FINAL REPORT

AQUATIC INJURY ASSESSMENT

M/T ATHOS 1 OIL SPILL, DELAWARE RIVER SYSTEM

Prepared by:

Aquatic Technical Working Group

21 June 2007

PREFACE

This report was prepared by the Aquatic Assessment Team for the *M/T Athos* oil spill. Membership included the following agencies and individuals:

Delaware Department of Natural Resources and Environmental Control – Rob Hossler, Rick Greene, Stewart Michels, Craig Shirey

New Jersey Department of Environmental Protection – David Bean, Tom Baum

Pennsylvania Department of Environmental Protection – Mike Boyer

National Oceanic and Atmospheric Administration – Jim Hoff, Joe Steinbacher, Kate Clark, Simeon Hahn

U.S. Fish and Wildlife Service – Fred Pinkney

Industrial Economics, Inc. – Ann Shellenbarger Jones, Michael Donlan

Polaris Applied Sciences, Inc. – Greg Challenger

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

On 26 November 2004, the *M/T ATHOS I (Athos)* struck a submerged anchor that punctured the vessel's bottom, resulting in the discharge of nearly 265,000 gallons of crude oil into the Delaware River and nearby tributaries (NOAA 2006). Subsequent shoreline surveys documented the presence of oil along 280 miles of shoreline in the mainstem of the Delaware River, as well as in tributaries within the spill area.

The oil from the *Athos* was a heavily biodegraded crude oil that had the potential to adhere to sediments and lose buoyancy (Michel *et al*. 2004). Polycyclic aromatic hydrocarbons (PAHs) composed approximately 0.6% of the oil, with the remaining product (95%+) primarily an unresolved complex mixture. Potential pathways of injury to aquatic organisms associated with the release of this oil include (1) physical smothering and fouling effects from oil and (2) toxicity (including impacts on survival, reproduction, and growth) due to various constituents of the oil.

To assess injuries to aquatic resources, the Trustees focus on potential impacts to sediment-dwelling biota, for several reasons. Field data confirm that benthic resources were exposed to and impacted by spilled oil. Field data do not provide evidence of significant fish kills, and low concentrations of oil constituents were observed in water samples and water column biota. The characteristics of the spilled oil (a heavily biodegraded crude oil) and its behavior in the environment (e.g., tendency to adhere to sediments and not refloat) suggest that potential benthic impacts are of particular concern. In addition, sediment-dwelling biota are a key component of the aquatic food web, as they are an important source of energy for fish and aquatic-dependent wildlife.

Both intertidal and subtidal sediment samples were collected in the three weeks following the incident. Of the 28 subtidal sediment samples, four were collected near Tinicum Island, ten at Marcus Hook and points south, five above the Tacony-Palmyra Bridge, and nine in tributaries. The highest total PAH concentration observed in subtidal sediments (calculated based on the levels of 13 parent PAHs as per NOAA's National Status and Trends (NS&T) methods) was 12.9 mg/kg dry weight (DW) in Woodbury Creek. Subtidal sediment samples collected near Tinicum Island (west and south of the island) had NS&T total PAH concentrations between 0.3 and 5.9 mg/kg DW. Eleven intertidal sediment samples were collected from Crosswicks Creek, NJ, at the Tacony-Palmyra Bridge, in Raccoon Creek, NJ, and on Tinicum Island, PA. Intertidal samples at Tinicum (on the eastern edge of the island) had NS&T total PAH concentrations between 15.0 and 24.4 mg/kg DW.

The Trustees also collected subtidal sediment samples for a sediment quality triad study at Tinicum Island, Claymont, and Pea Patch Island approximately one and three months after the incident. The sediment samples collected in the vicinity of Tinicum Island were toxic to amphipods on both dates (as indicated by control-adjusted survivals of 39 and 62 percent, respectively), while samples collected at the locations more distant from the spill origin did not exhibit toxicity that was significantly different from control samples. The samples collected near Tinicum presented both sheening and odor. Chemical analysis for PAHs was conducted on the two sediment samples from Tinicum, and NS&T total PAH levels of 14.0 mg/kg DW and 6.8 mg/kg DW were found at one and three months after the incident, respectively. Based on PAH toxicity, neither sample was predicted to be acutely toxic, while the earlier sample was predicted to exhibit chronic toxicity to benthic biota. The sediment toxicity test does not specify the cause of mortality, which could arise from physical impacts, toxicity due to PAHs, UCM, or other components of the spilled oil, and/or some other cause.

Subtidal sediment sampling was conducted in September 2005 to evaluate the potential extent of oiling 10 months after the release and evaluate the potential for longer term ecological injuries. A random stratified sampling plan was developed to collect samples that would be statistically representative of specific areas. In total, 162 sediment samples were collected between upstream of the Schuylkill River and downstream of the Delaware Memorial Bridge, covering approximately 20,000 acres (30 square miles). Screening PAH concentrations were determined for all samples using an ultraviolet fluorescence method, and for twenty of the sediment samples, complete laboratory PAH and total organic carbon analyses were conducted. The results from the laboratory were used to estimate total PAH concentrations (i.e., based on the levels of the 13 parent PAHs) from the screening PAH concentrations for the remaining dataset. These levels were compared to estimates of the chemistry-toxicity relationship identified from prior sets of matched sediment chemistry and toxicity data.

Forensic petrochemistry analysis provided by the responsible party (Appendix B) suggests that, based on PAH distributions, samples collected 10 months after the spill generally have less than ten percent *Athos* oil in them, although one sample is estimated to have 15-20 percent *Athos* oil contributing to its PAH profile. While this information has been considered by the Trustees, additional fingerprinting analyses have not been conducted because: 1) available information suggests that multiple pathways contributed to estimated injuries, including physical effects as well as toxicity from PAHs, UCM and/or other components of the oil; 2) estimated spill-related injuries are low 10 months after the spill, consistent with a modest contribution from *Athos* oil as suggested by RP fingerprinting analysis; and 3) few (four) subtidal samples were collected in earlier post-spill periods from the heavily oiled geographic areas that are the focus of this injury analysis. In the Trustees' judgment, further analysis on this or other topics is not warranted given the relatively modest injury quantification estimated in this analysis and the limited likelihood that additional time, effort and expense will substantially improve the precision of associated estimates.

The Trustees used a multi-step process to apply the HEA methodology to aquatic resource injury quantification for this spill. First, the spatial extent of injury was estimated, based on the simplifying assumption that subtidal impacts were most likely to occur in areas adjacent to heavy shoreline oiling, which is consistent with available VSORS and sediment toxicity data. This approach resulted in a total injury area of 412 acres. Next, based on background contamination and toxicity data from prior studies, the Trustees identified a baseline service loss of 10 percent. Service losses were then estimated for different periods following the spill based on toxicity tests, PAH levels, and benthic community information, and from which the Trustees developed a recovery curve for the affected area. Based on this approach, the Trustees believe that baseline conditions (i.e., no spill-associated service losses) were reached in 14 months, with a substantial impact on productivity in the months immediately following the spill, and the need for some additional generations of benthic biota (many of which turn over every few months) to recover from the initial impact and the likely low levels of longer term toxicity associated with the spill. Finally, HEA calculations were performed using relevant inputs from the above analyses to estimate aquatic resource losses using a discounted service acre years (DSAY) metric. Table ES-1 presents the HEA parameters and the total discounted injury to subtidal resources (97 DSAYs).

Table ES-1 HEA Parameters for Estimated Subtidal Injury		
Injury Parameter	**Value**	**Source/Notes**
Injury Area: Acres with Substantial Subtidal Oiling	412	Subtidal Zones adjacent to Heavily Oiled Shoreline (to 18' depth contour)
Background Service Loss	9.9%	Hartwell *et al*. 2001, Mid-river region
Duration of Injury	14 Months	
Recovery Curve Shape	Linear	Non-continuous at Month 3
Discount Rate	3%	Standard rate used in NRDA analyses
Service Loss Anchor Points		(*Athos*-related Injury)
Month 1 (Day 19)	51%	Triad Sample at Tinicum
Month 3 (Day 83)	28%	Triad Sample at Tinicum
Month 10 (Day 295)	10%	September 2005 Sediment Sampling Results
Results		
Total DSAYs of Injury (subtidal)	97 DSAYs	

1 INTRODUCTION

1.1 Background

On 26 November 2004, the *M/T ATHOS I (Athos)* struck a large, submerged anchor while preparing to dock at a refinery in Paulsboro, New Jersey. The anchor punctured the vessel's bottom, resulting in the discharge of nearly 265,000 gallons of crude oil into the Delaware River and nearby tributaries (NOAA 2006). The incident affected a variety of natural resources, including subtidal habitats and sediment-dwelling organisms.

Under the Oil Pollution Act, the states of Delaware and New Jersey, the Commonwealth of Pennsylvania, the U.S. Fish and Wildlife Service on behalf of the Department of the Interior, and the National Oceanic and Atmospheric Administration on behalf of the Department of Commerce (collectively referred to as the Trustees), are responsible for assessing natural resource losses resulting from this incident and restoring those losses to baseline conditions (i.e., the condition that would have existed had the incident not occurred). The Trustees are working cooperatively with representatives of the responsible party (Tsakos Shipping and Trading S.A) to assess injuries through joint Technical Working Groups (TWGs). This report, prepared by the Aquatic Technical Working Group (TWG) describes the methodology, data collection, and findings on the spatial and temporal extent of injury to the subtidal and water-column habitats of the Delaware River. Industrial Economics, Incorporated (IEc), MacDonald Environmental Science Ltd. (MESL), and NewFields Environmental Forensics Practice LLC (NewFields) are providing technical assistance to the Trustees; Polaris Applied Sciences, Inc. is the technical representative for Tsakos Shipping and Trading S.A.

The organization of this report reflects key injury quantification issues. Following the Introduction (Chapter 1) are sections describing Injury Determination (Chapter 2), Injury Quantification (Chapter 3) and a Summary of Results (Chapter 4). This report also includes several appendices. Appendix A is a technical appendix that provides additional information related to the derivation of whole sediment chemistry - toxicity relationships from local and national data sets cited in this report. Appendix B provides the results of chemical fingerprinting analyses undertaken by the RP on subtidal sediment samples collected 10 months after the spill. Appendices C - F include several documents produced by the Aquatic TWG as part of damage assessment activities and cited in this analysis. Appendix H provides the calculations for the habitat equivalency analysis described in Section 3.3.

1.2 Oil Characteristics

NOAA (2006) provides the analytical results of the physical and chemical properties of the spilled oil. In general, the oil is a heavily biodegraded crude oil, mostly (95%+) comprised of thousands of compounds that are not individually quantified, but referred to generally as the unresolved complex mixture (UCM). The UCM is composed of compounds that fall into several categories, including branched alkanes and cycloalkanes, complex aromatics, resin/NSO compounds, and asphaltenes (Frysinger *et al.* 2003). Three specific sub-classes of chemicals of potential concern (COPCs) have been quantified by laboratory analysis, including: 1) monocyclic aromatic hydrocarbons (MAHs), primarily including benzene, toluene, ethylbenzene and xylenes (collectively identified as BTEX compounds); 2) polycyclic aromatic hydrocarbons

(PAHs); and 3) trace metals. MAHs (BTEX) comprise approximately 0.02% of the oil, while PAHs comprise approximately 0.6%. The metals with the highest concentrations in the source oil sample were vanadium and nickel (averaging 445 ppm and 57 ppm, respectively; n=2) (Donlan *et al*. 2005a: see Appendix C).

