88	4.48	0.25	4.48	35.6	0.25	35.6	19	0.25	19	50.8	0.25	50.8	ND	0.25	0.125	0.345	0.25	0.345	0.25	0.345	0.25	0.345	114
#12 DF2 diesel fuel FW 2D	spiked & filtered water	0.421	0.025	0.421	0.0321	0.025	0.0321	0.227	0.025	0.227	ND	0.025	0.0125	0.446	0.025	0.446	0.09	0.025	0.09	0.276	0.025	0.276	0.141	0.025	0.141	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	1.6	
#10 DF diesel fuel W 3A	carboy water	0.777	0.025	0.777	0.0672	0.025	0.0672	0.505	0.025	0.505	ND	0.025	0.0125	0.483	0.025	0.483	ND	0.025	0.0125	0.0922	0.025	0.0922	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	1.92	
#10 DF diesel fuel DB 3B	diffusion bag	1.2	0.025	1.2	0.947	0.025	0.947	0.774	0.025	0.774	0.994	0.025	0.994	0.885	0.025	0.885	1.7	0.025	1.7	0.402	0.025	0.402	1.02	0.025	1.02	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	7.92	
#10 DF diesel fuel SW 3C	spiked water	1.45	0.25	1.45	6.91	0.25	6.91	1.76	0.25	1.76	13.8	0.25	13.8	3.23	0.25	3.23	22.4	0.25	22.4	4.21	0.25	4.21	13.7	0.25	13.7	ND	0.25	0.125	0.328	0.25	0.328	0.25	0.328	67.8		
#10 DF diesel fuel FW 3D	spiked & filtered water	1.16	0.025	1.16	0.558	0.025	0.558	0.607	0.025	0.607	0.243	0.025	0.243	0.541	0.025	0.541	0.159	0.025	0.159	0.12	0.025	0.12	0.0671	0.025	0.0671	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	3.45	
#9 Jet A W 4A	carboy water	1.74	0.05	1.74	0.296	0.05	0.296	1.21	0.05	1.21	0.108	0.05	0.108	0.769	0.05	0.769	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	4.12	
#9 Jet A DB 4B	diffusion bag	1.15	0.025	1.15	1.05	0.025	1.05	1.13	0.025	1.13	0.618	0.025	0.618	0.954	0.025	0.954	0.181	0.025	0.181	0.0414	0.025	0.0414	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	5.09	
#9 Jet A SW 4C	spiked water	1.4	0.25	1.4	10.3	0.25	10.3	2.19	0.25	2.19	21.1	0.25	21.1	2.15	0.25	2.15	12.6	0.25	12.6	ND	0.25	0.125	0.469	0.25	0.469	ND	0.25	0.125	ND	0.25	0.125	ND	0.25	0.125	50.2	
#9 Jet A FW 4D	spiked & filtered water	1.81	0.05	1.81	2.5	0.05	2.5	1.75	0.05	1.75	2.51	0.05	2.51	1.42	0.05	1.42	1.1	0.05	1.1	0.0658	0.05	0.0658	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	11.2	
#9 Jet A W 4E	carboy water	1.17	0.025	1.17	0.586	0.025	0.586	1.03	0.025	1.03	0.272	0.025	0.272	0.779	0.025	0.779	0.0555	0.025	0.0555	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	3.9	
#9 Jet A DB 4F	diffusion bag	1.21	0.025	1.21	0.82	0.025	0.82	1.02	0.025	1.02	0.378	0.025	0.378	0.793	0.025	0.793	0.0849	0.025	0.0849	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	4.31	
#4 DF1 diesel fuel W 5A	carboy water	1.07	0.025	1.07	0.512	0.025	0.512	0.838	0.025	0.838	0.159	0.025	0.159	0.863	0.025	0.863	0.0355	0.025	0.0355	0.0449	0.025	0.0449	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	3.44	
#4 DF1 diesel fuel DB 5B	diffusion bag	0.275	0.025	0.275	1.16	0.025	1.16	0.889	0.025	0.889	0.386	0.025	0.386	1.09	0.025	1.09	0.148	0.025	0.148	0.06	0.025	0.06	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	4.01	
#4 DF1 diesel fuel SW 5C	spiked water	1.27	0.25	1.27	11.9	0.25	11.9	1.52	0.25	1.52	15.5	0.25	15.5	2.42	0.25	2.42	16.6	0.25	16.6	0.763	0.25	0.763	1.07	0.25	1.07	ND	0.25	0.125	ND	0.25	0.125	ND	0.25	0.125	51	
#4 DF1 diesel fuel FW 5D	spiked & filtered water	1.57	0.05	1.57	1.43	0.05	1.43	1.31	0.05	1.31	0.869	0.05	0.869	1.46	0.05	1.46	0.716	0.05	0.716	0.124	0.05	0.124	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	7.48	
#4 DF1 diesel fuel W 5E	carboy water	1.31	0.025	1.31	0.852	0.025	0.852	1.13	0.025	1.13	0.259	0.025	0.259	1.28	0.025	1.28	0.0595	0.025	0.0595	0.0745	0.025	0.0745	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	ND	0.025	0.0125	4.96	
#4 DF1 diesel fuel DB 5F	diffusion bag	2.14	0.05	2.14	0.7	0.05	0.7	1.4	0.05	1.4	0.181	0.05	0.181	1.34	0.05	1.34	ND	0.05	0.025	0.057	0.05	0.057	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	ND	0.05	0.025	5.81	
#4 DF1 diesel fuel SW 5G	spiked water	2.05	0.25	2.05	12	0.25	12	2.15	0.25	2.15	15.2	0.25	15.2	3.19	0.25	3.19	15.9	0.25	15.9	0.841	0.25	0.841	0.997	0.25	0.997	ND	0.25	0.125	ND	0.25	0.125	ND	0.25	0.125	52.2	

Sample #3 JP4 W 6A was rejected; Sample #10 DF DB 3B is not interpreted to represent dissolved concentrations

Table 3 Ratio of VPH to EPH in the C8 to C10 and C10 to C12 Aromatic and Aliphatic Fractions in the Carboy Water and Diffusion Bag Samples

Sample # & Product Type	C8-C10 Aromatics	C8-C10 Aliphatics	C10-C12 Aromatics	C10-C12 Aliphatics
	ratio (VPH/EPH)	ratio (VPH/EPH)	ratio (VPH/EPH)	ratio (VPH/EPH)
#3 JP4 Jet Fuel Water	25.0	NA	1.5	0.9
#3 JP4 Jet Fuel Diffusion Bag	30.2	NA	1.2	0.8
#12 DF2 Diesel Fuel Water	6.7	NA	1.2	1.4
#12 DF2 Diesel Fuel Diffusion Bag	10.3	NA	1.6	1.0
#10 DF Diesel Fuel Water	4.3	NA	1.8	95.2
#10 DF Diesel Fuel Diffusion Bag	3.0	NA	1.3	1.3
#9 Jet A Water	3.2	NA	1.3	12.3
#9 Jet A Diffusion Bag	4.1	NA	1.4	4.9
#4 DF1 Diesel Fuel Water	4.1	NA	1.1	7.2
#4 DF1 Diesel Fuel Diffusion Bag	4.4	NA	1.1	6.0
average	9.5	NA	1.4	13.1

Table 4 Summary of Hydrocarbon Concentrations in Water Samples from Combined BTEX, VPH & EPH Data

Aromatic Fractions	Median Equivalent Carbon	Sample #3 JP4 W 6A	Sample #3 JP4 DB 6B	Sample #3 JP4 W 6E	Sample #3 JP4 DB 6F	Sample #12 DF2 Diesel Fuel W 2A	Sample #12 DF2 Diesel Fuel DB 2B	Sample #10 Diesel Fuel W 3A	Sample #9 Jet A W 4A	Sample #9 Jet A DB 4B	Sample #9 Jet A W 4E	Sample #9 Jet A DB 4F	Sample #4 DF1 Diesel Fuel W 5A	Sample #4 DF1 Diesel Fuel DB 5B	Sample #4 DF1 Diesel Fuel W 5E	Sample #4 DF1 Diesel Fuel DB 5F	Sample #6 Regular Gasoline W 1A	Sample #6 Regular Gasoline W 1B	Sample #6 Regular Gasoline DB 1C	Sample #6 Regular Gasoline DB 1D
		Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)	Dissolved Conc. (mg/L)				
Benzene	6.5	18.3	18.1	18.1	18.	0.562	0.593	0.492	0.444	0.435	0.43	0.433	0.795	0.767	0.779	0.8	107	113	111	111
Toluene	7.58	13.6	13.7	13.5	13.5	0.825	0.888	1.39	1.42	1.41	1.35	1.39	1.92	1.9	1.87	1.98	90.4	96.	100	100
Ethylbenzene	8.5	0.823	0.848	0.81	0.834	0.0806	0.0913	0.315	0.371	0.376	0.343	0.366	0.44	0.456	0.427	0.471	3.57	3.76	4.07	4.09
Xylene	8.63	4.06	4.16	3.97	4.09	0.434	0.497	1.82	2.23	2.26	2.09	2.21	2.78	2.88	2.69	2.96	18.8	20.	21.7	21.8
C ₉ -C ₁₀	9.25	0.387	0.472	0.38	0.396	0.1534	0.1907	1.185	2.169	2.254	1.967	2.144	1.74	1.964	1.673	1.959	2.03	1.74	2.03	2.01
C ₁₀ -C ₁₂	10.5	0.496	0.424	0.382	0.36	0.178	0.21	0.922	1.52	1.62	1.38	1.48	1.08	1.23	1.05	1.22	2.13	0.611	0.278	0.479
C ₁₂ -C ₁₆	13	0.14	0.487	0.471	0.545	0.612	0.518	0.483	0.769	0.954	0.779	0.793	0.863	1.09	1.28	1.34	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C ₁₆ -C ₂₁	16.5	0.0125	0.0332	0.0332	0.0374	0.416	0.478	0.0922	0.025	0.0414	0.0125	0.0125	0.0449	0.06	0.0745	0.057	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C ₂₁ -C ₃₅	25	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.025	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.025	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum of Aromatics		37.831	38.2367	37.6587	37.7749	3.2735	3.4785	6.7117	8.973	9.3629	8.364	8.841	9.6754	10.3595	9.856	10.812	224	235	239	239
Aliphatic Fractions																				
C ₅ -C ₆	5.5	3.09	3.56	2.94	3.14	0.0081	0.0092	0.0112	0.012	0.0187	0.004	0.01	0.0062	0.0052	0.0047	6.00E-04	3.04	2.86	2.85	3.21
C ₆ -C ₈	7	24.2	25.5	24.4	24.7	0.868	0.917	1.17	1.14	1.13	1.08	1.13	1.58	1.64	1.53	1.65	110	114	116	117
C ₈ -C ₁₀	9	0.0125	2.15	1.39	0.0921	0.183	0.261	0.0672	0.296	1.05	0.586	0.82	0.512	1.16	0.852	0.7	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C ₁₀ -C ₁₂	11	0.165	0.169	0.146	0.158	0.103	0.119	1.19	2.43	2.53	2.26	2.4	1.54	1.71	1.45	1.68	3.24	2.37	2.36	2.44
C ₁₂ -C ₁₆	14	0.0125	0.24	0.0654	0.065	0.0682	0.504	0.0125	0.025	0.181	0.0555	0.0849	0.0355	0.148	0.0595	0.025	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C ₁₆ -C ₂₁	16.5	0.0125	0.0125	0.0125	0.0125	0.0125	0.659	0.0125	0.025	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.025	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C ₂₁ -C ₃₅	25	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.025	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.025	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum of Aliphatics		27.505	31.644	28.9664	28.1801	1.2553	2.4817	2.4759	3.953	4.9347	4.0105	4.4699	3.6987	4.6882	3.9212	4.1056	116	119	121	123
Total Hydrocarbon		65.336	69.8807	66.6251	65.955	4.5288	5.9602	9.1876	12.926	14.2976	12.3745	13.3109	13.3741	15.0477	13.7772	14.9176	340	354	360	362
GRO (C₅ to C₁₀)		64.4725	68.49	65.49	64.7521	3.1141	3.4472	6.4504	8.082	8.9337	7.85	8.503	9.7732	10.7722	9.8257	10.5206	335	351	358	359
DRO (C₁₀ to C₂₁)		0.8385	1.3657	1.1101	1.1779	1.3897	2.488	2.7122	4.794	5.3389	4.4995	4.7829	3.5759	4.2505	3.9265	4.347	5.37	2.981	2.638	2.919
RRO (C₂₁ to C₃₅)		0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.05	0.025	0.025	0.025	0.025	0.025	0.025	0.05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TAH (BTEX)		36.783	36.808	36.38	36.424	1.9016	2.0693	4.017	4.465	4.481	4.213	4.399	5.935	6.003	5.766	6.211	220	233	237	237

Table 5 PAH Concentrations in the Carboy Water Samples

ANALYTE	ADEC groundwater ingestion risk based concentration ug/L	Solubility of Compound ug/L	Risk Level Above Pure Phase Solubility	#3 JP4 W 6A			#12 DF2 W 2A			#9 Jet A W 4A			#10 DF W 3A			#4 DF1 W 5A		
				P5B1042-01			P5B1042-11			P5B1042-24			P5B1042-20			P5B1042-28		
				Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L	Lab Result ug/L	Method Detection Limit ug/L	Stat Value ug/L
Acenaphthene	2,190.0	4,240	No	ND	0.5	0.25	1.29	0.5	1.29	ND	0.5	0.25	1.24	0.5	1.24	0.731	0.5	0.731
Acenaphthylene	2,200.0			ND	0.5	0.25	ND	1	0.5	ND	0.5	0.25	ND	1	0.5	ND	0.5	0.25
Anthracene	10,950.0	43	Yes	ND	0.5	0.25	ND	1	0.5	ND	0.5	0.25	ND	1	0.5	ND	0.5	0.25
Benzo (a) anthracene	1.0	9.40	No	ND	0.5	0.25												
Benzo (a) pyrene	0.2	1.62	No	ND	0.5	0.25												
Benzo (b) fluoranthene	1.0	1.50	No	ND	0.5	0.25												
Benzo (ghi) perylene	1,100.0			ND	0.5	0.25												
Benzo (k) fluoranthene	1.0	0.80	Yes	ND	0.5	0.25												
Chrysene	100.0	1.60	Yes	ND	0.5	0.25												
Dibenzo (a,h) anthracene	0.1	2.49	No	ND	1	0.5												
Fluoranthene	1,460.0	206	Yes	ND	0.5	0.25												
Fluorene	1,460.0	1,980	No	1.11	0.5	1.11	9.79	0.5	9.79	1.08	0.5	1.08	6.89	0.5	6.89	2.34	0.5	2.34
Indeno (1,2,3-cd) pyrene	1.0	0.02	Yes	ND	0.5	0.25												
Naphthalene	700.0	31,000	No	210	5	210	124	5	124	462	5	462	324	5	324	552	5	552
Phenanthrene	11,000.0			ND	0.5	0.25	9.63	0.5	9.63	ND	0.5	0.25	4.91	0.5	4.91	ND	0.5	0.25
Pyrene	1,095.0	135	Yes	ND	0.5	0.25												
Sum of PAHs in Sample				211.110			144.710			463.080			337.040			555.071		

green = risk level below method detection limit

PAH Fraction of Groundwater Ingestion Risk

ANALYTE	ADEC groundwater ingestion risk based concentration ug/L	Solubility of Compound ug/L	Risk Level Above Pure Phase Solubility (NAPL must be present for risk to be present)	#3 JP4 W 6A	#12 DF2 W 2A	#9 Jet A W 4A	#10 DF W 3A	#4 DF1 W 5A
				P5B1042-01	P5B1042-11	P5B1042-24	P5B1042-20	P5B1042-28
				Fraction of Risk Based Level				
Acenaphthene	2,190.0	4,240	No		0.001		0.001	0.0003
Acenaphthylene	2,200.0							
Anthracene	10,950.0	43	Yes					
Benzo (a) anthracene	1.0	9.40	No					
Benzo (a) pyrene	0.2	1.62	No					
Benzo (b) fluoranthene	1.0	1.50	No					
Benzo (ghi) perylene	1,100.0							
Benzo (k) fluoranthene	1.0	0.80	Yes					
Chrysene	100.0	1.60	Yes					
Dibenzo (a,h) anthracene	0.1	2.49	No					
Fluoranthene	1,460.0	206	Yes					
Fluorene	1,460.0	1,980	No	0.001	0.007	0.001	0.005	0.002
Indeno (1,2,3-cd) pyrene	1.0	0.02	Yes					
Naphthalene	700.0	31,000	No	0.300	0.177	0.660	0.463	0.789
Phenanthrene	11,000.0				0.001		0.0004	
Pyrene	1,095.0	135	Yes					