The fresh source oil was "evaporatively weathered" by heating it to 90°C under vacuum and less than three percent was lost by evaporation after four hours. Therefore, the weathered oil after evaporation was still expected to float. However, in the field, samples of oil were found to adhere to sediments and not refloat (Michel *et al*. 2004). Based on the low concentrations of MAH and naphthalenes, and after reviewing the GC/MS total ion chromatogram, it is highly probable that evaporative losses from this oil resulted in minimal change in product volume and density because of the relatively low proportion of these compounds in the oil. The behavior of oil-borne PAHs in the environment is generally well understood. Once released into the environment, the concentration of total PAH in the oil will decrease due to various environmental weathering processes that include volatilization, dissolution (transport of soluble hydrocarbons from the oil to the water column), and biodegradation (National Research Council 2003; Stout *et al.* 2002). The rate of weathering is dependent on many factors; however, the more soluble and volatile hydrocarbons (*e.g*., naphthalenes) may be lost within days to weeks after an oil spill, whereas the 3-6 ring PAH compounds (*e.g*., chrysenes) may persist for months to years (Donlan *et al*. 2005a: see Appendix C).

1.3 Aquatic Resources of Potential Concern

Aquatic resources of concern potentially affected by the oil spill include water column and benthic resources, ranging from interstitial-sediment dwellers to larger mobile predators. The River supports numerous adult and larval fish and shellfish, including the federally-endangered shortnose sturgeon (*Acipenser brevirostrum*) that winter in certain areas of the Delaware River. The waters around Little Tinicum Island are also known to contain high numbers of pre-spawn and spawning striped bass (*Morone saxatilis*) in April and May. The Bay supports commercial and natural oyster beds (*Crassostrea virginica*), commercial blue crab (*Callinectes sapidus*), horseshoe crab (*Limulus polyphemus*), and whelk (*Busycon* spp.) fisheries, as well as a variety of recreational fisheries. Other aquatic resources include red-bellied turtles *(Pseudemys rubriventris)* and eastern painted turtles (NOAA 2006). Amphipods (e.g., *Gammarus* spp.), aquatic earthworms (*e.g*., *Limnodrilus*), midge larvae (*e.g*., *Chironomus*) and other types of sediment infauna are commonly found within the study area (Hartwell *et al*. 2001). Observed zooplankton include a variety of copepods. Table 1 provides summary biological information for many of the resources found in benthic habitats in this region of the river.

1.4 Potential Exposure Pathways

Aquatic organisms may be injured due to smothering effects from oil or from toxicity due to various constituents of the oil. Significant physical impacts associated with smothering and fouling are possible. Analysis during the spill response indicated that the heavy crude oil had the potential to adhere to sediments and lose buoyancy (Michel *et al*. 2004). As noted above, most of the oil (95+%) is comprised of UCM (Donlan *et al*. 2005a: see Appendix C). Such compounds can become attached to bottom sediments as a non-aqueous phase liquid (NAPL), limiting oxygen transfer and contributing to physical smothering effects (Rick Greene, personal communication). Because of the characteristics of the spilled oil, physical smothering effects are considered a potentially important mechanism of harm for this spill.

In addition to physical effects, several of the constituents present in the crude oil released during the *Athos* oil spill have the potential to have toxic effects on aquatic biota, including impacts on survival, reproduction, and growth. COPC sub-classes that have been quantified by laboratory analysis included MAHs and PAHs. While most of the oil MAHs are present in the source oil at low concentrations (approximately 0.02%) relative to other oils and typically are lost within hours to days after an oil spill (Donlan *et al*. 2005a: see Appendix C). While this class of compounds is of potential significance with respect to toxicity to water-column species immediately following the spill, the low MAH content of the oil and available field data suggest a limited potential for acute, toxic impacts to water column and benthic resources.

PAHs are associated with a wide range of effects in aquatic organisms, and comprise approximately 0.6% of the source oil (Donlan *et al*. 2005a: see Appendix C). The acute toxicity of PAHs is primarily associated with their action as non-polar narcotics. That is, PAHs tend to enter the organism and bind irreversibly to lipophilic sites within the cell. Binding to sites on cell membranes tend to disrupt surface membrane processes, inhibit ion and gas exchange, and increase the movement of water across the membrane. In fish, hypoxia and osmotic imbalances may result from impaired membrane function. In tissues, changes in membrane permeability can disrupt neurological and muscular function. Together, these effects can lead to metabolic dysfunction, immobility, and death. While non-polar narcosis is the primary mode of toxicity for PAH with three or fewer aromatic rings, many high molecular weight PAHs may also be associated with mutagenic, carcinogenic, and teratogenic effects (Eisler 1987).

While the PAH content of the source oil also is low relative to other oils, if present in sufficient concentrations it could have toxic effects. Additionally, high-molecular weight PAHs within the oil can persist for months to years in the environment, increasing the opportunity for chronic exposure of organisms to toxic compounds in the oil (Donlan *et al*. 2005a: see Appendix C). The estimated narcotic potency of the PAH mixture was 41.9 acute toxicity units and 213 chronic toxicity units. About 33 percent of this toxicity was due to naphthalenes, another 37 percent was due to fluorenes and phenanthrenes, 17 percent was due to dibenzothiophenes, and the balance was due to other specific PAHs (Greene 2005a: See Appendix F). Although little information is available on the toxicity of UCMs, there is some toxicological data available that suggests that these substances may contribute to the toxicity of crude oil (*e.g*., Neff *et al*. 2000, Donkin *et al*. 2003).

Aquatic resources in the Delaware river were potentially exposed via all of the above pathways (i.e., physical smothering effects as well as toxic effects associated with the UCM, PAHs, and/or other components of the spilled oil), through transport of the oil and its residues from the incident site. Trustee analyses take into account these multiple pathways of potential harm.

1.5 Post-Spill Data Collection

In the weeks and months following the incident, a variety of data were collected to assess potential spill-related impacts to aquatic resources. Data collected by the Trustees and RP to facilitate injury assessment are briefly summarized below. Additional, more detailed information is available in the cited documents.

1.5.1 Water Chemistry

In the first two weeks following the incident, 66 surface water and 13 bottom water samples were collected to characterize PAH concentrations. One sample had a total PAH concentration of 26,634 ng/L (near Marcus Hook), but the remaining samples all measured less than 5,000 ng/L total PAH (NOAA 2006).[1]

1.5.2 Submerged Oil Surveys

Submerged oil was confirmed in locations near the discharge origin in the first two weeks following the incident, using Vessel-Submerged Oil Recovery System (V-SORS) monitoring.[2] In particular, the heaviest subtidal oiling noted with V-SORS was on the south side of Tinicum Island. Additionally, two trenches containing pooled oil were found near the discharge site, covering an approximate area of 317 square feet. Snare samplers were deployed at various locations within the River and visually inspected for the presence of oil with depth, and the amount of oil on the snare (estimated as percent coverage). In general, most of the subsurface, mobile oil occurred several feet off the bottom, though small amounts of oil were present on the snares suspended in the middle and upper water column. Highest amounts of oil were detected by snares around Tinicum Island (Michel *et al*. 2004).

1.5.3 Shoreline Surveys

Shoreline Cleanup Assessment Team (SCAT) surveys identified and classified shoreline oiling between the Tacony-Palmyra Bridge and the mouth of the Delaware Bay.[3] In total, oiling was noted on approximately 280 miles of shoreline in the mainstem of the Delaware River. Substantial additional oiling was noted in tributaries (Shoreline Assessment Team 2006). Tarballs, tarmats, and similar products of discharged oil have been observed and collected that, based on laboratory analysis, appear to be associated with the *Athos* incident (Coast Guard 2006).[4]

Search teams surveying oiled shorelines recovered 25 dead fish, including two bullhead catfish (*Ameiurus nebulosus)*, five striped bass, fifteen white perch (*Morone americana)*, and one

---

[1] Two values are given in the laboratory data for sample WMH #1-S (also listed as WMH #1-5) from Marcus Hook. The two values are 26,634 ng/L and 293 ng/L. Only one sample is listed in the collection log and the laboratory chain of custody. The disparity may be due to particulate oil in the sample or to a laboratory error, but no explanation for the duplication or description of the sample is provided.

[2] The Vessel-Submerged Oil Recovery System (V-SORS) consists of a pipe with attached chains and snare. The V-SORS is towed behind a vessel on the bottom at slow speeds. It is pulled up regularly and inspected for oil.

[3] While most of the specified length was canvassed, oiling was only noted between the Betsy Ross Bridge and just south of the Smyrna River.

[4] Samples also were analyzed by the Coast Guard that appear to be from other, non-*Athos* sources.

gizzard shad (*Dorosoma cepadianum*) that were oiled to varying degrees (E. Marek, personal communication[5]). Necropsies or other cause of death analysis would be required to determine the cause of mortality of these fish and when these fish were exposed to oil (*e.g.*, pre- or post-mortality) (NOAA 2006).[6]

1.5.4 Fish and Oyster Tissue Chemistry

Fish and oyster samples were collected from the Delaware River within three weeks of the incident. The Trustees and RPs collected oysters (*Crassostrea sp.*), perch, catfish, and gizzard shad from the Delaware River for tissue analysis (fillet and whole-body) to determine potential risks to fish and shellfish based on contaminant body burden and to piscivorous wildlife that might consume the tainted fish and shellfish (*e.g.*, aquatic mammals such as river otters, as well as birds such as ospreys, eagles, belted kingfishers, and great blue herons). Concentrations of total PAHs in oyster tissue from 7 and 9 December 2004 ranged from 15.7 to 28.5 ng/g wet weight (WW). Fish samples collected on 9 and 16 December 2004 ranged from 88.9 to 464.3 ng/g tPAH WW (whole body, catfish); 72.1-238.9 ng/g tPAH WW (fillet, perch and shad); and 205.6 to 1143.6 ng/g tPAH WW (carcass, perch and shad). Later samples were also collected. Oyster samples from February 2005 had total PAH concentrations ranging from 12 to 29 ng/g WW. Fifteen striped bass were also collected in May and July 2005 from the Delaware Bay and the Delaware River near Tinicum Island and north of the Schuylkill River. The average total PAH concentrations ranged from 9.7 to 130.6 ng/g WW for fillets and 11.5 to 291.5 ng/g WW for carcasses of striped bass (NOAA 2006).

Lipid-normalized concentrations of PAHs in all fish samples are below the threshold for PAH-induced narcosis in fish (Di Toro *et al*. 2000). Oyster and fish tissue PAH levels (specifically benzo[a]pyrene) were below thresholds of concern for human health and bioaccumulation in piscivorous mammals (Sample *et al*. 1996).[7] While further analysis of these data would be necessary to determine the nature and extent of *Athos* oil in the samples, such analysis was not pursued since no samples exceeded thresholds of concern.

1.5.5 Sediment Chemistry

Both intertidal and subtidal sediment samples were collected in the three weeks following the incident. During this time period, 28 subtidal sediment samples were collected throughout the River and analyzed to characterize PAH concentrations. Four of these subtidal samples were collected near Tinicum Island, ten at Marcus Hook and points south, five above the Tacony-Palmyra Bridge, and nine in tributaries (Mantua Creek, Woodbury Creek, and Big Timber Creek). Eleven intertidal sediment samples were collected from Crosswicks Creek, NJ, at the Tacony-Palmyra Bridge, in Raccoon Creek, NJ, and at Tinicum Island. Of the 28 subtidal sediment samples collected during the weeks immediately following the spill, the highest total

[5] Eric W. Marek, Special Agent, USFWS, Office of Law Enforcement, Elizabeth, NJ.

[6] A baseline number of dead fish that might be expected to be found during routine shoreline surveys is not available.

[7] In a conservative risk analysis, the total PAH concentration was compared to the benzo[a]pyrene threshold to compensate for the B[a]P toxicity equivalents from other PAHs.

PAH concentration observed (calculated based on the levels of 13 parent PAHs as per NOAA's National Status and Trends (NS&T) methods) was 12.9 mg/kg dry weight (DW) in Woodbury Creek.[8] Subtidal sediment samples provide a limited overview of the potential degree and spatial extent of oiling in the Delaware River mainstem, the relevant area for this injury report. With the exception of the four samples near Tinicum Island, the subtidal samples were either collected in tributaries (area covered by the Shoreline TWG) or outside the area that appears to be most affected by the discharge (e.g. south of Marcus Hook, north of the Tacony-Palmyra Bridge) (NOAA 2006). Subtidal sediment samples collected at Tinicum (west and south of the island) had NS&T total PAH concentrations between 0.3 and 5.9 mg/kg DW. Intertidal samples at Tinicum (on the eastern edge of the island) had NS&T total PAH concentrations between 15.0 and 24.4 mg/kg DW.[9]

To help further assess potential impacts to aquatic resources, approximately 10 months after the spill the Trustees collected sediment samples from 162 sites (primarily from depositional areas adjacent to heavily and moderately oiled shoreline habitats), and performed an initial PAH screening on all samples with UVF spectroscopy (IEc and MESL 2005: see Appendix E). Total PAH concentrations ranged from less than one part per million (ppm) up to 744 ppm in these samples.[10] The majority of samples had low total screening PAH concentrations: 52 below 5 ppm and an additional 76 below 20 ppm. Only 15 samples have screening values above 100 ppm. Most samples exhibiting very high PAH concentrations in the screening test were soft, silty sediments from sites within depositional areas, with an odor indicating the presence of petroleum products. Twenty samples were sent to the Texas A&M Geochemical and Environmental Research Group (GERG) laboratory for further analysis. The results of laboratory analyses using GC/MS indicated that total PAH concentrations ranged between 1.5 ppm and 32 ppm. TOC values ranged between 1.13 percent and 7.25 percent, with an average of 2.93 percent (IEc and MESL 2005: See Appendix E).

Forensic petrochemistry analysis provided by the responsible party (Appendix B) suggests that, based on PAH distributions, samples collected 10 months after the spill generally have less than ten percent *Athos* oil in them, although one sample is estimated to have 15-20 percent *Athos* oil contributing to its PAH profile (see Appendix B).

---

[8] The NS&T total PAH value is used for subtidal and intertidal sediment chemistry results to allow comparison with field-based toxicity thresholds identified in the technical literature (Field *et al*. 2002). Appendix A discusses the development of ecological injury calculations based on the relationship between the NS&T total PAH value and observed amphipod mortality, as derived from a national database. Compounds included in NS&T total PAH calculations and in laboratory total PAH calculations are listed in Table 2. Using laboratory total PAH values calculated as the sum of 51 PAHs, subtidal samples ranged from 0.2 to 24.0 mg/kg tPAH DW and intertidal samples ranged from 0.9 to 44.0 mg/kg tPAH DW.

[9] Laboratory total PAH values for the subtidal samples at Tinicum were between 0.5 and 12.8 mg/kg DW and for intertidal were between 27.8 and 44.0 mg/kg DW.

[10] Based on the calibration study performed on sediment samples collected during the preassessment activities, UVF PAH screening values appear to generally overstate the PAH concentration by a factor of 2 to 3, with a factor of up to 10 possible in areas with high concentrations of organic matter.

1.5.6 Sediment Toxicity Tests

Sediment samples were collected for a sediment quality triad study at Tinicum Island, Claymont, and Pea Patch Island approximately one and three months after the incident.[11] The sediment samples collected in the vicinity of Tinicum Island (at the eastern end of the island, Figure 1a) approximately one month (19 days) and three months (83 days) after the incident were toxic to amphipods on both dates (as indicated by control-adjusted survivals of 39 and 62 percent, respectively), while samples collected at locations more distant from the spill origin did not exhibit toxicity that was significantly different from control samples (EA Engineering 2005b, 2005c).[12] Chemical analysis for PAHs was conducted on the two sediment samples from Tinicum, and NS&T total PAH levels of 14.0 mg/kg DW and 6.8 mg/kg DW were found at one and three months after the incident, respectively.[13] Based on PAH toxicity, neither sample is predicted to be acutely toxic, while the earlier sample is predicted to exhibit chronic toxicity to benthic biota. The sediment toxicity test does not specify the cause of mortality, which could arise from physical smothering and/or toxicity pathways.

1.5.7 Aquatic Resource Monitoring

The Trustees also monitored DNREC's juvenile and adult fish trawl surveys between March and September 2005. As of September 2005, 234 juvenile fish surveys (39 stations x 6 months) and 63 adult fish surveys (9 stations x 7 months) were made and no oil was observed in trawls conducted adjacent to the Delaware shoreline. Striped bass young of year surveys conducted by NJDEP were also monitored. As part of annual effort in the Delaware River since 1980, thirty-two fixed stations are sampled twice a month from June through November. During the 2005 seining surveys, some type of oil was observed at most stations from Raccoon Creek to Eagle Point (NOAA 2006). During warm and hot days, small (dime-sized or smaller) oil globules were observed in the shallow waters. These globules would dissipate to a sheen and eventually completely dissociate when disturbed. While tarballs are occasionally observed during surveys in other years, oil globules are not common. Following the 1989 Presidente Rivera spill near Marcus Hook, tar was also observed during seining surveys near Raccoon Creek (T. Baum, written communication[14]).

Twenty-three dredge tows were made in the upper Delaware Bay on 18 March 2005 by DNREC to collect and observe horseshoe crab and knobbed whelks. Sampling was conducted

[11] Samples were also collected three days after the incident at Claymont/Oldmans Point and Pea Patch Island, and showed no significant toxicity to amphipods (*Leptocheirus plumulosus*) relative to control in 10-day whole sediment toxicity tests (endpoint: survival) (EA Engineering 2005a: Included as Appendix G). The "one month" sample was collected 19 days after the incident on December 15, 2004 and the "three month" sample was collected 83 days after the incident on February 17, 2005. In calculations, the exact date is used.

[12] The presence of oil was confirmed in the Tinicum Island sediment samples based on sheening and odor (EA Engineering 2005b, 2005c: Included as Appendix G). Association with the spill is based on physical proximity to the incident site, compared to the Claymont and Pea Patch Island samples, and observations of submerged oil near Tinicum Island (See Section 1.5.2).

[13] Total laboratory PAH levels of 34.9 mg/kg DW and 15.7 mg/kg DW were obtained in the one month and three month samples, respectively.

[14] Mr. Tom Baum, NJDEP. Via email, 15 June 2006.

by removing all live horseshoe crabs and whelks from half of the dredge contents. Live horseshoe crabs and whelks in the samples were counted and examined for the presence of oil. In 23 tows, a total of 136 horseshoe crabs and 477 knobbed whelks were examined. No oil was observed.

2 INJURY DETERMINATION

Multiple lines of evidence indicate that aquatic resources have been injured by the *Athos* oil spill. Under Oil Pollution Act of 1990 (OPA) regulations, injury is defined as "an observable or measurable adverse change in a natural resource or resource service".[15] To make the determination of injury, Trustees must also evaluate if an injured natural resource has been exposed to the discharged oil, and a pathway can be established from the discharge to the exposed natural resource.[16]

As noted above, aquatic resources clearly were exposed to *Athos* oil. Nearly 265,000 gallons of crude oil were spilled directly into the Delaware River. SCAT data document the presence of spilled oil along 280 miles of shoreline in the mainstem of the Delaware River. Substantial additional oiling was noted in tributaries. Submerged oil was confirmed in locations near the discharge origin in the first two weeks following the incident, using Vessel-Submerged Oil Recovery System (V-SORS) monitoring. Additionally, two trenches containing pooled oil were found near the discharge site, covering an approximate area of 317 square feet. Snare samplers were deployed at various locations within the Delaware River, and confirmed the presence of oil following the spill. Geographic (i.e., proximity to the spill source) and temporal trends in V-SORS and snare data are consistent with aquatic resource exposure to spill-related oiling. Tarballs, tarmats, and similar products of discharged oil have been observed and collected that, based on Coast Guard analysis, appear to be associated with the *Athos* incident.[17]

Analysis of available data confirms spill-related impacts to some aquatic resources, and negligible or no impacts to others.

- <u>Impacts to sediment-dwelling organisms</u> - Observations of pooled oil on the river bottom near the incident site indicate some level of ecological impact. Likewise, V-SORS and snare data indicate the presence of substantial subtidal oiling in some areas (greater than 50 percent coverage of towed snares in some cases), also consistent with some level of ecological impact. Heavy oil coverage on V-SORS and snares was particularly noted south (V-SORS) and east (snares) of Tinicum Island. While PAH fingerprinting was not conducted on recovered oil samples, the proximity, both temporally and spatially, of heavy oiling to the *Athos* spill site provides a strong association. As noted above, sediment samples collected at the eastern end of Tinicum Island approximately one month and three months after the incident were toxic to amphipods on both dates (as indicated by control-

[15] 15 C.F.R. § 990.30.

[16] 15 C.F.R. § 990.51.

[17] A variety of oiled substrates, sheens, and tarballs located near the incident site were tested. While some samples indicated a match to *Athos* oil, other samples analyzed by the Coast Guard appear to be from non-*Athos* sources.

adjusted survivals of 39 and 62 percent, respectively), while samples collected at locations more distant from the spill origin were not.