Table 6 Measured Fuel Solubilities Compared to Groundwater Risk Criteria

Aromatic Fractions	Median Equivalent Carbon	Pure Phase Solubility (mg/L)	Groundwater MCL Concentration (mg/L)	Groundwater Ingestion Risk Based Concentration (mg/L)	Vadose Zone Soil Moisture Target Concentration (Risk Based Concentration multiplied by DAF)	Risk Level Above Pure Phase Solubility (NAPL must be present for risk to be present)	Sample #6 Regular Gasoline			Sample #3 JP4			Sample #4 DF1 Diesel Fuel			Sample #9 Jet A			Sample #10 Diesel Fuel			Sample #12 DF2 Diesel Fuel			Average Jet A & Diesel Fuel			
							Sample #6 Regular Gasoline Average Dissolved Conc. (mg/L)	Groundwater Ingestion Potential Fraction of Risk	Migration to Groundwater Potential Fraction of Risk	Sample #3 JP4 Average Dissolved Conc. (mg/L)	Groundwater Ingestion Potential Fraction of Risk	Migration to Groundwater Potential Fraction of Risk	Sample #4 DF1 Diesel Fuel Average Dissolved Conc. (mg/L)	Groundwater Ingestion Potential Fraction of Risk	Migration to Groundwater Potential Fraction of Risk	Sample #9 Jet A Average Dissolved Conc. (mg/L)	Dissolved Conc / MCL or Risk Conc	Dissolved Conc / MCL or Risk Conc* DAF	Sample #10 Diesel Fuel Average Dissolved Conc. (mg/L)	Groundwater Ingestion Potential Fraction of Risk	Migration to Groundwater Potential Fraction of Risk	Sample #12 DF2 Diesel Fuel Average Dissolved Conc. (mg/L)	Groundwater Ingestion Potential Fraction of Risk	Migration to Groundwater Potential Fraction of Risk	Average Jet A & Diesel Fuel Dissolved Conc. (mg/L)	Groundwater Ingestion Potential Fraction of Risk	Migration to Groundwater Potential Fraction of Risk	
Benzene	6.5	1750.0	0.005	0.015	0.2	No	111	7,367	554	18.125	1,208	90,8521	0.7853	52.35	3,9361	0.4355	29.0333	2.183	0.492	32.8	2,4662	0.5775	38.5	2,8947	0.5726	38.1708	2.87	
Toluene	7.58	526.0	1.000	7.3	97.1	No	96.6	13,2329	0.995	13.575	1,8596	0.1398	1.9175	0.2627	0.0197	1.3925	0.1908	0.0143	1.39	0.1904	0.0143	0.8565	0.1173	0.0088	1.3891	0.1903	0.0143	
Ethylbenzene	8.5	169.0	0.700	3.65	48.5	No	3.8725	1,061	0.0798	0.8288	0.2271	0.0171	0.4485	0.1229	0.0092	0.364	0.0997	0.0075	0.315	0.0863	0.0065	0.086	0.0235	0.0018	0.3034	0.0831	0.0062	
Xylene	8.63	161.0	10.000	73	970.9	No	20.575	0.2818	0.0212	4.07	0.0558	0.0042	2.8275	0.0387	0.0029	2.1975	0.0301	0.0023	1.82	0.0249	0.0019	0.4655	0.0064	4.79E-04	1.8276	0.025	0.0019	
C9-C10	9.25	57.2		7.30	97.1	No	1.9525	0.2675	0.0201	0.4088	0.056	0.0042	1.834	0.2512	0.0189	2.1335	0.2923	0.022	1.185	0.1623	0.0122	0.1721	0.0236	0.0018	1.3311	0.1823	0.0137	
C10-C12	10.5	31.3		1.46	19.4	No	0.8745	0.599	0.045	0.4155	0.2846	0.0214	1.145	0.7842	0.059	1.5	1,0274	0.0772	0.922	0.6315	0.0475	0.194	0.1329	0.01	0.9403	0.644	0.0484	
C12-C16	13	9.33		1.46	19.4	No	0.00E+00	0.00E+00	0.00E+00	0.4108	0.2813	0.0212	1.1433	0.783	0.0589	0.8238	0.5642	0.0424	0.483	0.3308	0.0249	0.565	0.387	0.0291	0.7538	0.5163	0.0388	
C16-C21	16.5	1.94		1.46	19.4	No	0.00E+00	0.00E+00	0.00E+00	0.0291	0.0199	0.0015	0.0591	0.0405	0.003	0.0229	0.0157	0.0012	0.0922	0.0632	0.0047	0.447	0.3062	0.023	0.1553	0.1064	0.008	
C21-C35	25	0.01		1.10	14.6	Yes	0.00E+00	0.00E+00	0.00E+00	0.0125	0.0114	8.54E-04	0.0156	0.0142	0.0011	0.0156	0.0142	0.0011	0.0125	0.0114	8.54E-04	0.0125	0.0114	8.54E-04	0.0125	0.0128	9.61E-04	
Sum of Aromatics							234			37.8753			10.1757			8.8852			6.7117			3.376			7.2872			
Aliphatic Fractions																												
C5-C6	5.5	29.85		182.50	2427.3	Yes	2.99	0.0164	0.0012	3.1825	0.0174	0.0013	0.0042	2.30E-05	1.73E-06	0.0112	6.12E-05	4.60E-06	0.0112	6.14E-05	4.61E-06	0.0086	4.73E-05	3.56E-06	0.0088	4.82E-05	3.63E-06	
C6-C8	7	4.47		182.50	2427.3	Yes	114	0.626	0.0471	24.7	0.1353	0.0102	1.6	0.0088	6.59E-04	1.12	0.0061	4.61E-04	1.17	0.0064	4.82E-04	0.8925	0.0049	3.68E-04	1.1956	0.0066	4.93E-04	
C8-C10	9.25	0.35		182.50	2427.3	Yes	0.00E+00	0.00E+00	0.00E+00	0.9112	0.005	3.75E-04	0.806	0.0044	3.32E-04	0.688	0.0038	2.83E-04	0.0672	3.68E-04	2.77E-05	0.222	0.0012	9.15E-05	0.4458	0.0024	1.84E-04	
C10-C12	10.5	0.03		3.65	48.5	Yes	2.6025	0.713	0.0536	0.1595	0.0437	0.0033	1.595	0.437	0.0329	2.405	0.6589	0.0495	1.19	0.326	0.0245	0.111	0.0304	0.0023	1.3253	0.3631	0.0273	
C12-C16	13	6.3E-04		3.65	48.5	Yes	0.00E+00	0.00E+00	0.00E+00	0.0957	0.0262	0.002	0.067	0.0184	0.0014	0.0866	0.0237	0.0018	0.0125	0.0034	2.57E-04	0.2861	0.0784	0.0059	0.1131	0.031	0.0023	
C16-C21	16.5	1.1E-06		3.65	48.5	Yes	0.00E+00	0.00E+00	0.00E+00	0.0125	0.0034	2.57E-04	0.0156	0.0043	3.22E-04	0.0156	0.0043	3.22E-04	0.0125	0.0034	2.57E-04	0.3358	0.092	0.0069	0.0949	0.026	0.002	
C21-C35	25	1.3E-11		73.00	970.9	Yes	0.00E+00	0.00E+00	0.00E+00	0.0125	1.71E-04	1.29E-05	0.0156	2.14E-04	1.61E-05	0.0156	2.14E-04	1.61E-05	0.0125	1.71E-04	1.29E-05	0.0125	1.71E-04	1.29E-05	0.0141	1.93E-04	1.45E-05	
Sum of Aliphatics							120			29.0739			4.1034			4.342			2.4759			1.8685			3.1975			
Total Hydrocarbon				NA	NA		354	NA	NA	66.9492	NA	NA	14.2792	NA	NA	13.2273	NA	NA	9.1876	NA	NA	5.2445	NA	NA	10.4846	NA	NA	
GRO aromatics				7.30	97.1		234	31,9863	2,405	37.0075	5,0695	0.3812	7.8128	1,0702	0.0805	6.523	0.8936	0.0672	5.202	0.7126	0.0536	2.1575	0.2955	0.0222	5.4238	0.743	0.0559	
GRO aliphatics				182.50	2427.3		117	0.6424	0.0483	28.7937	0.1578	0.0119	2.4102	0.0132	9.93E-04	1.8192	0.01	7.49E-04	1.2484	0.0068	5.14E-04	1.1231	0.0062	4.63E-04	1.6502	0.009	6.80E-04	
GRO (C5 to C10)				NA	NA		351	NA	NA	65.8012	NA	NA	10.2229	NA	NA	8.3422	NA	NA	6.4504	NA	NA	3.2806	NA	NA	7.074	NA	NA	
DRO aromatics				1.46	19.4		0.8745	0.599	0.045	0.8553	0.5858	0.044	2.3474	1,6078	0.1209	2.3466	1,6073	0.1208	1.4972	1,0255	0.0771	1.206	0.826	0.0621	1.8493	1,2666	0.0952	
DRO aliphatics				3.65	48.5		2.6025	0.713	0.0536	0.2677	0.0733	0.0055	1.6776	0.4596	0.0346	2.5072	0.6869	0.0516	1.215	0.3329	0.025	0.7329	0.2008	0.0151	1.5332	0.42	0.0316	
DRO (C10 to C21)				NA	NA		3.477	NA	NA	1.1231	NA	NA	4.025	NA	NA	4.8538	NA	NA	2.7122	NA	NA	1.9389	NA	NA	3.3825	NA	NA	
RRO aromatics				1.10	14.6		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
RRO aliphatics				73.00	970.9		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
RRO (C21 to C35)				NA	NA		0.00E+00	NA	NA	0.025	NA	NA	0.0313	NA	NA	0.0313	NA	NA	0.025	NA	NA	0.025	NA	NA	0.0281	NA	NA	
TAH (BTEX)				0.01	0.1		232	23,155	1,741	36.5988	3,660	275	5.9788	598	44,953	4.3895	439	33,0038	4.017	402	30,203	1.9855	199	14,9282	4.0927	409	30,772	
TAQH (BTEX+PAH)				0.015	0.2		232	15,437	1,161	36.8099	2,454	185	6.5338	436	32,751	4.8526	324	24,3237	4.354	290	21,8248	2.1302	142	10,6775	4.4677	298	22,3942	

Groundwater Ingestion Potential Fraction of Risk (Dissolved Conc / MCL or Risk Conc)

Migration to Groundwater Potential Fraction of Risk = Dissolved Conc / (MCL or Risk Conc* DAF)

default DAF = 13.30

Vadose Zone Soil Moisture Target Concentration = MCL or Risk Based Concentration multiplied by DAF