- Water column toxicity - Using chronic toxicity thresholds based on the narcotic potency of various PAHs to benthic aquatic organisms (Neff *et al*. 2005), two of 66 samples (at Marcus Hook and downstream of the mouth of the Schuylkill River) had exceedances, for both alkylated chrysenes and alkylated phenanthrene/ anthracenes. Due to the low levels found, no determination was made as to whether the PAHs were in a dissolved phase or were present in particulate oil in the water sample.

- Impacts to fish and bivalves - With respect to contamination-related risks to fish and shellfish themselves, all fish and oyster PAH concentrations were below the level of concern (3.8 μmol PAHs/g lipid) for PAH-induced narcosis (DiToro *et al*. 2000). While 25 dead, oiled fish were collected following the spill, available information is insufficient to determine if these fish died because of oiling or died prior to the spill and were subsequently oiled.

- Impacts to piscivorous wildlife - With respect to potential impacts to fish-eating wildlife that might consume contaminated fish and shellfish, total PAH concentrations in fish and oyster tissue samples were below the relevant threshold of concern (i.e., a benzo[a]pyrene threshold of concern for dietary exposure in piscivorous mammals (Sample *et al*. 1996)).[18,19]

- Human health risks associated with consumption of fish - Although analysis of human health risks are outside of the scope of natural resource damage assessments (and addressed through other regulatory authorities), we note that PAH concentrations found in fish and shellfish were below levels used for setting consumption advisories.

3 INJURY QUANTIFICATION

3.1 Overview

Habitat equivalency analysis (HEA) was used to quantify aquatic resource injuries. The principal concept underlying the HEA method is that lost habitat resources/services can be

---

[18] Total PAH concentration is used as a conservative substitute for calculating benzo[a]pyrene toxicity equivalents.

[19] A comparable published threshold in prey is not available for piscivorous birds. However, diet studies in mallards indicate that a chronic (7-month) exposure to a diet containing 4,000 mg PAH/kg food produced only the sub-lethal effect of increased liver weight (Eisler 2000). Given the significantly lower potential food-chain exposure associated with this spill (i.e., maximum observed prey concentration of approximately 1 mg PAH/kg food), risks to birds arising from PAH levels in fish and oyster tissues consumed by birds are negligible. We note that mallards may be less sensitive to the effects of petroleum contamination than other waterfowl. However, given the 4,000-fold difference between observed prey contamination levels and the sub-lethal effects threshold, risks to piscivorous birds from consumption of contaminated prey likely are minimal.

compensated through habitat replacement projects providing additional resources/services of the same type (NOAA 2000).

Under the HEA method, Trustees quantify the injury with metrics that can be used to scale appropriate compensatory restoration options. The size of a restoration action is scaled to ensure that the present discounted value of project gains equals the present discounted value of interim losses. That is, the proposed restoration action should provide services of the same type and quality, and of comparable value as those lost due to injury (NOAA 2000).

This report presents the Trustees' quantification of injuries to aquatic resources. Appropriate restoration alternatives will be scaled to this injury and evaluated in the Damage Assessment Restoration Plan (DARP). Under the HEA method, the injuries are quantified in terms of the percent loss of ecological services (compared to baseline levels) and the rate at which the lost services recover over time. Injury (percent service loss) is calculated for each year (or month) following the incident, with consideration of any restoration actions or natural recovery. Service-acres are calculated for each year, with a service-acre defined as the percent service loss multiplied by the area of the injury. Future (and past) losses are discounted relative to the current year, similar to investments, to provide discounted service-acre-years (DSAYs). These are summed from the beginning of service loss until recovery, to provide a present-day calculation of total injury.

The injury quantification is focused on potential impacts to sediment-dwelling biota, for several reasons. Field data confirm that benthic resources were exposed to and impacted by spilled oil. The characteristics of the spilled oil (a heavily biodegraded crude oil) and its behavior in the environment (e.g., tendency to adhere to sediments and not refloat) suggest that potential benthic impacts are of particular concern. In addition, sediment-dwelling biota are a key component of the aquatic food web, as they are an important source of energy for fish and aquatic-dependent wildlife. Finally, as discussed in the following sections of this report, substantial data are available that can be used to help quantify potential spill-related impacts to sediment-dwelling biota.

Although the Trustees also considered quantifying injuries to other aquatic resources in addition to sediment-dwelling organisms, available information suggests such injuries, if they occurred, are likely limited in magnitude and difficult to measure by reasonably available methods. As noted in the previous chapter, comparison of PAH concentrations in post-spill water samples to relevant PAH toxicity thresholds suggests low risk to aquatic organisms. Likewise, spill-related risks to fish (based on tissue concentrations and collections of oiled, dead fish) and piscivorous wildlife (arising from dietary exposure to PAH-contaminated prey) appear to be low.

A multi-step process was used to apply the HEA methodology to aquatic resource injury quantification for this spill. First, the Trustees evaluated the spatial extent of injury. Next, the Trustees estimated baseline services, considering the potential impacts of background contamination. The Trustees then estimated service losses for different periods following the spill and developed a recovery curve for the impacted area. Finally, HEA calculations were performed using relevant inputs from the above analyses to estimate aquatic resource losses using a discounted service acre years (DSAY) metric.

3.2 Spatial Extent of Injury

SCAT shoreline oiling data capture the movement of spilled oil in the days and weeks following the *Athos* incident. To estimate the spatial extent of injury, we made the simplifying assumption that subtidal impacts were most likely found in areas adjacent to heavy shoreline oiling, for several reasons. First, such areas are generally near the spill origin and depositional, based on information provided in Sommerfield and Madsen (2003). V-SORS tows in the vicinity of Tinicum Island, an area generally adjacent to or slightly downstream from heavily oiled shoreline locations, resulted in substantial oiling of towed snares, while tows near areas further from the spill origin and exposed to less shoreline oiling generally resulted in little to no oiling of towed snares. Toxicity testing conducted on sediment samples taken approximately one month and three months after the incident from a heavily oiled location near Tinicum Island found statistically significant differences from control samples, while testing from two other subtidal sediment locations with much less exposure to spilled oil did not. While the available toxicity data are limited in number and location, the tests add to the weight of evidence indicating likely injury in the areas near heavily oiled shorelines.

Operationally, injured areas were delineated using a Geographic Information System (GIS) computer program. Injury "polygons" were delineated from the waterward edge of the intertidal zone to the 18' depth contour in areas adjacent to heavily oiled shoreline locations. Figure 1 provides a side-by-side comparison of the injury polygons and the reported shoreline and subtidal (V-SORS) oiling. Use of the 18' depth contour as a boundary reflects the observation that the highest concentration samples from the September 2005 sediment sampling were found at depths shallower than 22'.[20] Thus, measurements of PAH contamination are used to limit that estimated horizontal extent of impact “across” the river to shallower areas that appear (based on accumulated PAH concentrations) to accumulate greater amounts of contamination, rather than simply assuming that impacts extend all the way to the navigation channel.

The Shoreline Assessment Team quantified injuries to shoreline resources, including intertidal habitats (Shoreline Assessment Team 2006). To ensure consistency in the delineation of the intertidal-subtidal boundary used in the shoreline and aquatic injury quantification analyses, and therefore avoid potential double-counting, injury polygons from both analyses were compared and the aquatic injury polygons adjusted as necessary to remove any overlap.

We did not delineate injury polygons inside the Delaware River navigational channel, although the presence of oiling on both shorelines clearly indicates cross-river movement of oil. We made this assumption primarily because benthic communities are not expected to be robust in the navigational channel due to annual dredging. In addition, September 2005 sediment samples collected in the channel several months after the spill but prior to the first post-spill dredging event did not exhibit substantial oiling. For these reasons, potential spill-related impacts in the navigational channel are expected to be limited.

[20] Readily available contours for GIS mapping are the 18' and 40' depths. All samples above 10 ppm from within the mainstem of the Delaware River were at a depth of 22' or less. Portions of the heavily oiled areas were mapped to 22' manually, with a negligible increase in area (approximately one percent) compared to the 18' calculation, due to the steep slope at depths greater than 18'. Therefore, the 18' contour was used for the calculation.

This approach results in an estimated area of impact of 412 acres. Overall, we believe this estimate of spatial extent of impact makes appropriate use of available data and is well within reasonable bounds given the volume of oil spilled, documented indications of subtidal oiling and available sediment toxicity testing information. While we recognize that some subtidal areas adjacent to heavily oiled shoreline may not have been injured by the incident, other subtidal areas adjacent to shoreline habitat exposed to less oiling may have been injured. This approach clearly avoids double-counting with shoreline injury quantification, and takes into account the potential for physical smothering effects as well as oiling-related toxicity.

3.3 Service Loss and Recovery

To develop service loss estimates, we first evaluated the baseline condition of benthic resources in the study area. In light of baseline conditions, we developed estimates of spill-related service losses approximately one month, three months and ten months after the spill, and ultimately developed a recovery curve from these "anchor" points.[21] Calculations are presented in Appendix H.

3.3.1 Baseline Service Loss

Two broad sediment PAH studies were completed in the Delaware River in the ten years preceding the *Athos* incident. Under the Environmental Protection Agency Environmental Monitoring and Assessment Program (EMAP), PAH data for 2000 and 2001 are available for the Delaware River and Delaware Bay. However, EMAP sampling sites near the spill origin were located in tributaries (Christina and Schuylkill rivers) and in the navigation channel, and so are unlikely to be representative of conditions in the mainstem Delaware River.[22]

In 1997, NOAA completed a broad triad study throughout the Delaware River and Bay to examine the spatial extent and severity of sediment toxicity (Hartwell *et al*. 2001).[23] Sediment chemistry data, including total PAHs, as well as various toxicity tests and benthic invertebrate population studies, were conducted at 81 sites from the Delaware River at Trenton, NJ to the mouth of the Delaware Bay and adjacent open ocean.[24] Seventeen sites, described as the "mid-river region" are located in the mainstem of the river in the areas closest to the incident (Raccoon Creek to Petty's Island).[25] The average total PAH concentration for these 17 sites was 3.4 ppm

[21] The HEA calculations are summed from a daily basis, and so the exact dates for the anchors (19 days, 83 days, and 295 days) are used in the calculations.

[22] For completeness, we note that mean and median PAH concentrations for the eight EMAP samples located in the Christina River, the Schuylkill River and the Delaware River navigation channel, are 2.8 ppm and 1.5 ppm, respectively.

[23] Dr. Ian Hartwell of NOAA participated in discussions with the Trustees on issues related to background contamination levels and the types and abundance of aquatic biota present in the study area.

[24] Four separate toxicity tests were conducted: 10-day amphipod mortality using *Ampelisca abdita*, sea urchin fertilization impairment, Microtox, and induction of the cytochrome p450 1A1 gene.

[25] Eighteen sites are included in the mid-river region. However, the chemistry at one site is marked by the authors as suspect, and so the site is dropped from the current analysis.

(standard deviation 2.4 ppm, maximum 8.2 ppm tPAH and minimum 0.3 ppm tPAH). Average control-adjusted survival of amphipods (*Ampelisca abdita*) was 90.1 percent in 10-day mortality tests using sediments from these sites. These data suggest that amphipod populations were slightly depressed (i.e., by 10 percent) in the study area prior to the *Athos* spill. Based on these data, we make the simplifying assumption that a 10 percent reduction in benthic service levels is associated with baseline conditions (i.e., conditions that would have existed in the absence of the spill).

In our view, it is reasonable to rely on amphipods as an indicator organism for benthic service loss estimates due to the prevalence of data regarding their sensitivity to PAHs and the presence of these organisms in the Delaware River. Amphipods (most commonly *Gammarus tigrinus*) were often found in Delaware River sediment samples taken as part of the 1997 NOAA study (Hartwell *et al*. 2001).[26] We use amphipod mortality as our endpoint due to the wider availability of data for that endpoint and because we often see a strong relationship between contaminant concentrations and 10-day amphipod toxicity tests at other sites. In addition, data from studies conducted at other PAH-contaminated sites show that this endpoint is generally as sensitive as growth and/or reproduction of marine and estuarine amphipods at PAH-contaminated sites (Farrar *et al*. 2005).

Finally, we note that our baseline service loss estimate derived from the 1997 site-specific data from the NOAA study is also generally consistent with information from a larger database of matched sediment chemistry and toxicity data collected from industrialized waterways from around the country. This finding provides additional support for the use of a 10 percent baseline service loss estimate. See Appendix A for more information.

3.3.2 Service Loss Estimate: 1 Month Post-Spill

Sediment toxicity data are available from a heavily-oiled site near Tinicum Island collected approximately one month after the spill. Amphipod control-adjusted survival was 39 percent (see Appendix G). Based on these data, we assume a 61 percent service loss (i.e., reduction in benthic productivity) one month after the spill to the estimated 412 acre area of impact (see Section 3.2 above). However, for reasons described in the previous section, baseline conditions are associated with an approximately 10 percent service loss, which we subtract from 61 percent to arrive at a 51 percent, spill-related service loss one month post-spill.

The 51 percent service loss is applied to the entire 412 acre impact area, as this area represents the Trustees' best estimate of locations exposed to the greatest amount of subtidal oiling (see Section 3.2). The toxicity test used to develop this service loss estimate was conducted with a sediment sample collected from the eastern end of Tinicum Island, an area that was heavily oiled.[27] Because sediment samples collected at two less heavily oiled locations further south were not found to be acutely toxic, the Trustees do not include subtidal areas potentially exposed to modest levels of oiling in injury calculations.

[26] Other benthic fauna commonly found in study sediment samples included various worms, midges, isopods and Asian clams and other bivalves.

[27] Laboratory personnel also reported observations of oil (sheen and odor) in the Tinicum Island sample.

3.3.3 Service Loss Estimate: 3 Months Post-Spill

Sediment toxicity data also are available from the site near Tinicum Island approximately three months after the spill. Amphipod control-adjusted survival was 62 percent (see Appendix G). Based on these data, we assume a 38 percent service loss (i.e., reduction in benthic productivity) three months after the spill to the estimated 412 acre area of impact. We subtract a 10 percent service loss to account for baseline resource conditions, and therefore arrive at a 28 percent, spill-related service loss three months post-spill. As discussed for the one month post-spill loss, the 28 percent service loss at three months post-spill is applied to the entire 412 acre impact area.

3.3.4 Service Loss Estimate: 10 Months Post-Spill

Subtidal sediment sampling was conducted in September 2005 to evaluate the potential extent of oiling 10 months after the release. A random stratified sampling plan was developed to collect samples that would be statistically representative of specific areas. For the depositional areas, a spatial grid was imposed to ensure coverage throughout the area, and a random location was chosen within each grid cell. Such an approach maximizes the ability to estimate the areal extent of contamination from the data. In the navigational channel, samples were collected at regular intervals in the study area. Samples from non-depositional areas are spread roughly evenly throughout the study area. Prior to collection, specific GPS "target" coordinates were identified for each sample. In total, 162 sediment samples were collected between upstream of the Schuylkill River and downstream of the Delaware Memorial Bridge, covering approximately 20,000 acres (30 square miles).

Screening PAH concentrations were determined for all samples using an ultraviolet fluorescence method (IEc and MESL 2005: See Appendix E). For twenty of the sediment samples, complete laboratory PAH and total organic carbon analyses were conducted.[28] The results from the laboratory were used to estimate total PAH concentrations (i.e., based on the levels of the 13 parent PAHs) from the screening PAH concentrations for the remaining dataset. Table 3 shows the estimated total PAH concentration at each sampling site. See MacDonald *et al*. (2005: See Appendix D) and IEc and MESL (2005: See Appendix E) for more information on the September 2005 sampling plan and results.

Overall, we found these data indicative of low levels of service loss at the time they were collected. Consistent with this general finding, we assigned a 10 percent spill-related service loss to the injured area 10 months after the spill. Our rationale underlying this approach is summarized below.

First, the September 2005 sediment data strongly suggest that substantial spill-related impacts were not present 10 months after the spill. Survey and analysis teams observed visual sheen and possible petroleum odor in roughly 15 percent of the sediment samples, but not heavy levels of oiling. In terms of tPAH levels, for the 20 samples analyzed in the laboratory, the

[28] The 20 samples analyzed in the laboratory included 6 of the 15 samples with the highest screening concentrations (>100 ppm tPAH), 6 of the 11 samples with the next highest screening concentrations (>35 ppm tPAH, <100 ppm tPAH), 4 of the 21 samples in the >15 ppm but < 35ppm tPAH category, and 4 of the 116 samples with screening concentrations < 15 ppm tPAH.

average total PAH (NS&T) concentration was 5.2 ppm (standard deviation 3.7 ppm, maximum 13.5 ppm and minimum 0.9 ppm tPAH).[29] For the entire 162 sample data set, the estimated average total PAH (NS&T) concentration was approximately 2.8 ppm (standard deviation 2.9 ppm, maximum 19.6 ppm and minimum 0.2 ppm tPAH).

While comparisons to available background data from Hartwell et al. (2001) need to be undertaken cautiously, tPAH concentrations generally are similar (average tPAH concentration for the 17 Hartwell sites was 3.4 ppm, standard deviation 2.4 ppm, maximum 8.2 ppm and minimum 0.3 ppm tPAH).[30] Thus, across the entire study area, sediment tPAH levels 10 months after spill are difficult to distinguish from available pre-spill sediment tPAH concentrations (recognizing that pre-spill data were collected several years prior to the spill and include almost an order of magnitude fewer samples).

However, as noted previously, the area of impact estimated for this injury quantification analysis (412 acres) is defined to include those areas expected to be exposed to the greatest amount of oiling. Given the difficulty in precisely identifying such locations to estimate the total area of impact, we make the reasonable, simplifying assumption that they are found near heavily oiled shorelines. The September 2005 data suggest that sediment samples collected 10 months after the spill within the segment of the Delaware River exposed to heavy shoreline oiling generally have higher tPAH concentrations than sediment samples from areas further from the spill origin. For example, 12 of the 15 sediment samples (80 percent) with the highest estimated tPAH concentrations were from the river segment that includes heavily oiled shoreline locations, although only about 55 percent of the sediment samples were collected from that river segment. Estimated average tPAH concentrations for samples from the river segment including heavily oiled shoreline locations were approximately 50 percent higher than those collected from locations more distant from the spill origin (3.3 vs. 2.1 ppm).

In addition, we note that the estimated 412 acre area of injury represents less than five percent of the total area sampled in the September 2005 field study. The most contaminated five percent of September 2005 samples have estimated tPAH concentrations exceeding 9 ppm, a level associated with toxic effects to amphipods (control-adjusted mortality of approximately 20 to 25 percent) based on both Hartwell et al. (2001) and national whole sediment chemistry – toxicity data sets (see Figure A-2 in Appendix A). These data sets also suggest if the spill was responsible for even a few additional ppm tPAH at such locations ten months after the spill, spill-associated increases in amphipod mortality due to PAHs would be modest but measurable. Potential chronic mortality or residual community effects related to smothering or toxicity due to other components of the oil (e.g., UCM) are not directly measured by these PAH-based estimates.

Equilibrium partitioning and narcotic potency calculations for the 20 sample subset of the 2005 field effort submitted for laboratory analysis (Greene 2005c: See Appendix F) also are consistent with low toxicity risks. The equilibrium partitioning analysis first partitions PAH mass

[29] As noted above, the subset of samples sent for laboratory analysis was not randomly selected; selected samples reflected a range of expected contamination levels (based on field screening data), although included a greater-than-proportional number of highly contaminated samples.

[30] The NS&T total PAH value and the total non-alkyl PAH value from the Hartwell study are comparable. Seven additional PAHs beyond the 13 NS&T parent PAHs are included in the Hartwell values.

between the sorbed phase (carbon coating on sediment particles) and the dissolved phase (sediment pore water). The dissolved phase concentrations are then compared to the acute narcotic toxicity for the individual compounds. The ratios for the individual compounds are then summed to produce acute toxicity units. Finally, chronic toxic units are estimated as acute toxic units divided by an acute to chronic ratio from the literature. A toxic unit greater than one indicates that the PAH exposure concentration in the sediment pore water exceeds the narcotic toxicity threshold for benthic aquatic organisms. Sample 82, near Tinicum Island, was predicted to be chronically toxic to benthic organisms based on the equilibrium partitioning-based calculations. Two additional samples (Sample 8, between Woodbury Creek and Big Timber Creek, and Sample 18, near the mouth of the Schuylkill River) had chronic toxicity units just below 1.[31]

Thus, in our view the September 2005 sediment data suggest that longer-term risks from PAH toxicity are limited, but not absent in areas of highest concentrations. In addition, it is reasonable to expect that benthic communities were continuing to recover from the initial, substantial reduction in productivity that occurred in the first few months following the spill. Overall, in light of this information, we believe it is reasonable to assign a 10 percent, *Athos* spill-related service loss 10 months after spill to the relatively limited subtidal areas believed to be most exposed to *Athos* oiling. While impacts may be higher at some locations, we need to account for reductions in benthic productivity associated with baseline conditions, and so chose what we believe to be an appropriately modest level of spill-related service loss 10 months after the spill.

Forensic petrochemistry analysis provided by the responsible party (Appendix B) suggests that, based on PAH distributions, samples collected 10 months after the spill generally have less than ten percent *Athos* oil in them, although one sample is estimated to have 15-20 percent *Athos* oil contributing to its PAH profile. While this information has been considered by the Trustees, additional fingerprinting analyses have not been conducted for several reasons. As discussed throughout this document: 1) available information suggests that multiple pathways contributed to estimated injuries, including physical effects as well as toxicity from PAHs, UCM and/or other components of the oil; 2) estimated spill-related injuries are low 10 months after the spill, consistent with a modest contribution from *Athos* oil as suggested by RP fingerprinting analysis;[32] and 3) few (four) subtidal samples were collected in earlier post-spill periods from the heavily oiled geographic areas that are the focus of this injury analysis. For completeness, the Trustees also note that the PAH constituents bar chart provided in RP comments is for Sample 18, which is not "near Tinicum Island" as labeled, but rather in the Schuylkill tributary in a particularly highly industrialized area. Injuries to tributaries are addressed in the shoreline injury report, not the aquatic injury report.