Table 7 Calculated Fuel Solubilities Compared to Groundwater Risk Criteria

Aromatic Fractions	Median Equivalent Carbon	Single Component Solubility (mg/L)	Groundwater MCL Concentration (mg/L)	Groundwater Ingestion Risk Based Concentration (mg/L)	MCL or Risk Based Concentration multiplied by DAF (13.3)	Risk Level Above Pure Phase Solubility (NAPL must be present for risk to be present)	Sample #1 Regular Gas			Sample #2 Premium Gas			Sample #6 Regular Gas			Sample #7 Premium Gas			Sample #8 Av Gas			Sample #3 JP4			Sample #4 DF1 (Jet A)			Sample #11 Jet A			Sample #9 Jet A			Sample #10 Diesel Fuel			Sample #5 DF2			Sample #12 DF2			
							Sample #1 Regular Gas Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #2 Premium Gas Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #6 Regular Gas Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #7 Premium Gas Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #8 Av Gas Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #3 JP4 Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #4 DF1 (Jet A) Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #11 Jet A Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #9 Jet A Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #10 Diesel Fuel Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #5 DF2 Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	Sample #12 DF2 Dissolved Conc (mg/L)	Groundwater Ingestion Fraction of Risk (Dissolved Conc/ Risk Conc)	Migration to Groundwater Fraction of Risk (Dissolved Conc/ Risk Conc/ DAF)	
Benzene	6.5	1750.00	0.005	0.015	0.20	No	62.5454	4,170	314	55.9519	3,730	280	89.4427	5,963	448	94.9643	6,331	476	1.296	86.4	6,4962	13.4298	895	67,3174	0.9793	65,2863	4,9087	0.2893	19,2882	1,4502	0.4127	27,5158	2,0689	0.7986	53,2422	4,0032	0.3004	20,0286	1,5059	0.7827	52,1828	3,9235	
Toluene	7.58	526.00	1.000	7.3	97.09	No	61.0242	8,3595	0.6285	74.7603	10,2411	0.77	70.388	9,6422	0.725	86.5648	11,8582	0.8916	78.9458	10,8145	0.8131	8.838	1,2107	0.091	2.112	0.2893	0.0218	2.1321	0.2921	0.022	1.1302	0.1548	0.0116	2.0884	0.2861	0.0215	0.5674	0.0777	0.0058	1.0948	0.15	0.0113	
Ethylbenzene	8.5	169.00	0.700	3.65	48.55	No	3.8421	1,0526	0.0791	4.8275	1,3226	0.0994	3.663	0.999	0.0751	4.6627	1,2775	0.096	0.0528	0.0145	0.0011	0.6446	0.1766	0.0133	0.4037	0.1106	0.0083	0.7153	0.196	0.0147	0.3208	0.0879	0.0066	0.4324	0.1185	0.0089	0.0814	0.0223	0.0017	0.1079	0.0296	0.0022	
Xylene	8.63	161.00	10.000	73	970.90	No	17.1752	0.2353	0.0177	21.9412	0.3006	0.0226	18.0574	0.2474	0.0186	23.3645	0.3201	0.0241	0.2348	0.0032	2.42E-04	2.9702	0.0407	0.0031	2.3325	0.032	0.0024	4.9349	0.0676	0.0051	1.7818	0.0244	0.0018	2.353	0.0322	0.0024	0.3953	0.0054	4.07E-04	0.5585	0.0077	5.75E-04	
C ₉ -C ₁₀	9.25	57.21		7.30	97.09	No	3.6221	0.4962	0.0373	4.3868	0.6009	0.0452	3.8293	0.5246	0.0394	3.5639	0.4882	0.0367	0.0173	0.0024	1.79E-04	2.0294	0.0279	0.0021	0.0853	0.0117	8.78E-04	0.15	0.0206	0.0015	0.0191	0.0026	1.97E-04	0.0547	0.0075	5.63E-04	0.0027	3.74E-04	2.81E-05	7.40E-04	1.01E-04	7.63E-06	
C ₁₀ -C ₁₂	10.5	31.26		1.46	19.42	No	1.6105	1,1031	0.0829	1.8316	1,2545	0.0943	0.6402	0.4385	0.033	0.8888	0.6087	0.0458	0.0159	0.0109	8.17E-04	0.4407	0.3019	0.0227	0.9872	0.6762	0.0508	1.4066	0.9635	0.0724	0.5399	0.3698	0.0278	0.6693	0.4584	0.0345	0.0305	0.0209	0.0016	0.0161	0.0124	9.32E-04	
C ₁₂ -C ₁₆	13	9.33		1.46	19.42	No	0.0261	0.0179	0.0013	0.0208	0.0143	0.0011	0.0088	0.006	4.52E-04	0.0129	0.0089	6.66E-04	0.00E+00	0.00E+00	0.00E+00	0.3346	0.2292	0.0172	0.7172	0.4912	0.0369	0.8286	0.5676	0.0427	0.4559	0.3122	0.0235	0.5554	0.3804	0.0286	0.1294	0.0886	0.0067	0.157	0.1075	0.0081	
C ₁₆ -C ₂₁	16.5	1.94		1.46	19.42	No	3.52E-05	2.41E-05	1.81E-06	1.78E-05	1.22E-05	9.15E-07	4.54E-04	3.11E-04	2.34E-05	4.42E-04	3.03E-04	2.28E-05	0.00E+00	0.00E+00	0.00E+00	0.0239	0.0164	0.0012	0.053	0.0363	0.0027	0.0269	0.0185	0.0014	0.0229	0.0157	0.0012	0.1417	0.0971	0.0073	0.354	0.2424	0.0182	0.3194	0.2188	0.0165	
C ₂₁ -C ₂₅	25	6.6E-03		1.10	14.63	Yes	5.25E-07	4.77E-07	3.59E-08	3.30E-07	3.00E-07	2.25E-08	1.41E-07	1.28E-07	9.66E-09	1.53E-07	1.39E-07	1.05E-08	6.14E-10	5.58E-10	4.20E-11	6.61E-07	6.01E-07	4.52E-08	4.40E-07	4.00E-07	3.01E-08	7.42E-07	6.75E-07	5.07E-08	4.86E-09	4.42E-09	3.32E-10	5.18E-05	4.71E-05	3.54E-06	1.71E-10	1.56E-10	1.17E-11	2.38E-04	2.16E-04	1.63E-05	
Sum of Aromatics							150			164			186			214			80.5626			26.8853			7.6701			10.4839			4.683			7.0935			1.8611			3.0394			
Aliphatic Fractions																																											
C ₂ -C ₃	5.5	29.85		182.50	2427.25	Yes	11.2015	0.0614	0.0046	9.863	0.054	0.0041	8.0774	0.0443	0.0033	6.2932	0.0345	0.0026	5.7473	0.0315	0.0024	2.6939	0.0148	0.0011	0.0277	1.52E-04	1.14E-05	0.0094	5.14E-05	3.86E-06	0.0272	1.49E-04	1.12E-05	0.0297	1.63E-04	1.23E-05	0.0198	1.08E-04	8.15E-06	0.0349	1.91E-04	1.44E-05	
C ₄ -C ₅	7	4.47		182.50	2427.25	Yes	0.2272	0.0012	9.36E-05	0.0811	4.44E-04	3.34E-05	0.3636	0.002	1.50E-04	0.1144	6.27E-04	4.71E-05	1.1278	0.0062	4.65E-04	1.291	0.0071	5.32E-04	0.0593	3.25E-04	2.44E-05	0.0377	2.06E-04	1.55E-05	0.0464	2.54E-04	1.91E-05	0.0381	2.09E-04	1.57E-05	0.006	3.30E-05	2.48E-06	0.00E+00	0.00E+00	0.00E+00	
C ₆ -C ₁₀	9	0.35		182.50	2427.25	Yes	0.0392	2.15E-04	1.61E-05	0.0364	1.99E-04	1.50E-05	0.0741	4.08E-04	0.0795	4.36E-04	3.28E-05	0.1415	7.75E-04	5.83E-05	0.1242	6.81E-04	5.12E-05	0.0392	2.15E-04	1.61E-05	0.0416	2.28E-04	1.72E-05	0.0274	1.50E-04	1.13E-05	0.0268	1.47E-04	1.10E-05	0.0033	1.79E-05	1.35E-06	0.0048	2.63E-05	0.0048	2.63E-05	1.97E-06
C ₁₀ -C ₁₂	11	0.03		3.65	48.55	Yes	0.0017	4.75E-04	3.57E-05	0.002	5.40E-04	4.06E-05	8.54E-04	2.34E-04	1.76E-05	0.0015	4.08E-04	3.07E-05	5.96E-05	1.63E-05	1.23E-06	0.0014	3.73E-04	2.81E-05	0.009	0.0025	1.86E-04	0.0088	0.0024	1.82E-04	0.0106	0.0029	1.28E-04	0.0062	0.0017	1.28E-04	8.61E-04	2.36E-04	1.77E-05	7.69E-04	2.11E-04	1.58E-05	
C ₁₂ -C ₁₆	14	6.3E-04		3.65	48.55	Yes	1.92E-06	5.26E-07	3.96E-08	1.53E-06	4.19E-07	3.15E-08	7.99E-07	2.19E-07	1.65E-08	1.48E-06	4.05E-07	3.04E-08	4.68E-07	1.28E-07	9.65E-09	6.17E-05	1.69E-05	1.27E-06	2.21E-04	6.05E-05	4.55E-06	2.09E-04	5.72E-05	4.30E-06	2.66E-04	7.28E-05	5.47E-06	2.07E-04	5.68E-05	4.27E-06	1.28E-04	3.50E-05	2.63E-06	1.29E-04	3.54E-05	2.66E-06	
C ₁₆ -C ₂₁	16.5	1.1E-06		3.65	48.55	Yes	1.90E-11	5.21E-12	3.91E-13	9.60E-12	2.63E-12	1.98E-13	3.04E-10	8.32E-11	6.26E-12	3.72E-10	1.02E-10	7.66E-12	5.76E-11	1.58E-11	1.19E-12	1.33E-08	3.64E-09	2.73E-10	5.26E-08	1.44E-08	1.08E-09	4.56E-08	1.25E-08	9.39E-10	2.45E-08	6.71E-09	5.05E-10	1.99E-07	5.44E-08	4.09E-09	5.94E-07	1.63E-07	1.22E-08	5.78E-07	1.58E-07	1.19E-08	
C ₂₁ -C ₂₅	25	1.3E-11		73.00	970.90	Yes	9.13E-16	1.25E-17	9.41E-19	5.74E-16	7.86E-18	5.91E-19	3.04E-16	4.17E-18	3.13E-19	4.14E-16	5.67E-18	4.26E-19	1.99E-16	2.72E-18	2.05E-19	2.64E-17	3.62E-19	2.72E-20	7.87E-16	1.08E-17	8.11E-19	1.72E-16	2.35E-18	1.77E-19	1.90E-16	2.60E-18	1.95E-19	4.92E-14	6.74E-16	5.07E-17	3.19E-13	4.37E-15	3.28E-16	1.33E-13	1.82E-15	1.37E-16	
Sum of Aliphatics							11.4696			9.9825			8.5159			6.4886			7.0166			4.1105			0.1355			0.0977			0.1118			0.1011			0.03			0.0406			
Total Hydrocarbon				NA	NA		161	NA	NA	174	NA	NA	195	NA	NA	221	NA	NA	87.5792	NA	NA	30.9958	NA	NA	7.8056	NA	NA	10.5816	NA	NA	4.7948	NA	NA	7.1946	NA	NA	1.8911	NA	NA	3.08	NA	NA	
GRO aromatics				7.30	97.09		148	20,3026	1,5265	162	22,1737	1,6672	185	25,3923	1,9092	213	29,1945	2,1951	80.5467	11,0338	0.8296	26.086	3,5734	0.2687	5.9127	0.81	0.0609	8.2216	1,1263	0.0847	3.6643	0.502	0.0377	5.7271	0.7845	0.059	1.3472	0.1845	0.0139	2.5447	0.3486	0.0262	
GRO aliphatics				182.50	2427.25		11.4679	0.0628	0.0047	9.9805	0.0547	0.0041	8.5151	0.0467	0.0035	6.4871	0.0355	0.0027	7.0166	0.0384	0.0029	4.1091	0.0225	0.0017	0.1263	6.92E-04	5.20E-05	0.0887	4.86E-04	3.65E-05	0.101	5.53E-04	4.16E-05	0.0947	5.19E-04	3.90E-05	0.0291	1.59E-04	1.20E-05	0.0397	2.18E-04	1.64E-05	
GRO (C ₈ to C ₁₀)				NA	NA		160	NA	NA	172	NA	NA	194	NA	NA	220	NA	NA	87.5633	NA	NA	30.1951	NA	NA	6.039	NA	NA	8.3103	NA	NA	3.7653	NA	NA	5.8217	NA	NA	1.3762</						

Figures

Figure 1 Example 1 Change in DRO Concentration through Time and Estimated Groundwater Cleanup Time

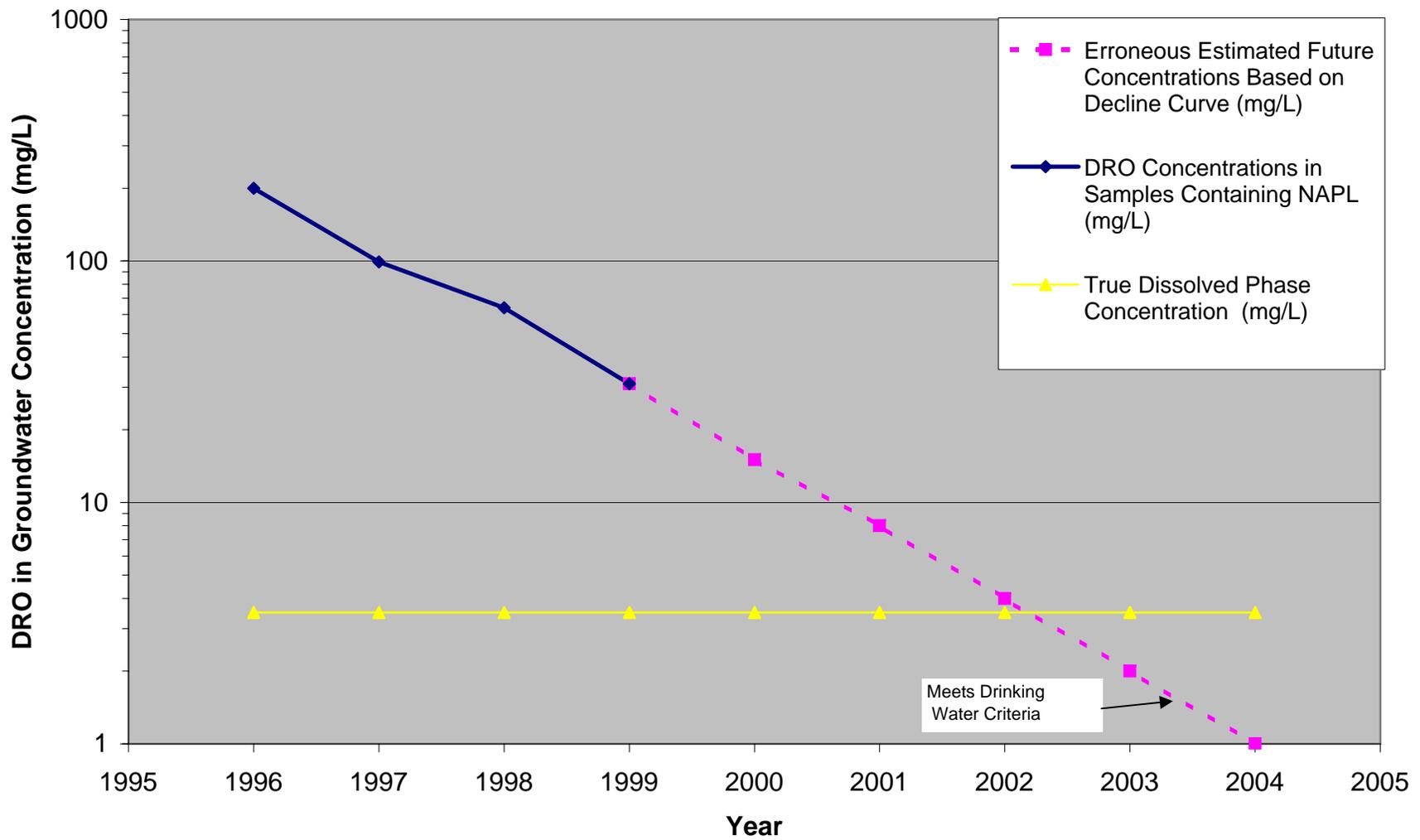
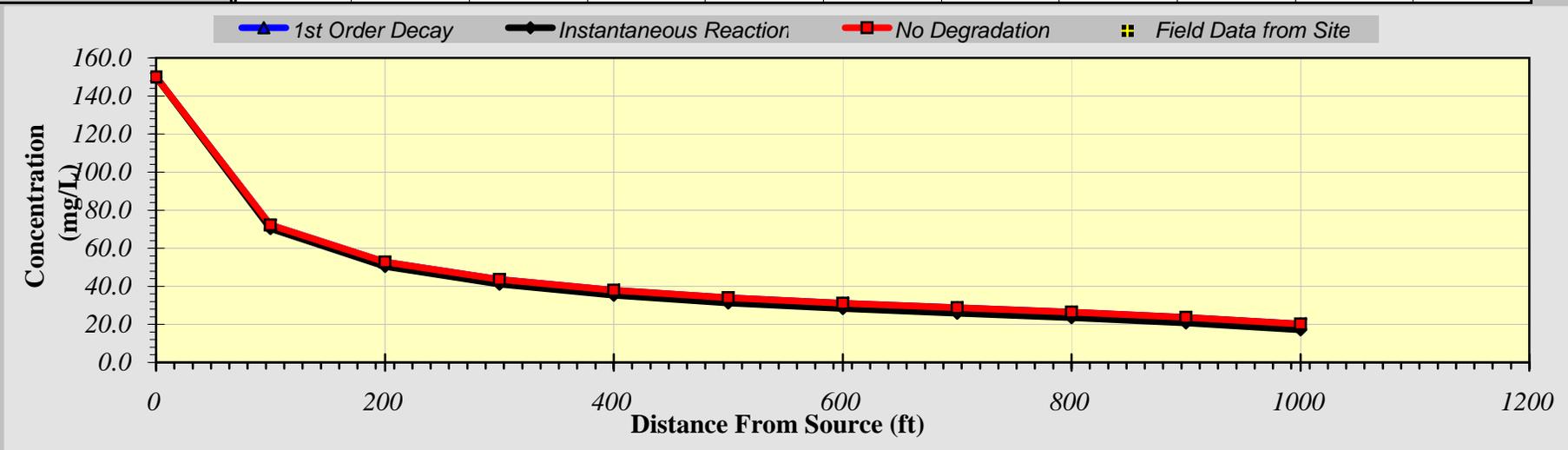