In the Trustees' judgment, further analysis on this topic is not warranted given the relatively modest injury quantification estimated in this analysis and the limited likelihood that

[31] We note that Sample 18 is in the Schuylkill tributary, and as a tributary site, any injury in that area is addressed in the shoreline injury assessment.

[32] While spill-related contributions to PAH concentrations may be low 10 months after the spill, (modest) additional injury is likely due to the fact that background PAH levels already are above injury thresholds. Thus, any incremental contamination reasonably can be expected to increase service losses.

additional time, effort and expense will substantially improve the precision of associated estimates.

3.3.5 Service Loss Recovery Curve

Figure 3 shows the recovery curve used in our analysis, and is based on linear extrapolation and interpolation around the "anchor" points described above (i.e., service losses one month, three months and ten months post-spill). The curve has two linear portions: from immediately following the incident until Month 3 and from Month 3 through Month 10, continuing at the same slope until service loss is zero. The curve suggests that baseline conditions (i.e., no spill-associated service losses) are reached in 14 months, which is generally consistent with a substantial impact on productivity in the months immediately following the spill, and the need for some additional generations of benthic biota (many of which turn over every few months) to recover from the initial impact and likely low levels of longer term toxicity.

Although the actual recovery pathway may involve non-linear processes, the Trustees adopt the simplified approach of linear approximation. Given the short time frame within which recovery is estimated to occur, use of a non-linear recovery curve would likely have a negligible effect on injury quantification.

4 SUMMARY OF RESULTS

HEA inputs and results are summarized in Table 4. The basis for most of the inputs has been described in previous portions of this document. The discount rate of three percent used in HEA calculations is a standard figure used in natural resource damage analyses. As indicated in the table, HEA calculations based on the identified parameters result in an injury of 97 discounted service acre years (DSAYs). A separate report will identify and evaluate the type and size of restoration project(s) best suited to compensate for this loss.

Overall, we believe this analysis makes reasonable use of incident-specific data as well as relevant information from technical literature to quantify spill-related injuries to aquatic resources. We considered alternative injury quantification approaches, including use of mass balance calculations to estimate the concentrations of tPAH that might have been deposited by the spill in aquatic sediment. Preliminary mass balance calculations were performed in Donlan *et al*. (2005) (see Appendix 2 of that document), and suggest that the spill could have contributed levels of PAHs consistent with the analysis presented in this document. However, in our view such an approach will not lead to a more precise or otherwise enhanced quantification of injury compared to that presented in this document, due to substantial uncertainties in key mass balance parameters. The Trustees also note that USCG and RP contractors, after considerable effort, could not reach agreement on official mass balance parameters for the spill, based on substantial disagreements and uncertainties on issues including percent recovery from oiled shorelines. Further, mass balance calculations are not suitable for consideration of potential physical effects of spilled oil.

REFERENCES

Coast Guard. 2006. Excel spreadsheet "Oil_Summary Tarmats, Tarballs, etc." 2006.

Di Toro, D.M., J.A. McGrath, D.J. Hansen. 2000. Technical Basis for Narcotic Chemicals and Polycyclic Aromatic Hydrocarbon Criteria. I. Water and Tissue. *Environmental Toxicology and Chemistry*. Vol. 19, No. 8, pp. 1951-1970.

Donkin, P., E.L. Smith, and S.J. Rowland. 2003. Toxic effects of unresolved complex mixtures of aromatic hydrocarbons accumulated by mussels, *Mytilus edulis*, from contaminated sites. *Environmental Toxicology and Chemistry*. Vol. 37, No. 21, pp. 4825-4830.

Donlan, M.C., G. Douglas, and D.D. MacDonald. 2005a. An Evaluation of the Composition, and Potential Environmental Fate and Toxicity of Heavy Venezuelan Crude Oil Released into the Delaware River During the *M/T ATHOS I* Oil Spill. Prepared for the Aquatic Technical Work Group for *ATHOS* I Spill. Prepared by Industrial Economics, Incorporated, Cambridge, Massachusetts; New Fields Environmental Forensics Practice LLC, Rockland, Massachusetts; and MacDonald Environmental Sciences Ltd., Nanaimo, British Columbia. **Included in Appendix C to this report.**

EA Engineering, Science, and Technology, Inc. 2005a. Results of Toxicity Testing with *Leptocheirus pumulosus* on Sediment Samples from the Delaware River (EA Report Number 4677, dated 27 January 2005). Report prepared for the Delaware Department of Natural Resources and Environmental Control, Division of Air and Waste Management, New Castle, DE.

EA Engineering, Science, and Technology, Inc. 2005b. Results of Toxicity Testing with *Leptocheirus pumulosus* on 17 February 2005 Sediment Samples from the Delaware River (EA Report Number 4750, dated 26 April 2005). Report prepared for the Delaware Department of Natural Resources and Environmental Control, Division of Air and Waste Management, New Castle, DE.

EA Engineering, Science, and Technology, Inc. 2005c. Results of Toxicity Testing with *Leptocheirus pumulosus* on 15 December 2005 Sediment Samples from the Delaware River (EA Report Number 4691, dated 4 March 2005). Report prepared for the Delaware Department of Natural Resources and Environmental Control, Division of Air and Waste Management, New Castle, DE.

Eisler, R. 1987. Polycyclic Aromatic Hydrocarbon Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. U.S. Fish and Wildlife Service, Laurel, Maryland.

Eisler, R. 2000. Handbook of Chemical Risk Assessment, Volume 2 (Organics), Chapter 25 (Polycyclic Aromatic Hydrocarbons). CRC Press, Boca Raton, Florida.

Exponent. 2006. NOAA Sediment Sample Analysis Summary, Chromatograms, Figures. Submitted to the Aquatic Technical Working Group. 2006.

Farrar, J.D., A. Kennedy, G. Lotufo, and C. McNemar. 2005. Comparative evaluation of the efficacy of acute and chronic sublethal sediment tests for assessing sediment quality.

United States Army Corps of Engineers. Vicksburg, Mississippi. Poster presented at SETAC 2005 conference. Baltimore, Maryland. November 2005.

Field, L.J., D.D. MacDonald, S.B. Norton, C.G. Ingersoll, C.G. Severn, D.E. Smorong, and R.A. Lindskoog. 2002. Predicting amphipod toxicity from sediment chemistry using logistic regression models. *Environmental Toxicology and Chemistry* 21(9):1993-2005.

Frysinger, G.S., R.B. Gaines, L. Xu, and C.M. Reddy. 2003. Resolving the unresolved complex mixture in petroleum-contaminated sediments. Environmental Science and Technology 37(8):1653-1662.

Greene, R. 2005a. Narcotic potency of the PAH mixture in the source oil. As presented in the Preassessment Data Report, Appendix A.6 (NOAA 2006). **Included in Appendix F to this report.**

Greene, R. 2005b. Preliminary evaluation of the risks posed by oil released from the M/T *Athos* to the Delaware River. As presented at the April 12, 2005 meeting of the Aquatic Technical Working Group. Delaware Department of Natural Resources and Environmental Control. Dover, Delaware. **Included in Appendix F to this report.**

Greene, R. 2005c. Assessment of Benthic Toxicity Associated with Polyaromatic Hydrocarbons in Aquatic Sediments of the Delaware Estuary. Submitted to the Aquatic Technical Working Group, November 23, 2005. Delaware Department of Natural Resources and Environmental Control. Dover, Delaware. **Included in Appendix F to this report.**

Hartwell, S.I., J. Hameedi, M. Harmon. 2001. Magnitude and extent of contaminated sediment and toxicity in Delaware Bay. NOS/NCOS/CCMA 148. National Oceanic and Atmospheric Administration, BioEffects Branch, Silver Spring, MD, USA.

IEc and MESL. 2005. Sediment Collection Field Data Report M/T *Athos* I Oil Spill Delaware River New Jersey, Pennsylvania and Delaware. 6 December 2005. **Included in Appendix E to this report**.

McCoy, D.L., J.M. Jones, J.W. Anderson, M. Harmon, I. Hartwell, J. Hameedi. 2002. Distribution of Cytochrome P4501A1-Inducing Chemicals in Sediments of the Delaware River-Bay System, USA. *Environmental Toxicology and Chemistry*. 21(8): 1618-1627.

MacDonald, D.D., M.C. Donlan, A. Shellenbarger Jones, C. Miller. Field Sampling Plan for the 2005 Sediment Quality Evaluation of the Delaware River Estuary. 9 September 2005. **Included in Appendix D to this report**.

Michel, J. 2004. Submerged Oil Assessment – *Athos 1* Oil Spill. Prepared by the Submerged Oil Assessment Unit Planning Section of the *Athos 1* Oil Spill Unified Command.

National Research Council. 2003. Oil in the Sea III. The National Academies Press. Washington, District of Columbia.

Neff, J.M., S.A. Strout, and D.G. Gunster. 2005. Ecological risk assessment of polycyclic aromatic hydrocarbons in sediments: Identifying sources and ecological hazards. *Integrated Environmental Assessment and Management* 1(1): 22-33

NOAA (National Oceanographic and Atmospheric Administration). 2000. Habitat Equivalency Analysis: An Overview. Damage Assessment and Restoration Program, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, 23 pp.

NOAA. 2006. Draft Preassessment Data Report, *M/T ATHOS I* Oil Spill, Delaware River, April 2006. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

Sample, B.E., D.M. Opresko, and G.W. Suter II. 1996. Toxicological benchmarks for wildlife:1996 Revision. ES/ER/TM-86/R3. Office of Environmental Management. United States Department of Energy. Oak Ridge, Tennessee.

Shellenbarger Jones, A. and M.C. Donlan. 2005. Preliminary Screening Results on Delaware River Sediment. Prepared for the Aquatic Technical Work Group for *ATHOS* I Spill. Prepared by Industrial Economics, Incorporated, Cambridge, Massachusetts.

Shoreline Assessment Team. 2006. Final Report: Shoreline Injury Assessment *M/T ATHOS 1* Oil Spill. 15 March 2006.

Sommerfield, C. K. and J.A. Madsen. 2003. Sedimentological and geophysical survey of the Upper Delaware Estuary. Delaware River Basin Commission. DEL-SG-04-04. College of Marine Studies. University of Delaware. Lewes, Delaware.

Stout, S.A., A.D. Uhler, K.J. McCarthy, and S.D. Emsbo-Mattingly. 2002. Chemical fingerprinting of hydrocarbons. *In:* Introduction to Environmental Forensics. B. Murphy and R. Morrison, Eds. Academic Press.