Figure 2 BioScreen Dissolved Phase Plume Length given a DRO concentration of 150 mg/L (Example 2A)

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)											
	0	100	200	300	400	500	600	700	800	900	1000	
No Degradation	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?
1st Order Decay	150.000	#NAME?										
Inst. Reaction	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?	#NAME?
Field Data from Site												0.000



Calculate Animation

Time:
10 Years

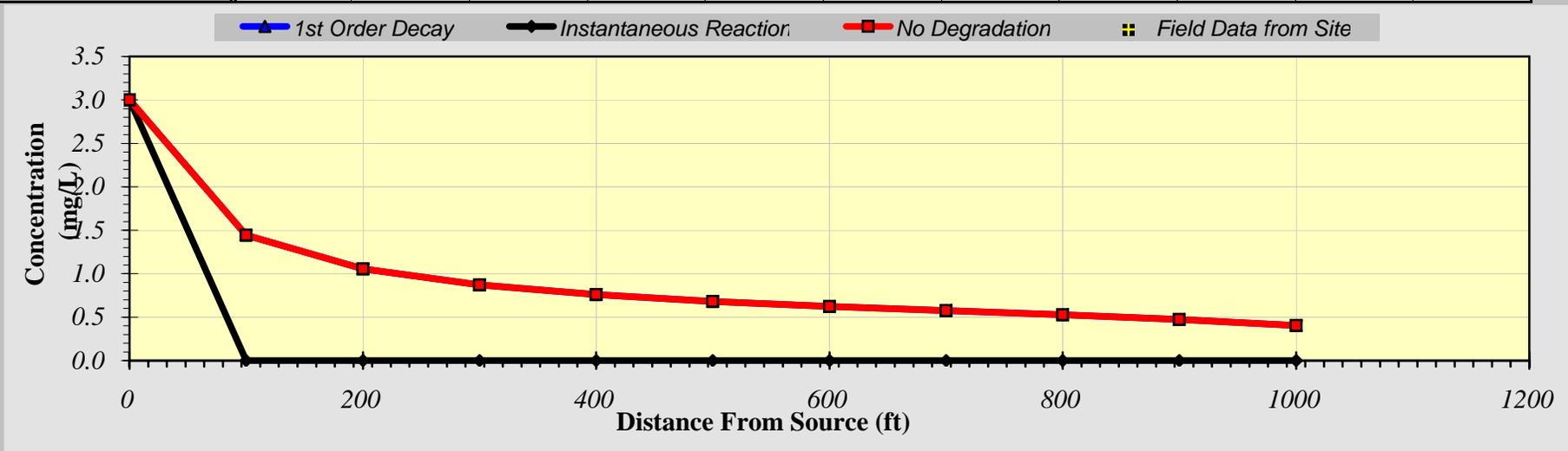
Return to Input

Recalculate This Sheet

Figure 3 BioScreen Dissolved Phase Plume Length given a DRO concentration of 3 mg/L (Example 2B)

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	100	200	300	400	500	600	700	800	900	1000
No Degradation	3.000	1.444	1.055	0.871	0.759	0.681	0.622	0.574	0.529	0.475	0.404
1st Order Decay	3.000	1.444	1.055	0.871	0.759	0.681	0.622	0.574	0.529	0.475	0.404
Inst. Reaction	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											0.000



Calculate Animation

Time:
10 Years

Return to Input

Recalculate This Sheet

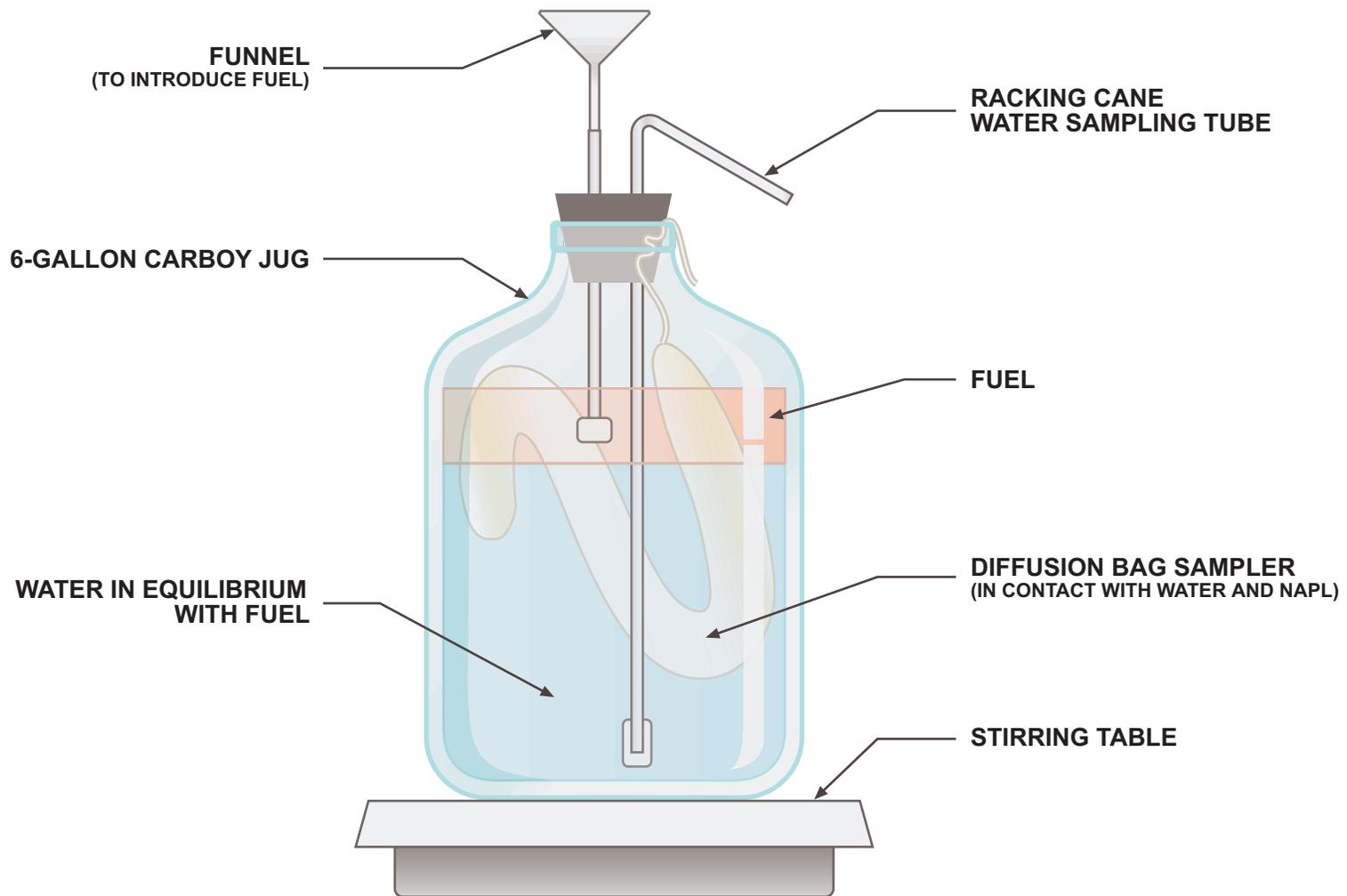


FIGURE 4
Laboratory Setup for Simulating
Groundwater in Equilibrium with Oil

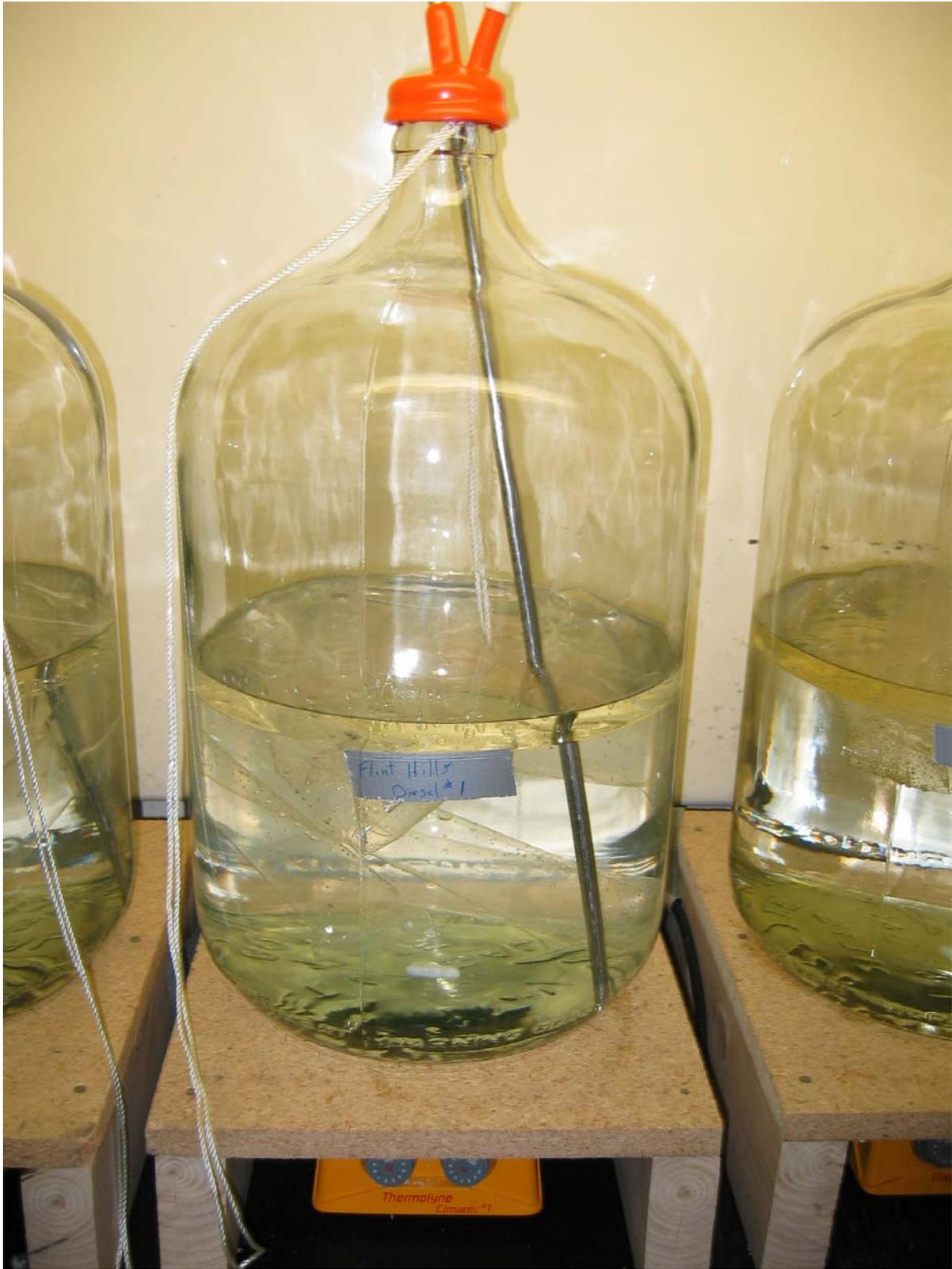


Figure 5 Photograph of Laboratory Carboy Setup for Simulating Groundwater in Equilibrium with Oil



Figure 6 Close-up Photograph of Laboratory Carboy Setup for Simulating Groundwater in Equilibrium with Oil

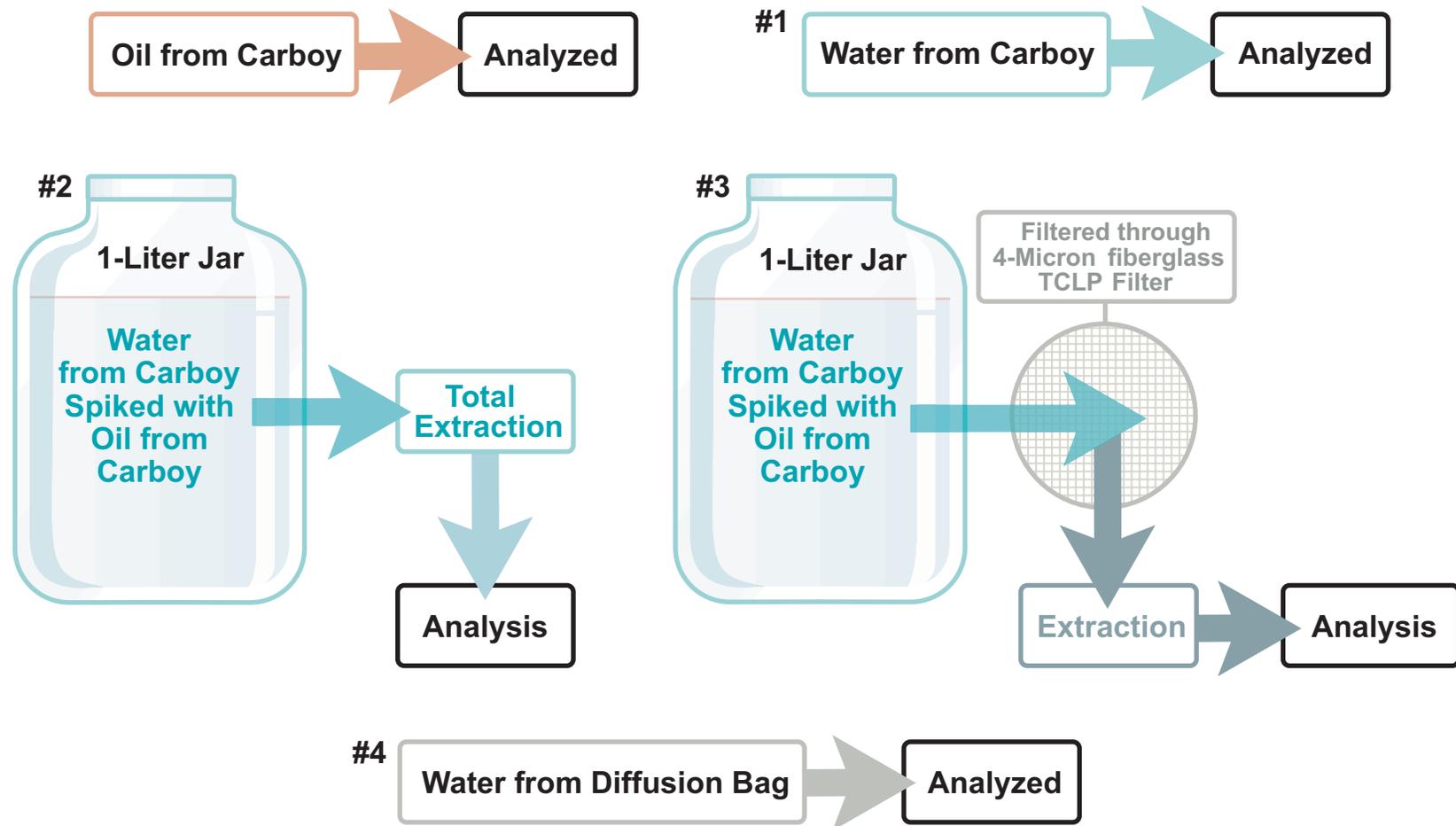


FIGURE 7
 Four Types of Water Samples Collected from Carboy
 (Approach for Simulating Groundwater Containing NAPL)

Figure 8A Correlation of Carboy Water & Diffusion Bag BTEX & VPH Test Results

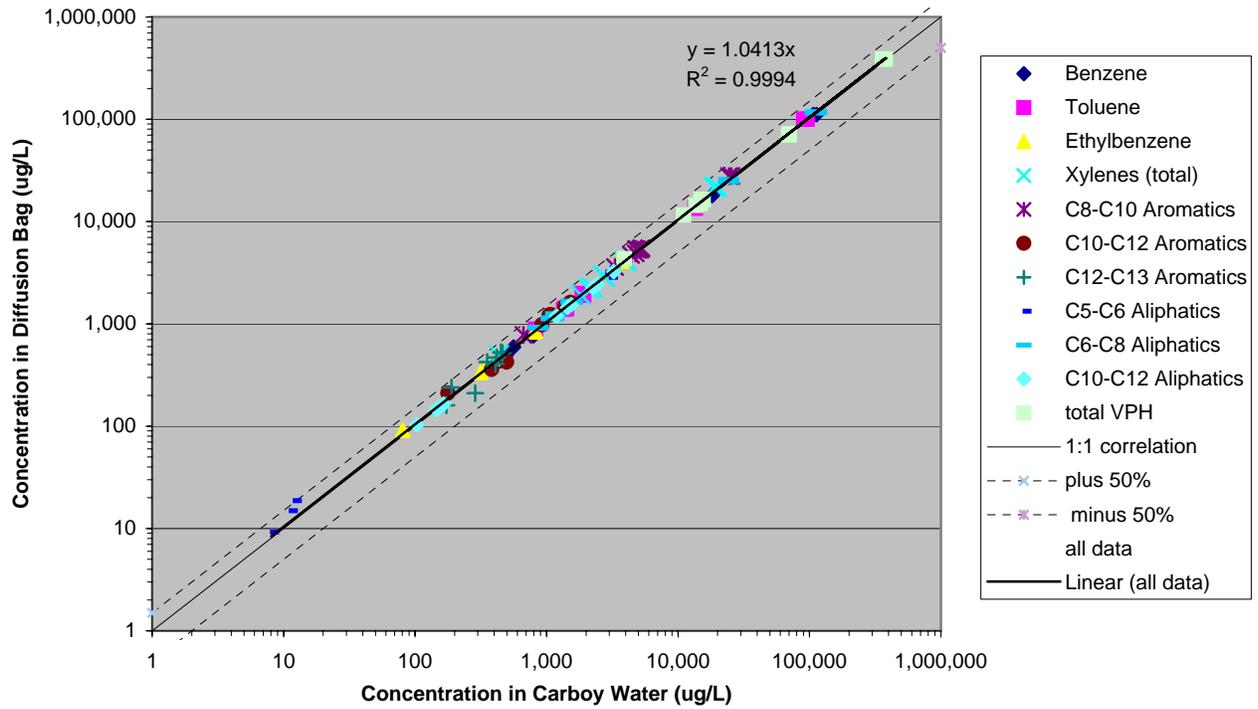


Figure 8B Correlation of Carboy Water & Diffusion Bag DRO Range VPH Test Results From Diesel & Jet Samples