Table 1 Summary Of Biota Using Benthic Habitats								
Common Name	**Scientific Name**	**Life Span**	**Habitat Type**	**Seasonality**	**Breeding Period**	**Reproductive Age**	**Food Sources**	**Sources**
Benthic Macroinvertebrates								
Aquatic worms	*Limnodrilus spp. (esp. Limnodrilus hoffmeisteri)*	1-2 yrs	Silty substrates	Present all year			Organic particulate matter, sediment ingestion	7, 8
Polychaete worms	*Scolecolepides viridis*		Mud/sand soft bottom					
Midge larvae	*Chironomus spp.*	Weeks - 1 year	Mud/sand bottom in freshwater		Adults usually emerge in summer		Small particulate organic matter	7
Midge	*Procladius spp.*		Silty, sand depositional zones					8
Midge	*Polypedilum spp.*		Silty, sand depositional zones					8
Crustaceans								
Amphipod	*Gammarus spp.*	<1 year	Shallow fresh water areas	Emerge spring to fall	Feb-Oct. once per year		Omnivorous, detritus	2, 8
Amphipod	*Corophium spp.*		Mud/sand soft bottom areas					
Isopod	*Cyathura polita*	3 yrs	Estuarine variable salinity, most common at 2-7 ppt on stable substrate	Most abundant late summer-early fall	May to August		Diatoms, detritus	8
Fiddler crabs	*Uca spp.*	1 to 1.5 yrs	Tidal flats and banks in intertidal intermediate marsh zone	Present throughout the year		1 year.	Particulate organic matter in muddy substrates.	4,7,9

Table 1 (continued)

Common Name	Scientific Name	Life Span	Habitat Type	Seasonality	Breeding Period	Reproductive Age	Food Sources	Sources
Bivalves								
Small clams	*Pisidium spp.*	1-2 yrs	Mostly soft sediments		Not in winter		Detritus	8
Eastern elliptio	*Elliptio complanata*	Approx. 10-15 yrs	any permanent body of water, from quiet water and muddy bottom, to large rivers with strong current and heavy gravel and rocks	Present throughout the year	April - August			6
Asiatic clam	*Corbicula spp.*	7 yrs	Stream pools on fine, clean sand and coarse substrate	Present throughout the year	Spring to fall	2-4 months		5
Ribbed mussels	*Geukensia demissa*	15 years	Intertidal zone on peat, roots and bridge pilings	Present throughout the year	June to August	2 years		3,7
Bivalve	*Rangia cuneata*		Oligohaline soft bottom areas					1
Eastern oyster	*Crassostrea virginica*	Up to 20 years	Shallow subtidal hard substrates with a salinity range of 5-30 ppt	Present throughout the year	Spawning July and August	2 years	Suspension feeder, phytoplankton, bacteria, detritus	7

1. Ettinger, W. S. 1995. Oligohaline/Freshwater Macroinvertebrate Community, Soft (Mud/Sand) Bottom. Pages 99-103 in L.E. Dove and R.M. Nyman, eds. Living Resources of the Delaware Estuary. The Delaware Estuary Program.
2. Everett, A. 2006. Personal communication. Pennsylvania Department of Environmental Protection.
3. Franz, D.R., 2001. Recruitment, Survivorship, and Age Structure of a New York Ribbed Mussel Population (Geukensia demissa) in Relation to Shore Level – A Nine Year Study. Estuaries 24: 319-327
4. Grimes, B.G., M.T. Huish, J.H. Kerby, and D. Morgan. Species Profile: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic) -- Atlantic Marsh Fiddler. US Fish and Wildlife Service Biol. Rep 82 (11.114). US Army Corps of Engineers, TR EL-82-4. 18 pp., 1989.
5. Gulf States Marine Fisheries Commission. 2005. Fact Sheet: Corbicula fluminea (Muller, 1774). Available online: http://nis.gsmfc.org/nis_factsheet.php?toc_id=128. Accessed: February 20, 2006.
6. Ortmann, A. E. 1919. A Monograph of the Naiades of Pennsylvania. Part III. Mem. Carn. Mus. 8: 1-384.
7. Stern, D.. 1995. Copepods. Pages 33-42 in L.E. Dove and R.M. Nyman, eds. Living Resources of the Delaware Estuary. The Delaware Estuary Program.
8. TAMS Consultants, Inc. Further site characterization and analysis, Volume 2e - Baseline Ecological Risk Assessment, Hudson River PCBs reassessment RI/FS. August 1999. For U.S. Environmental Protection Agency, Region II, and U.S. Army Corps of Engineers, Kansas City District. Book 3 of 3 Appendices.
9. Virginia Tech Species Information. 1996. “Atlantic Marsh fiddler crab”. Accessed August 24, 2005 at http://fwie.fw.vt.edu/WWW/macsis/lists/M070000.htm

Table 2
Compounds Included in Total PAH and NS&T PAH Calculations
(Compounds in bold are NS&T compounds)

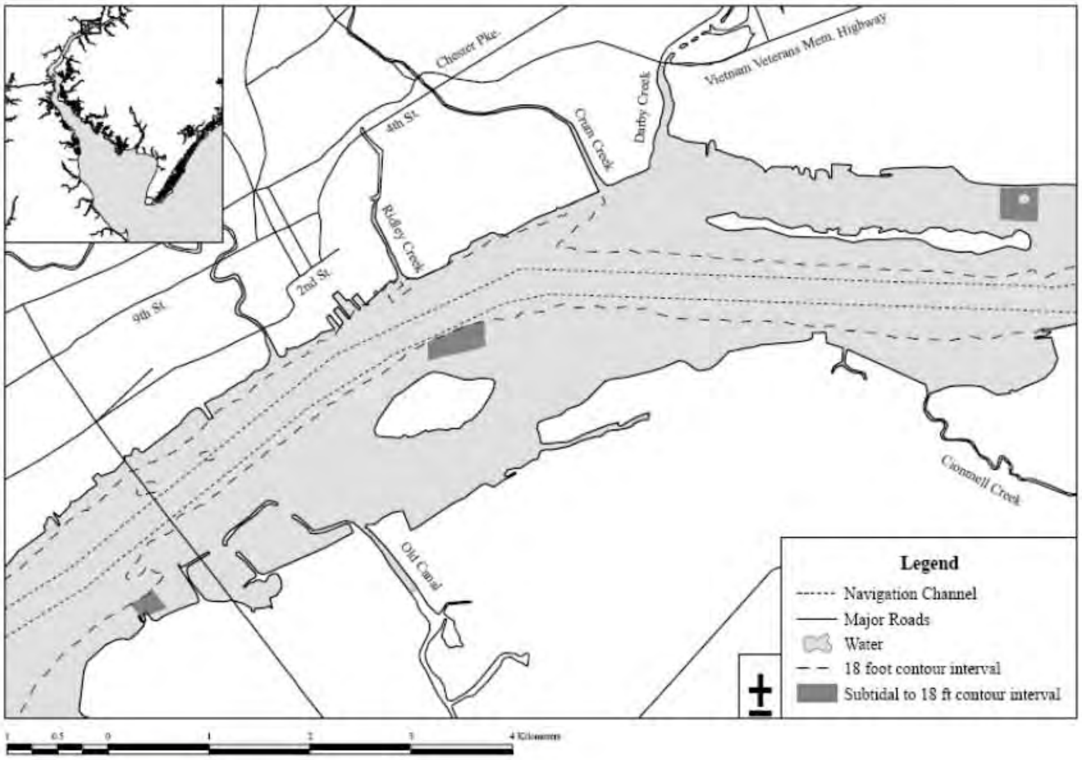
GERG Laboratories PAH List	
Naphthalene	**Fluoranthene**
C1-Naphthalenes	**Pyrene**
C2-Naphthalenes	C1-Fluoranthenes/Pyrenes
C3-Naphthalenes	C2-Fluoranthenes/Pyrenes
C4-Naphthalenes	C3-Fluoranthenes/Pyrenes
Biphenyl	**Benzo(a)anthracene**
Acenaphthylene	**Chrysene**
Acenaphthene	C1-Chrysenes
Fluorene	C2-Chrysenes
C1-Fluorenes	C3-Chrysenes
C2-Fluorenes	C4-Chrysenes
C3-Fluorenes	Benzo(b)fluoranthene
Anthracene	Benzo(k)fluoranthene
Phenanthrene	**Benzo(e)pyrene**
C1-Phenanthrenes/Anthracenes	**Benzo(a)pyrene**
C2-Phenanthrenes/Anthracenes	**Perylene**
C3-Phenanthrenes/Anthracenes	Indeno(1,2,3-c,d)pyrene
C4-Phenanthrenes/Anthracenes	**Dibenz(a,h)anthracene**
Dibenzothiophene	Benzo(g,h,i)perylene
C1-Dibenzothiophenes	
C2-Dibenzothiophenes	
C3-Dibenzothiophenes	
Measured, but not included in Total PAH	
2-Methylnaphthalene	
1-Methylnaphthalene	
2,6-Dimethylnaphthalene	
1,6,7-Trimethylnaphthalene	
1-Methylphenanthrene	

Table 3 Screening Level PAH Concentrations and Estimated NS&T PAH Concentrations					
Sample #	**Screen PAH Conc. (ppm)**	**Est. NS&T PAH Conc. (ppm)**	**Sample #**	**Screen PAH Conc. (ppm)**	**Est. NS&T PAH Conc. (ppm)**
1	1.6	0.8	44	61.1	5.4
2	0.8	0.6	45	10.8	2.2
3	1.5	0.8	46	20.1	3.0
4	171.6	9.2	47	12.9	2.4
5	2	0.9	48	352	3.8
6	1.6	0.8	49	22.7	3.2
7	7.2	1.8	50	2	0.9
8	73.3	4.9	51	12.6	2.4
9	6.1	1.6	52	121	7.7
10	3.2	1.2	53	161.4	8.9
11	3.3	1.2	54	6.6	1.7
12	3.2	1.2	55	35.4	0.9
13	47.7	7.3	56	45	4.6
14	744	19.6	58	9.4	2.1
14A	1.8	0.9	59	18.9	2.9
14B	442	15.0	60	1.3	0.7
15	9.5	2.1	61	10.8	2.2
16	21.7	3.2	62	15.1	2.6
17	8.7	2.0	63	13.6	2.5
18	47.6	13.5	64	14.4	2.6
19	0.6	0.5	65	101.1	7.6
20	10.6	2.2	67	13.5	2.5
21	12.6	2.4	68	10	2.1
22	2.8	1.1	69	15.2	2.6
23	9.3	2.0	70	127.2	7.9
24	6.4	1.7	71	3.2	1.2
26	3.3	1.2	72	14.1	2.5
27	9.1	2.0	75	16.2	2.7
28	25.6	3.4	76	4.1	1.3
29	2	0.9	77	19.6	3.0
31	111	7.3	79	14.7	3.4
32	18.8	2.9	80	1.4	0.8
33	3.8	1.3	81	3.2	1.2
34	120.6	7.5	82	31.5	12.2
37	16.3	2.7	83	6.8	1.7
38	7.8	1.9	84	16.8	2.8
39	1.8	0.9	85	3.1	1.2
40	16	2.7	86	2	1.0
42	62.2	5.4	87	3.4	1.2
43	42	1.9	88	2	0.9
43A	70.6	5.8	90	12	2.3
43B	13.6	2.5	91	211	10.2