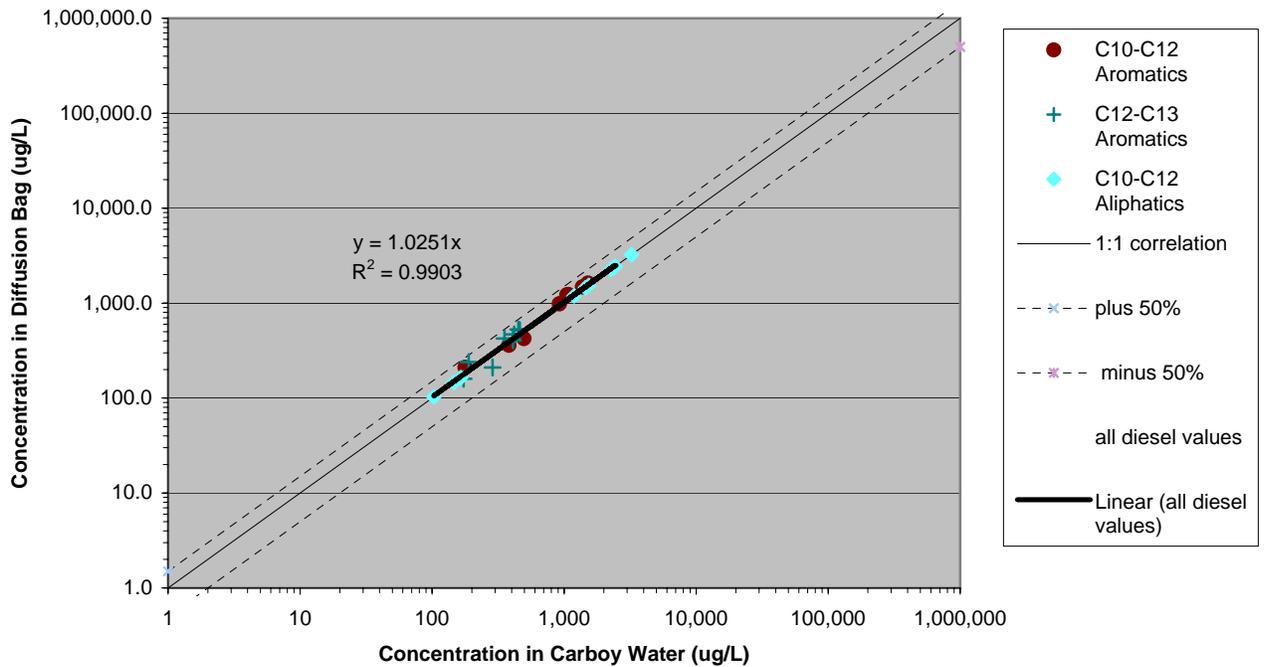


Figure 9 Correlation of Carboy Water & Diffusion Bag EPH Test Results

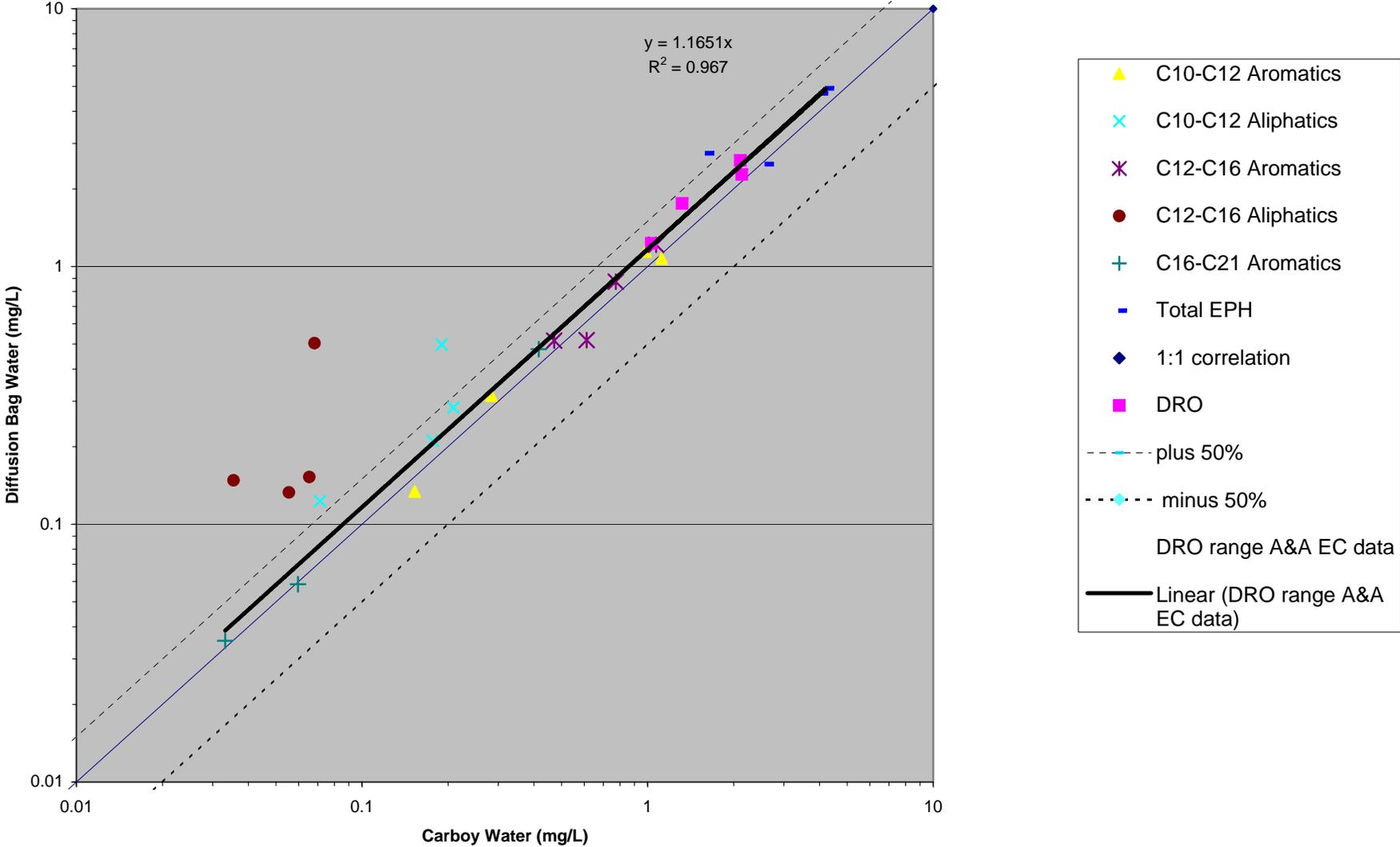


Figure 10 Comparison of Spiked Water and Spiked & Filtered Water

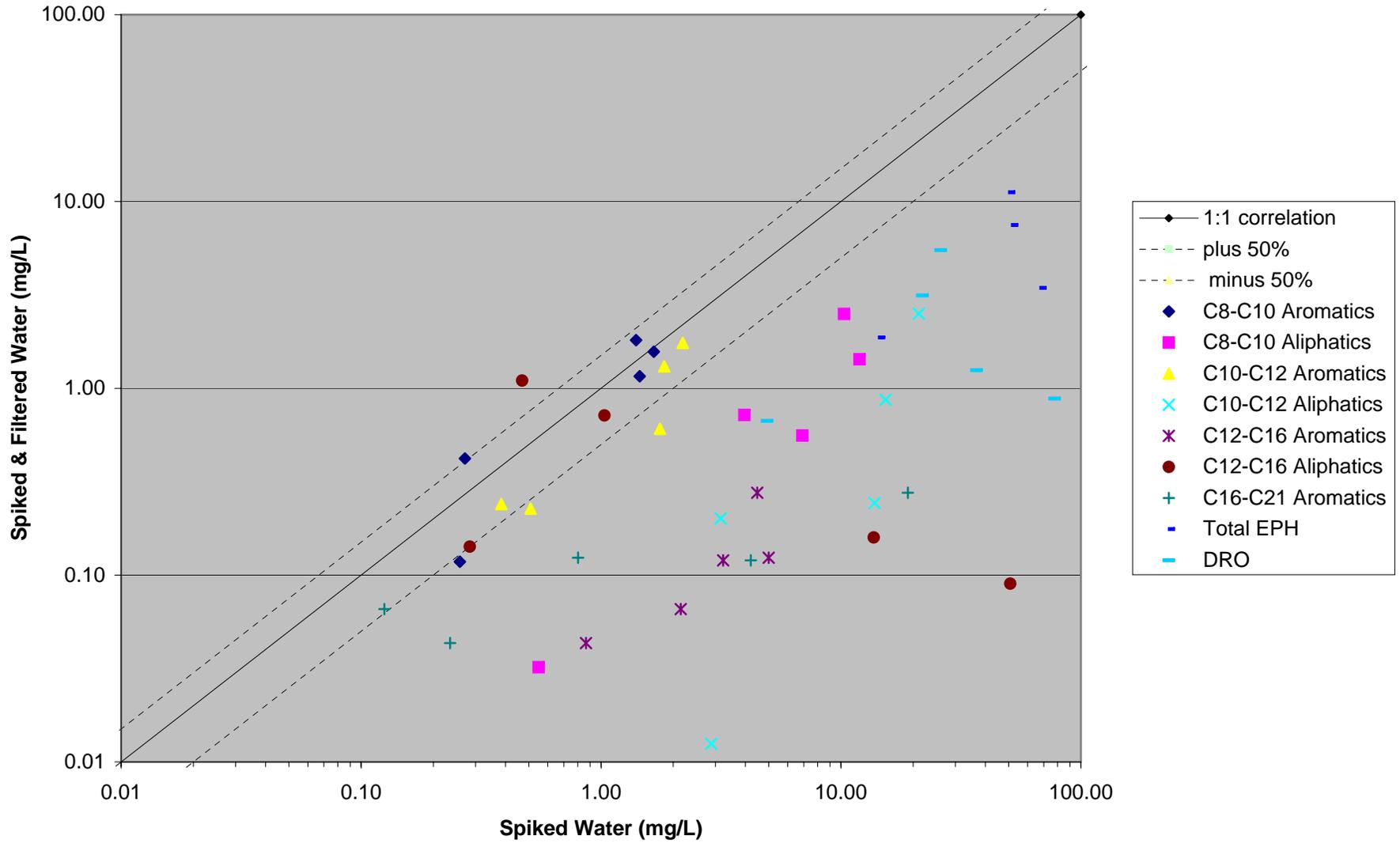


Figure 11 Comparison of Carboy Water and Spiked & Filtered Water

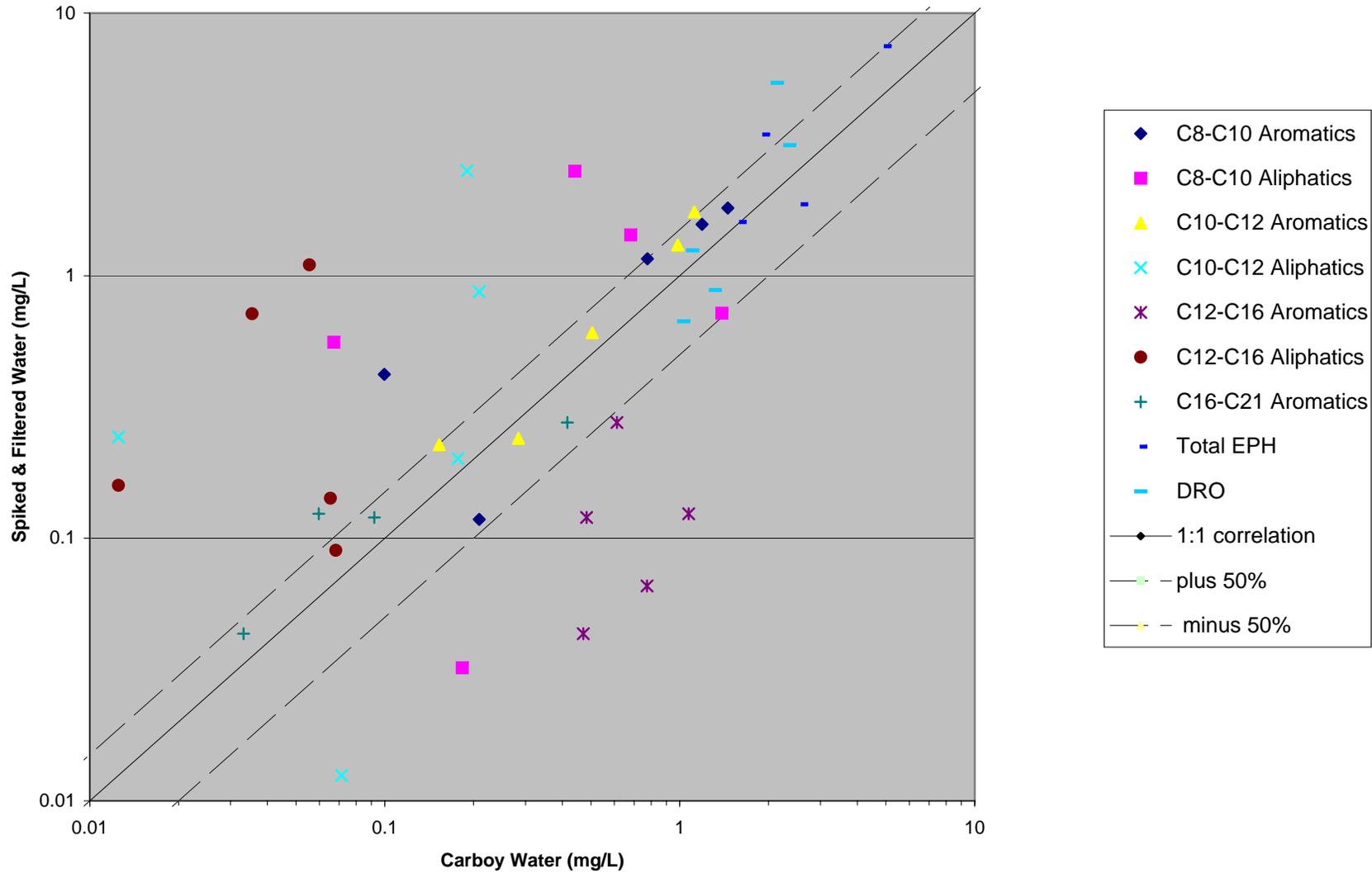


Figure 12 Compilation of Laboratory Test Results into Recommended Hydrocarbon Fractions

Equivalent Carbon Number	GRO AK101	DRO AK102	RRO AK103	GRO AK101 A&A	DRO AK102 A&A	RRO AK103 A&A	Washington VPH Test	Washington EPH Test	BTEX Test	Recommended Characterization						
5							C5 to C6 aliphatics			no aromatics in this range =C5 aliphatic result						
6	C6 to C10 aromatics & aliphatics			C6 to C10 aromatics	C6 to C10 aliphatics		C6 to C8 aliphatics		benzene	=benzene result						
7								toluene	=toluene							
8								ethylbenzene	=ethylbenzene							
9								xylene	=xylene							
9							C8 to C10 aromatics	C8 to C10 aliphatics	C8 to C10 aromatics	C8 to C10 aliphatics	=aromatic C8 to C10 - (ethylbenzene + xylene) =C8 to C10 aliphatic result					
10		C10 to C25 aromatics & aliphatics					C10 to C12 aromatics	C10 to C12 aliphatics	C10 to C12 aromatics	C10 to C12 aliphatics	=greater of C10 to C12 aromatic result from VPH or EPH test	=greater of C10 to C12 aliphatic result from VPH or EPH test				
11																
12					C10 to C25 aromatics	C10 to C25 aliphatics										
13																
16							C12 to C16 aromatics	C12 to C16 aliphatics			=C12 to C16 EPH aromatics test result	=C12 to C16 EPH aliphatics test result				
21							C16 to C21 aromatics	C16 to C21 aliphatics			C16 to C21 aromatics	C16 to C21 aliphatics				
25																
35			C25 to C35 aromatics & aliphatics			C25 to C35 aromatics	C25 to C35 aliphatics	C21 to C35 aromatics	C21 to C35 aliphatics		C21 to C35 aromatics	C21 to C35 aliphatics				

Figure 13 Average Dissolved Phase Concentrations from Carboy Water and Diffusion Bag Samples

Aromatic Fractions	Median Equivalent Carbon	Single Component Solubility (mg/L)	Sample #6	Sample #3	Sample #4	Sample #9	Sample #10	Sample #12	Average Jet A & Diesel Fuel
			Regular Gasoline	JP4	DF1 Diesel Fuel	Jet A	Diesel Fuel	DF2 Diesel Fuel	
			Average Dissolved Conc. (mg/L)						
Benzene	6.5	1750.0	111	18.125	0.7853	0.4355	0.492	0.5775	0.5726
Toluene	7.58	526.0	96.6	13.575	1.9175	1.3925	1.39	0.8565	1.3891
Ethylbenzene	8.5	169.0	3.8725	0.8288	0.4485	0.364	0.315	0.086	0.3034
Xylene	8.63	161.0	20.575	4.07	2.8275	2.1975	1.82	0.4655	1.8276
C9-C10	9.25	57.2	1.9525	0.4088	1.834	2.1335	1.185	0.1721	1.3311
C10-C12	10.5	31.3	0.8745	0.4155	1.145	1.5	0.922	0.194	0.9403
C12-C16	13	9.33	0.00E+00	0.4108	1.1433	0.8238	0.483	0.565	0.7538
C16-C21	16.5	1.94	0.00E+00	0.0291	0.0591	0.0229	0.0922	0.447	0.1553
C21-C35	25	0.01	0.00E+00	0.0125	0.0156	0.0156	0.0125	0.0125	0.0141
Sum of Aromatics			234	37.8753	10.1757	8.8852	6.7117	3.376	7.2872
Aliphatic Fractions									
C5-C6	5.5	29.85	2.99	3.1825	0.0042	0.0112	0.0112	0.0086	0.0088
C6-C8	7	4.47	114	24.7	1.6	1.12	1.17	0.8925	1.1956
C8-C10	9.25	0.35	0.00E+00	0.9112	0.806	0.688	0.0672	0.222	0.4458
C10-C12	10.5	0.03	2.6025	0.1595	1.595	2.405	1.19	0.111	1.3253
C12-C16	13	0.00	0.00E+00	0.0957	0.067	0.0866	0.0125	0.2861	0.1131
C16-C21	16.5	0.00	0.00E+00	0.0125	0.0156	0.0156	0.0125	0.3358	0.0949
C21-C35	25	0.00	0.00E+00	0.0125	0.0156	0.0156	0.0125	0.0125	0.0141
Sum of Aliphatics			120	29.0739	4.1034	4.342	2.4759	1.8685	3.1975
Total Hydrocarbon			354.217	66.9492	14.2792	13.2273	9.1876	5.2445	10.4846
GRO (C5 to C10)			351	65.8012	10.2229	8.3422	6.4504	3.2806	7.074
DRO (C10 to C21)			3.477	1.1231	4.025	4.8538	2.7122	1.9389	3.3825
RRO (C21 to C35)			0.00E+00	0.025	0.0313	0.0313	0.025	0.025	0.0281
TAH (BTEX)			232	36.5988	5.9788	4.3895	4.017	1.9855	4.0927

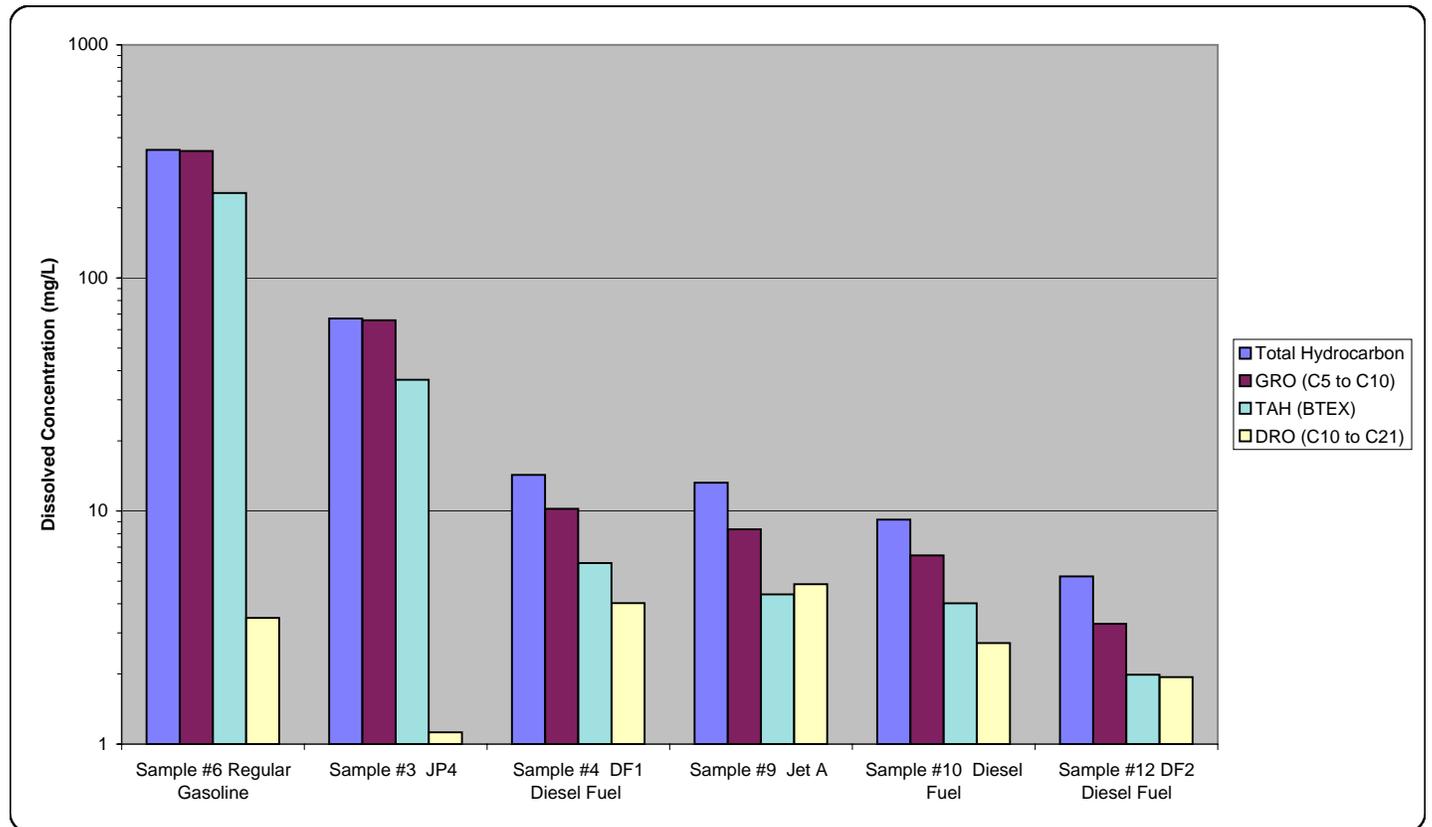


Figure 14 Comparison of Calculated and Measured Dissolved Concentrations Sample #3 JP4

Aromatic Fractions	Median Equivalent Carbon	Single Component Solubility (mg/L)	Measured Dissolved Conc. (mg/L)	Average Measured Dissolved Conc. (mg/L)	Calculated Dissolved Conc. (mg/L)	Ratio of Measured to Calculated Concentrations (measured/calculated)	Ratio of measured solubility to pure phase solubility (measured/ pure phase)			
			Sample #3 JP4 W 6A	Sample #3 JP4 DB 6B	Sample #3 JP4 W 6E	Sample #3 JP4 DB 6F	Sample #3 JP4 Average Measured Dissolved Conc.	Sample #3 JP4 Calculated Dissolved Conc.		
Benzene	6.5	1750	18.3	18.1	18.1	18.	18.125	13.4298	1.3496	0.0104
Toluene	7.58	526	13.6	13.7	13.5	13.5	13.575	8.838	1.536	0.0258
Ethylbenzene	8.5	169	0.823	0.848	0.81	0.834	0.8288	0.6446	1.2857	0.0049
Xylene	8.63	161	4.06	4.16	3.97	4.09	4.07	2.9702	1.3703	0.0253
C9-C10 aro	9.25	5.7E+01	0.387	0.472	0.38	0.396	0.4088	0.2034	2.0094	0.0071
C10-C12 aro	10.5	3.1E+01	0.496	0.424	0.382	0.36	0.4155	0.4407	0.9428	0.0133
C12-C16 aro	13	9.3E+00	0.14	0.487	0.471	0.545	0.4108	0.3346	1.2275	0.044
C16-C21 aro	16.5	1.9E+00	0.0125	0.0332	0.0332	0.0374	0.0291	0.0239	1.2151	0.015
C21-C35 aro	25	6.6E-03	0.0125	0.0125	0.0125	0.0125	0.0125	6.61E-07		1.892
Sum of Aromatics			37.831	38.2367	37.6587	37.7749	37.8753	26.8853	1.4088	
Aliphatic Fractions										
C5-C6 ali	5.5	3.0E+01	3.09	3.56	2.94	3.14	3.1825	2.6939	1.1814	0.1066
C6-C8 ali	7	4.5E+00	24.2	25.5	24.4	24.7	24.7	1.291	19.133	5.5296
C8-C10 ali	9	3.5E-01	0.0125	2.15	1.39	0.0921	0.9112	0.1242	7.3354	2.568
C10-C12 ali	11	2.8E-02	0.165	0.169	0.146	0.158	0.1595	0.0014	117	5.6593
C12-C16 ali	14	6.3E-04	0.0125	0.24	0.0654	0.065	0.0957	6.17E-05		
C16-C21 ali	16.5	1.1E-06	0.0125	0.0125	0.0125	0.0125	0.0125	1.33E-08		
C21-C35 ali	25	1.3E-11	0.0125	0.0125	0.0125	0.0125	0.0125	2.64E-17		
Sum of Aliphatics			27.505	31.644	28.9664	28.1801	29.0739	4.1105	7.0731	
Total Hydrocarbon			65.336	69.8807	66.6251	65.955	66.9492	30.9958	2.1599	
GRO (C5 to C10)			64.4725	68.49	65.49	64.7521	65.8012	30.1951	2.1792	
DRO (C10 to C21)			0.8385	1.3657	1.1101	1.1779	1.1231	0.8007	1.4026	
RRO (C21 to C35)			0.025	0.025	0.025	0.025	0.025	6.61E-07		
TAH (BTEX)			36.783	36.808	36.38	36.424	36.5988	25.8826	1.414	

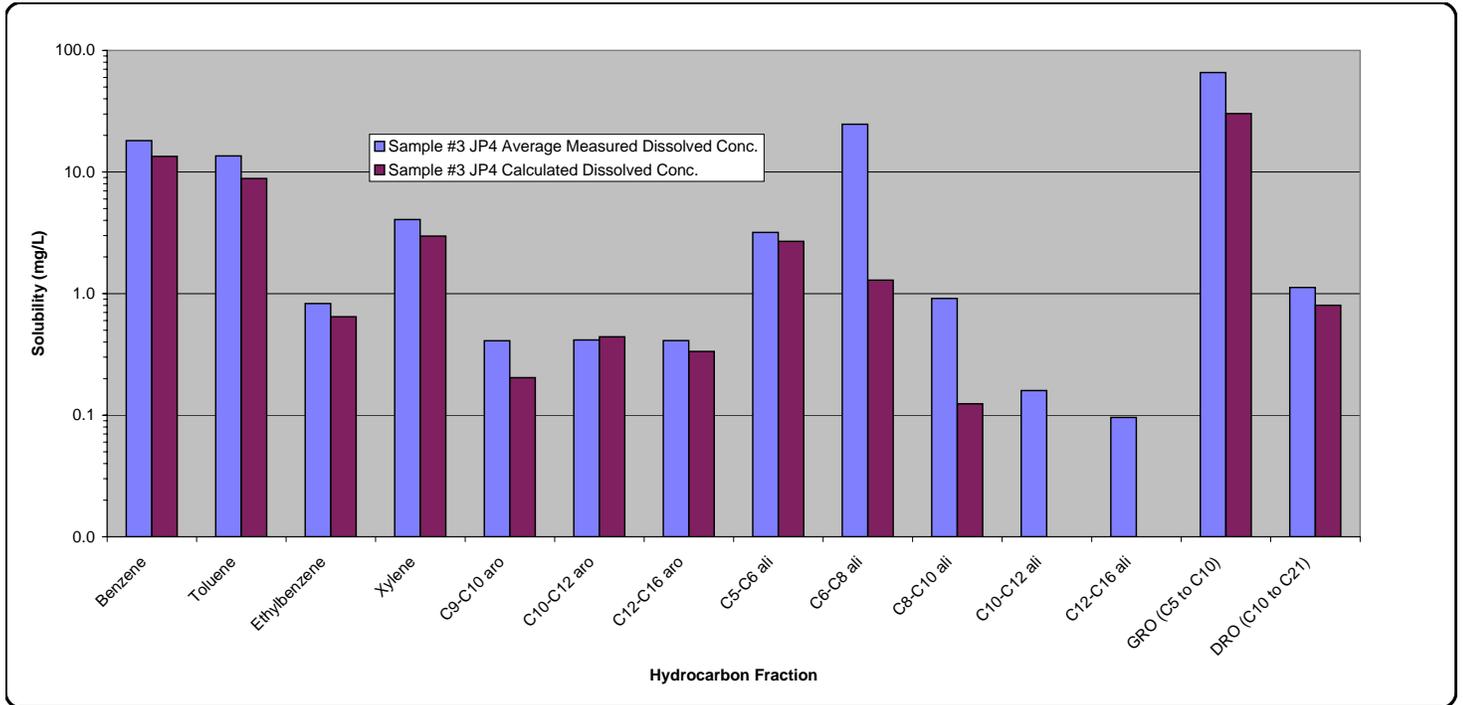


Figure 15 Comparison of Calculated and Measured Dissolved Concentrations Sample #6 Regular Gas

	Median Equivalent Carbon	Single Component Solubility (mg/L)	Measured Dissolved Conc. (mg/L)	Average Measured Dissolved Conc. (mg/L)	Calculated Dissolved Conc. (mg/L)	Ratio of Measured to Calculated Concentrations (measured/calculated)	Ratio of measured solubility to pure phase solubility (measured/pure phase)			
			Sample #6 Regular Gas W 1A	Sample #6 Regular Gas W 1B	Sample #6 Regular Gas DB 1C	Sample #6 Regular Gas DB 1D	Sample #6 Regular Gas Average Measured Dissolved Conc.	Sample #6 Regular Gas Calculated Dissolved Conc.		
Aromatic Fractions										
Benzene	6.5	1750	107	113	111	111	111	89.4427	1.2354	0.0631
Toluene	7.58	526	90.4	96.	100	100	96.6	70.388	1.3724	0.1837
Ethylbenzene	8.5	169	3.57	3.76	4.07	4.09	3.8725	3.6463	1.062	0.0229
Xylene	8.63	161	18.8	20.	21.7	21.8	20.575	18.0574	1.1394	0.1278
C9-C10 aro	9.25	5.7E+01	2.03	1.74	2.03	2.01	1.9525	3.8293	0.5099	0.0341
C10-C12 aro	10.5	3.1E+01	2.13	0.611	0.278	0.479	0.8745	0.6402	1.3661	0.028
C12-C16 aro	13	9.3E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0088	0.00E+00	0.00E+00
C16-C21 aro	16.5	1.9E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.54E-04	0.00E+00	0.00E+00
C21-C35 aro	25	6.6E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.41E-07		0.00E+00
Sum of Aromatics			224	235	239	239	234	186	1.26	
Aliphatic Fractions										
C5-C6 ali	5.5	3.0E+01	3.04	2.86	2.85	3.21	2.99	8.0774	0.3702	0.1002
C6-C8 ali	7	4.5E+00	110	114	116	117	114	0.3636	314	25.5774
C8-C10 ali	9	3.5E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.0741	0.00E+00	0.00E+00
C10-C12 ali	11	2.8E-02	3.24	2.37	2.36	2.44	2.6025	8.54E-04	3,049	92.3402
C12-C16 ali	14	6.3E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.99E-07		
C16-C21 ali	16.5	1.1E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.04E-10		
C21-C35 ali	25	1.3E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.04E-16		
Sum of Aliphatics			116	119	121	123	120	8.5159	14.0727	
Total Hydrocarbon			340	354	360	362	354	195	1.8209	
GRO (C5 to C10)			335	351	358	359	351	194	1.8091	
DRO (C10 to C21)			5.37	2.981	2.638	2.919	3.477	0.6502	5.3472	
RRO (C21 to C35)			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.41E-07		
TAH (BTEX)			220	233	237	237	232	182	1.2755	

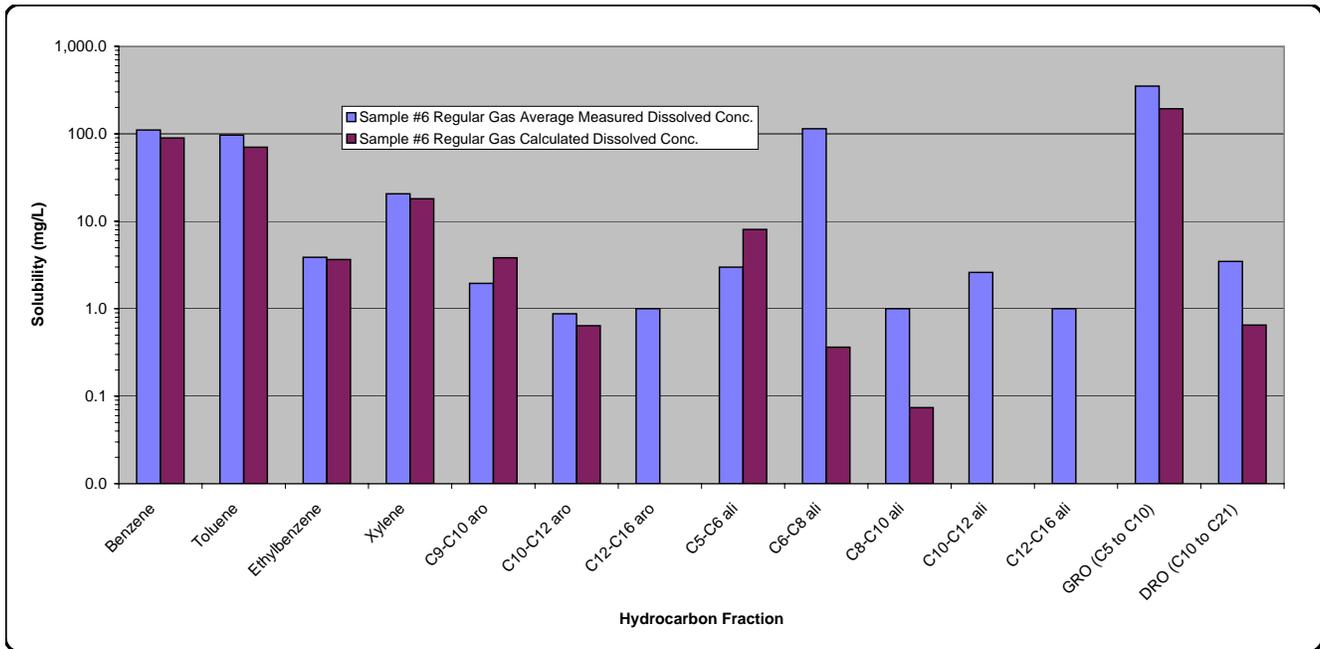


Figure 16 Comparison of Calculated and Measured Dissolved Concentrations Sample #12 DF2

Aromatic Fractions	Median Equivalent Carbon	Single Component Solubility (mg/L)	Measured Dissolved Conc. (mg/L)	Measured Dissolved Conc. (mg/L)	Average Measured Dissolved Conc. (mg/L)	Calculated Dissolved Conc. (mg/L)	Ratio of Measured to Calculated Concentrations (measured/calculated)	Ratio of measured solubility to pure phase solubility (measured/pure phase)
			Sample #12 DF2 W 2A	Sample #12 DF2 DB 2B	Sample #12 DF2 Average Measured Dissolved Conc.	Sample #12 DF2 Calculated Dissolved Conc.		
Benzene	6.5	1750	0.562	0.593	0.5775	0.7827	0.7378	3.30E-04
Toluene	7.58	526	0.825	0.888	0.8565	1.0948	0.7823	0.0016
Ethylbenzene	8.5	169	0.0806	0.0913	0.086	0.1079	0.7967	5.09E-04
Xylene	8.63	161	0.434	0.497	0.4655	0.5585	0.8335	0.0029
C9-C10 aro	9.25	5.7E+01	0.1534	0.1907	0.1721	7.40E-04	232	0.003
C10-C12 aro	10.5	3.1E+01	0.178	0.21	0.194	0.0181	10.7252	0.0062
C12-C16 aro	13	9.3E+00	0.612	0.518	0.565	0.157	3.5991	0.0605
C16-C21 aro	16.5	1.9E+00	0.416	0.478	0.447	0.3194	1.3993	0.2306
C21-C35 aro	25	6.6E-03	0.0125	0.0125	0.0125	2.38E-04		1.892
Sum of Aromatics			3.2735	3.4785	3.376	3.0394	1.1107	
Aliphatic Fractions								
C5-C6 ali	5.5	3.0E+01	0.0081	0.0092	0.0086	0.0349	0.2475	2.89E-04
C6-C8 ali	7	4.5E+00	0.868	0.917	0.8925	0.0124	72.2493	0.1998
C8-C10 ali	9	3.5E-01	0.183	0.261	0.222	0.0048	46.3177	0.6257
C10-C12 ali	11	2.8E-02	0.103	0.119	0.111	7.69E-04	144	3.9384
C12-C16 ali	14	6.3E-04	0.0682	0.504	0.2861	1.29E-04		
C16-C21 ali	16.5	1.1E-06	0.0125	0.659	0.3358	5.78E-07		
C21-C35 ali	25	1.3E-11	0.0125	0.0125	0.0125	1.33E-13		
Sum of Aliphatics			1.2553	2.4817	1.8685	0.053	35.2831	
Total Hydrocarbon			4.5288	5.9602	5.2445	3.0924	1.6959	
GRO (C5 to C10)			3.1141	3.4472	3.2806	2.5967	1.2634	
DRO (C10 to C21)			1.3897	2.488	1.9389	0.4954	3.9136	
RRO (C21 to C35)			0.025	0.025	0.025	2.38E-04		
TAH (BTEX)			1.9016	2.0693	1.9855	2.5439	0.7805	

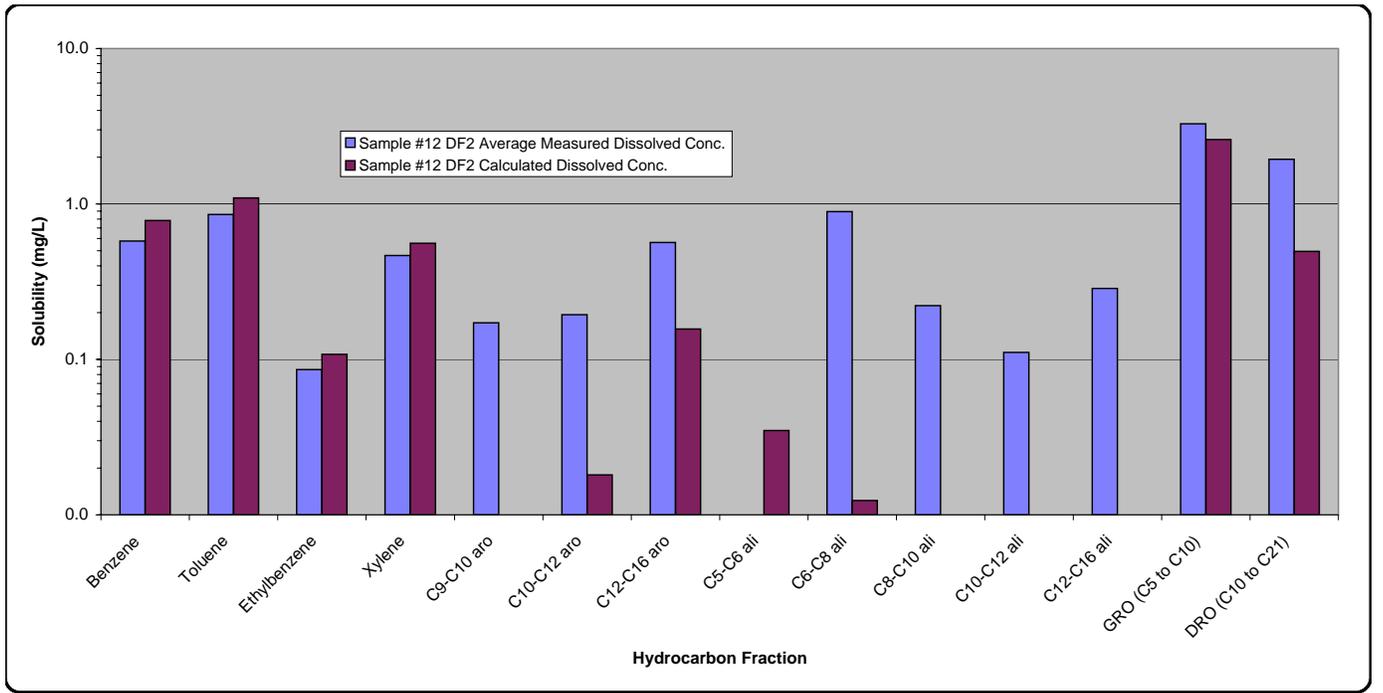


Figure 17 Comparison of Calculated and Measured Dissolved Concentrations Sample #10 Diesel Fuel

Aromatic Fractions	Median Equivalent Carbon	Single Component Solubility (mg/L)	Measured Dissolved Conc. (mg/L)	Measured Dissolved Conc. (mg/L)	Average Measured Dissolved Conc. (mg/L)	Calculated Dissolved Conc. (mg/L)	Ratio of Measured to Calculated Concentrations (measured/calculated)	Ratio of measured solubility to pure phase solubility (measured/pure phase)
			Sample #10 Diesel Fuel W 3A		Sample #10 Diesel Fuel Average Measured Dissolved Conc.	Sample #10 Diesel Fuel Calculated Dissolved Conc.		
Benzene	6.5	1750	0.492		0.492	0.7986	0.6161	2.81E-04
Toluene	7.58	526	1.39		1.39	2.0884	0.6656	0.0026
Ethylbenzene	8.5	169	0.315		0.315	0.4324	0.7285	0.0019
Xylene	8.63	161	1.82		1.82	2.353	0.7735	0.0113
C9-C10 aro	9.25	5.7E+01	1.185		1.185	0.0547	21.6823	0.0207
C10-C12 aro	10.5	3.1E+01	0.922		0.922	0.6693	1.3775	0.0295
C12-C16 aro	13	9.3E+00	0.483		0.483	0.5554	0.8697	0.0518
C16-C21 aro	16.5	1.9E+00	0.0922		0.0922	0.1417	0.6506	0.0476
C21-C35 aro	25	6.6E-03	0.0125		0.0125	5.18E-05		1.892
Sum of Aromatics			6.7117		6.7117	7.0935	0.9462	
Aliphatic Fractions								
C5-C6 ali	5.5	3.0E+01	0.0112		0.0112	0.0297	0.3765	3.75E-04
C6-C8 ali	7	4.5E+00	1.17		1.17	0.0381	30.6784	0.2619
C8-C10 ali	9	3.5E-01	0.0672		0.0672	0.0268	2.5105	0.1894
C10-C12 ali	11	2.8E-02	1.19		1.19	0.0062	191	42.2228
C12-C16 ali	14	6.3E-04	0.0125		0.0125	2.07E-04		
C16-C21 ali	16.5	1.1E-06	0.0125		0.0125	1.99E-07		
C21-C35 ali	25	1.3E-11	0.0125		0.0125	4.92E-14		
Sum of Aliphatics			2.4759		2.4759	0.1011	24.4915	
Total Hydrocarbon			9.1876		9.1876	7.1946	1.277	
GRO (C5 to C10)			6.4504		6.4504	5.8217	1.108	
DRO (C10 to C21)			2.7122		2.7122	1.3728	1.9756	
RRO (C21 to C35)			0.025		0.025	5.18E-05		
TAH (BTEX)			4.017		4.017	5.6724	0.7082	

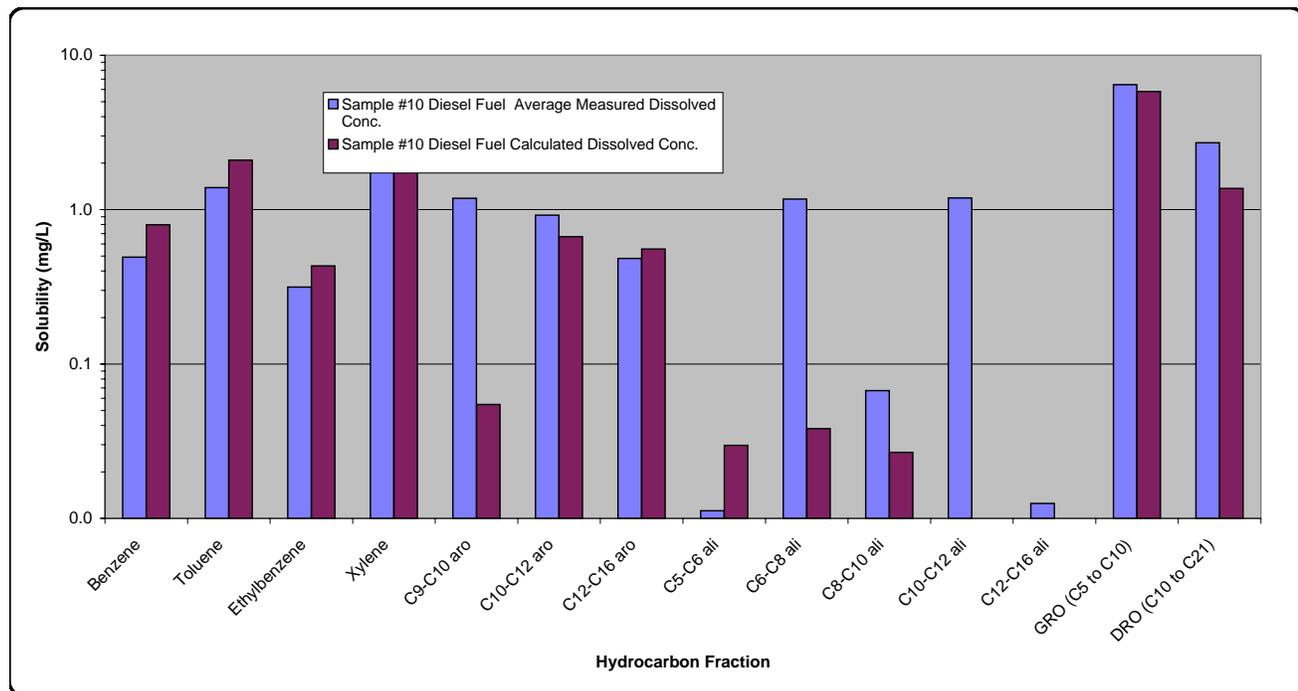


Figure 18 Comparison of Calculated and Measured Dissolved Concentrations Sample #9 Jet A

Aromatic Fractions	Median Equivalent Carbon	Single Component Solubility (mg/L)	Measured Dissolved Conc. (mg/L)	Average Measured Dissolved Conc. (mg/L)	Calculated Dissolved Conc. (mg/L)	Ratio of Measured to Calculated Concentrations (measured/calculated)	Ratio of measured solubility to pure phase solubility (measured/pure phase)			
			Sample #9 Jet A W 4A	Sample #9 Jet A DB 4B	Sample #9 Jet A W 4E	Sample #9 Jet A DB 4F	Sample #9 Jet A Average Measured Dissolved Conc.	Sample #9 Jet A Calculated Dissolved Conc.		
Benzene	6.5	1750	0.444	0.435	0.43	0.433	0.4355	0.4127	1.0552	2.49E-04
Toluene	7.58	526	1.42	1.41	1.35	1.39	1.3925	1.1302	1.2321	0.0026
Ethylbenzene	8.5	169	0.371	0.376	0.343	0.366	0.364	0.3208	1.1348	0.0022
Xylene	8.63	161	2.23	2.26	2.09	2.21	2.1975	1.7816	1.2335	0.0136
C9-C10 aro	9.25	5.7E+01	2.169	2.254	1.967	2.144	2.1335	0.0191	112	0.0373
C10-C12 aro	10.5	3.1E+01	1.52	1.62	1.38	1.48	1.5	0.5399	2.7784	0.048
C12-C16 aro	13	9.3E+00	0.769	0.954	0.779	0.793	0.8238	0.4559	1.807	0.0883
C16-C21 aro	16.5	1.9E+00	0.025	0.0414	0.0125	0.0125	0.0229	0.0229	0.9984	0.0118
C21-C35 aro	25	6.6E-03	0.025	0.0125	0.0125	0.0125	0.0156	4.86E-09		2.3649
Sum of Aromatics			8.973	9.3629	8.364	8.841	8.8852	4.683	1.8973	
Aliphatic Fractions										
C5-C6 ali	5.5	3.0E+01	0.012	0.0187	0.004	0.01	0.0112	0.0272	0.4111	3.74E-04
C6-C8 ali	7	4.5E+00	1.14	1.13	1.08	1.13	1.12	0.0464	24.1296	0.2507
C8-C10 ali	9	3.5E-01	0.296	1.05	0.586	0.82	0.688	0.0274	25.1072	1.939
C10-C12 ali	11	2.8E-02	2.43	2.53	2.26	2.4	2.405	0.0106	228	85.3326
C12-C16 ali	14	6.3E-04	0.025	0.181	0.0555	0.0849	0.0866	2.66E-04		
C16-C21 ali	16.5	1.1E-06	0.025	0.0125	0.0125	0.0125	0.0156	2.45E-08		
C21-C35 ali	25	1.3E-11	0.025	0.0125	0.0125	0.0125	0.0156	1.90E-16		
Sum of Aliphatics			3.953	4.9347	4.0105	4.4699	4.342	0.1118	38.8261	
Total Hydrocarbon			12.926	14.2976	12.3745	13.3109	13.2273	4.7948	2.7587	
GRO (C5 to C10)			8.082	8.9337	7.85	8.503	8.3422	3.7653	2.2155	
DRO (C10 to C21)			4.794	5.3389	4.4995	4.7829	4.8538	1.0295	4.7149	
RRO (C21 to C35)			0.05	0.025	0.025	0.025	0.0313	4.86E-09		
TAH (BTEX)			4.465	4.481	4.213	4.399	4.3895	3.6453	1.2042	

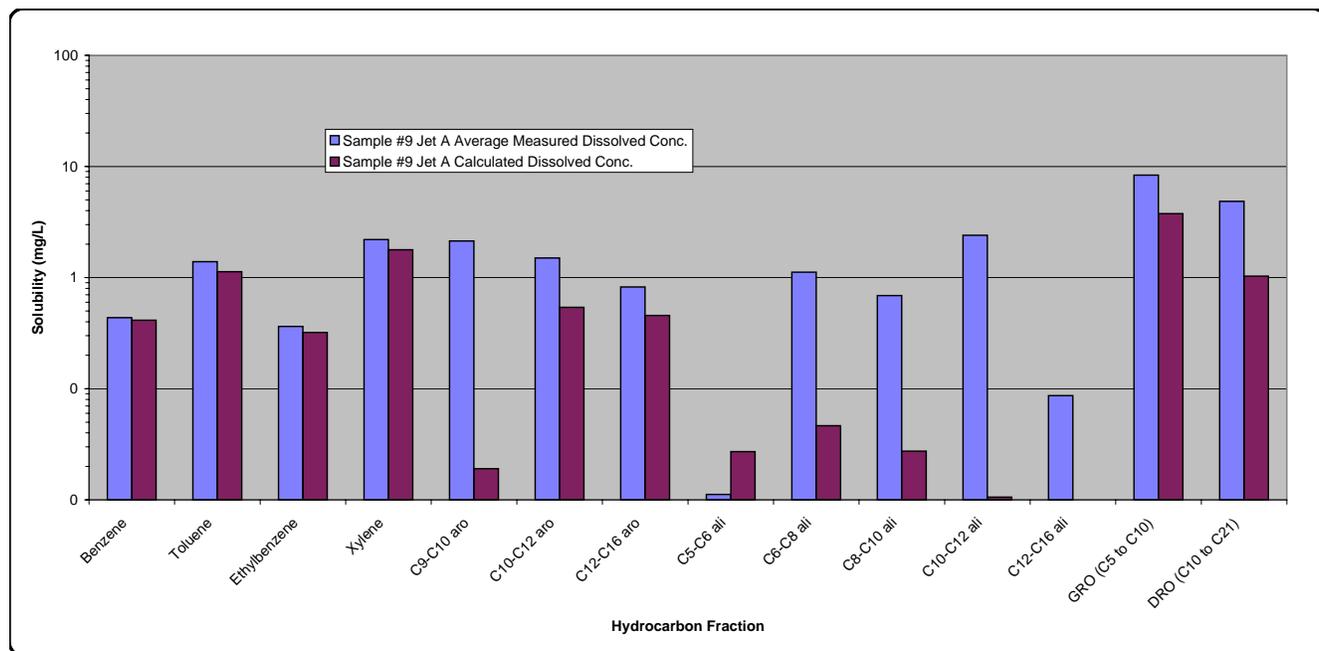


Figure 19 Comparison of Calculated and Measured Dissolved Concentrations Sample #4 DF1

Aromatic Fractions	Median Equivalent Carbon	Single Component Solubility (mg/L)	Measured Dissolved Conc. (mg/L)	Average Measured Dissolved Conc. (mg/L)	Calculated Dissolved Conc. (mg/L)	Ratio of Measured to Calculated Concentrations (measured/calculated)	Ratio of measured solubility to pure phase solubility (measured/pure phase)			
			Sample #4 DF1 W 5A	Sample #4 DF1 DB 5B	Sample #4 DF1 W 5E	Sample #4 DF1 DB 5F	Sample #4 DF1 (Jet A) Average Measured Dissolved Conc.	Sample #4 DF1 (Jet A) Calculated Dissolved Conc.		
Benzene	6.5	1750	0.795	0.767	0.779	0.8	0.7853	0.9793	0.8019	4.49E-04
Toluene	7.58	526	1.92	1.9	1.87	1.98	1.9175	2.112	0.9079	0.0036
Ethylbenzene	8.5	169	0.44	0.456	0.427	0.471	0.4485	0.4037	1.1111	0.0027
Xylene	8.63	161	2.78	2.88	2.69	2.96	2.8275	2.3325	1.2122	0.0176
C9-C10 aro	9.25	5.7E+01	1.74	1.964	1.673	1.959	1.834	0.0853	21.5024	0.0321
C10-C12 aro	10.5	3.1E+01	1.08	1.23	1.05	1.22	1.145	0.9872	1.1599	0.0366
C12-C16 aro	13	9.3E+00	0.863	1.09	1.28	1.34	1.1433	0.7172	1.594	0.1225
C16-C21 aro	16.5	1.9E+00	0.0449	0.06	0.0745	0.057	0.0591	0.053	1.1158	0.0305
C21-C35 aro	25	6.6E-03	0.0125	0.0125	0.0125	0.025	0.0156	4.40E-07		
Sum of Aromatics			9.6754	10.3595	9.856	10.812	10.1757	7.6701	1.3267	
Aliphatic Fractions										
C5-C6 ali	5.5	3.0E+01	0.0062	0.0052	0.0047	6.00E-04	0.0042	0.0277	0.1511	1.40E-04
C6-C8 ali	7	4.5E+00	1.58	1.64	1.53	1.65	1.6	0.0593	26.963	0.3582
C8-C10 ali	9	3.5E-01	0.512	1.16	0.852	0.7	0.806	0.0392	20.5626	2.2716
C10-C12 ali	11	2.8E-02	1.54	1.71	1.45	1.68	1.595	0.009	177	56.5927
C12-C16 ali	14	6.3E-04	0.0355	0.148	0.0595	0.025	0.067	2.21E-04		
C16-C21 ali	16.5	1.1E-06	0.0125	0.0125	0.0125	0.025	0.0156	5.26E-08		
C21-C35 ali	25	1.3E-11	0.0125	0.0125	0.0125	0.025	0.0156	7.87E-16		
Sum of Aliphatics			3.6987	4.6882	3.9212	4.1056	4.1034	0.1355	30.2839	
Total Hydrocarbon			13.3741	15.0477	13.7772	14.9176	14.2792	7.8056	1.8294	
GRO (C5 to C10)			9.7732	10.7722	9.8257	10.5206	10.2229	6.039	1.6928	
DRO (C10 to C21)			3.5759	4.2505	3.9265	4.347	4.025	1.7666	2.2784	
RRO (C21 to C35)			0.025	0.025	0.025	0.05	0.0313	4.40E-07		
TAH (BTEX)			5.935	6.003	5.766	6.211	5.9788	5.8274	1.026	