Table 3 (continued) Screening Level PAH Concentrations and Estimated NS&T PAH Concentrations					
Sample #	**Screen PAH Conc. (ppm)**	**Est. NS&T PAH Conc. (ppm)**	**Sample #**	**Screen PAH Conc. (ppm)**	**Est. NS&T PAH Conc. (ppm)**
93	ND	0.0	1-S	6.6	1.7
94	12.6	2.4	2-S	57.9	2.5
95	16.8	2.8	3-S	1.4	0.8
97	17	3.1	5-S	0.2	0.2
98	18.8	2.9	6-S	6.1	1.6
99	2	0.9	7-S	1.7	0.9
100	2.4	1.0	8-S	27.6	3.5
102	12.2	2.4	10-S	1.2	0.7
103	10.9	2.2	11-S	9.9	2.1
105	0.5	0.5	12-S	6.3	1.7
106	7	1.8	13-S	8.7	2.0
107	0.6	0.5	14-S	1.2	0.7
109	14.7	2.6	15-S	7.2	1.8
110	1.6	0.8	16-S	1.6	0.8
111	15.7	2.7	17-S	1.2	0.7
113	1.5	0.8	18-S	1.3	0.7
114	0.8	0.6	19-S	1.9	0.9
116	176	8.4	20-S	1.4	0.8
117	9.8	2.1	21-S	201.8	5.4
118	8.3	1.9	22-S	157.85	9.6
119	12.5	2.4	23-S	7.7	1.9
120	10.9	2.2	24-S	2.8	1.1
121	12	2.3	25-S	6	1.6
122	78.6	6.1	26-S	1.5	0.8
124	96.7	2.6	27-S	3.4	1.2
125	8.2	1.9	28-S	1.8	0.9
126	9.8	2.1	29-S	2.1	0.9
127	3.2	1.2	30-S	1.4	0.8
128	11.3	2.0	31-S	6.4	1.7
129	11.6	2.3	33-S	6.5	1.7
130	9.4	2.1	34-S	7.1	1.8
131	1.4	0.8	35-S	8.7	2.0
132	8	1.9	36-S	8.1	2.3
133	282.6	11.9	37-S	6.4	1.7
134	9.1	2.0	38-S	8.1	1.9
135	7.6	1.8	39-S	5.1	1.5
136	1.7	0.9	40-S	11.2	2.3
137	10.8	2.2			
138	14.1	2.5			
139	7	1.8			
140	31.4	3.8			
Cells highlighted green indicate values determined in the laboratory (GERG).					

Table 4 HEA Parameters for Estimated Subtidal Injury		
Injury Parameter	**Value**	**Source/Notes**
Injury Area: Acres with Substantial Subtidal Oiling	412	Subtidal Zones adjacent to Heavily Oiled Shoreline (to 18' depth contour)
Background Service Loss	9.9%	Hartwell *et al*. 2001, Mid-river region
Duration of Injury	14 Months	
Recovery Curve Shape	Linear	Non-continuous at Month 3
Discount Rate	3%	Standard rate used in NRDA analyses
Service Loss Anchor Points		(*Athos*-related Injury)
Month 1 (Day 19)	51%	Triad Sample at Tinicum
Month 3 (Day 83)	28%	Triad Sample at Tinicum
Month 10 (Day 295)	10%	September 2005 Sediment Sampling Results
Results		
Total DSAYs of Injury (subtidal)	97 DSAYs	

Figure 1a - Tinicum Island area
Aquatic Injury "Polygons" Adjacent to Heavily Oiled Shoreline Areas,
Extending from Outside Edge of Tidal Flat to 18 Foot Depth Contour and Shoreline/Subtidal Oiling



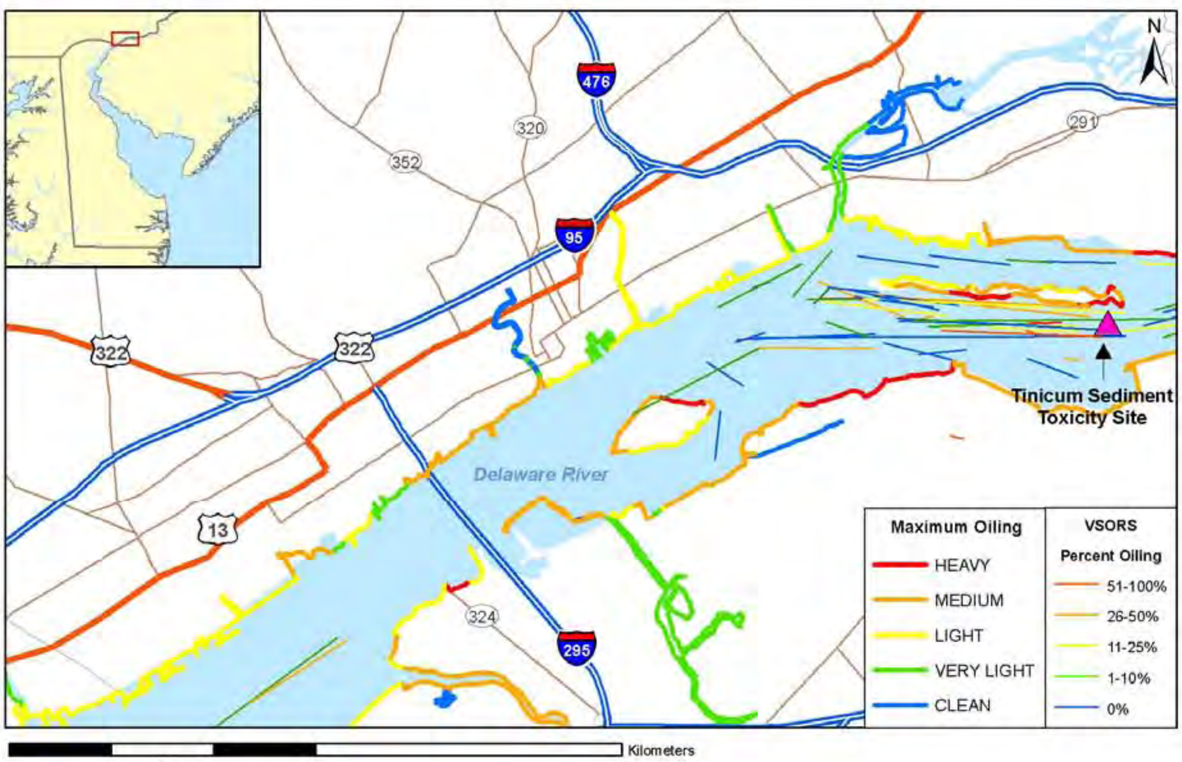


Figure 1b - Schuylkill River Area
Aquatic Injury "Polygons" Adjacent to Heavily Oiled Shoreline Areas,
Extending from Outside Edge of Tidal Flat to 18 Foot Depth Contour and Shoreline/Subtidal Oilin

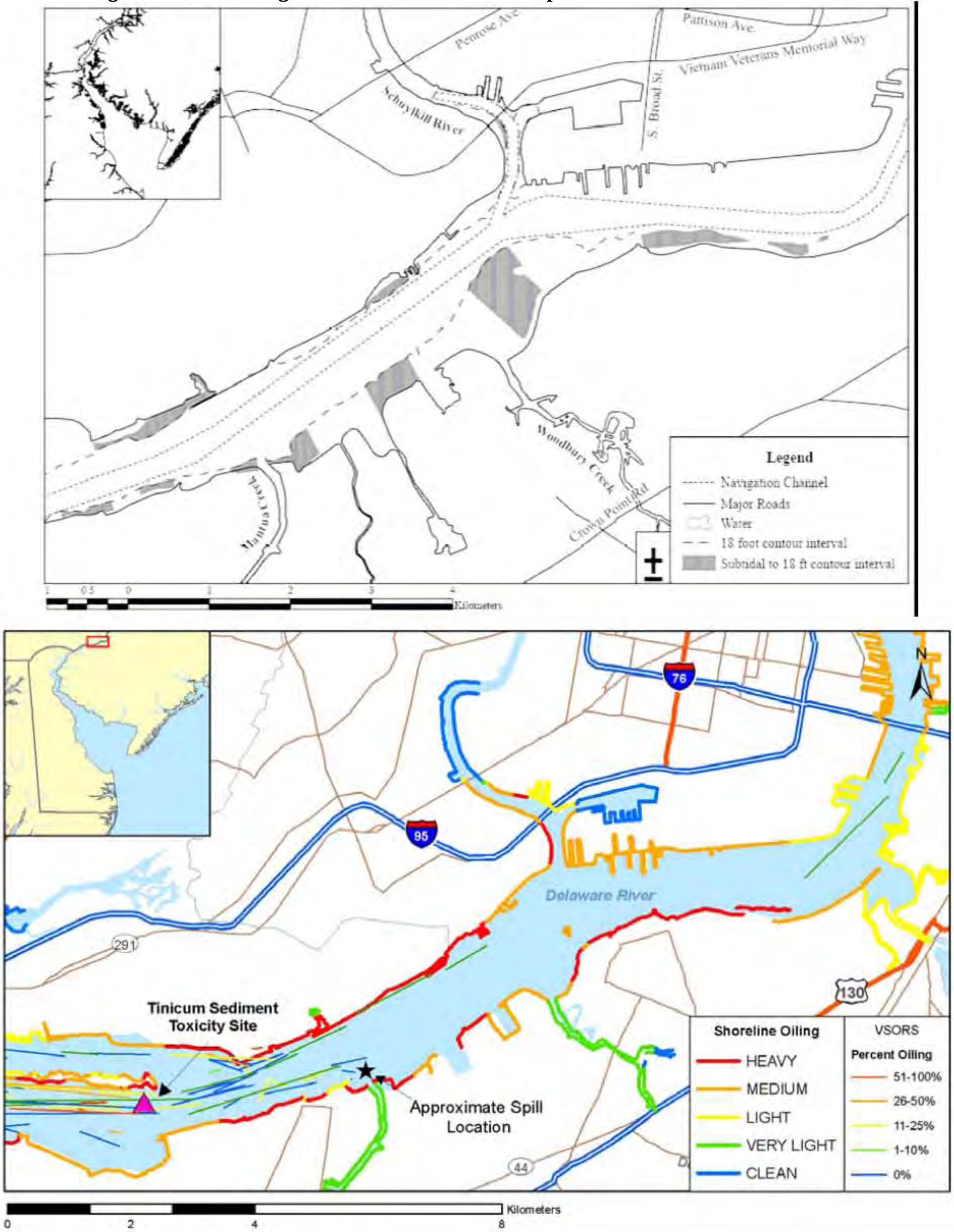
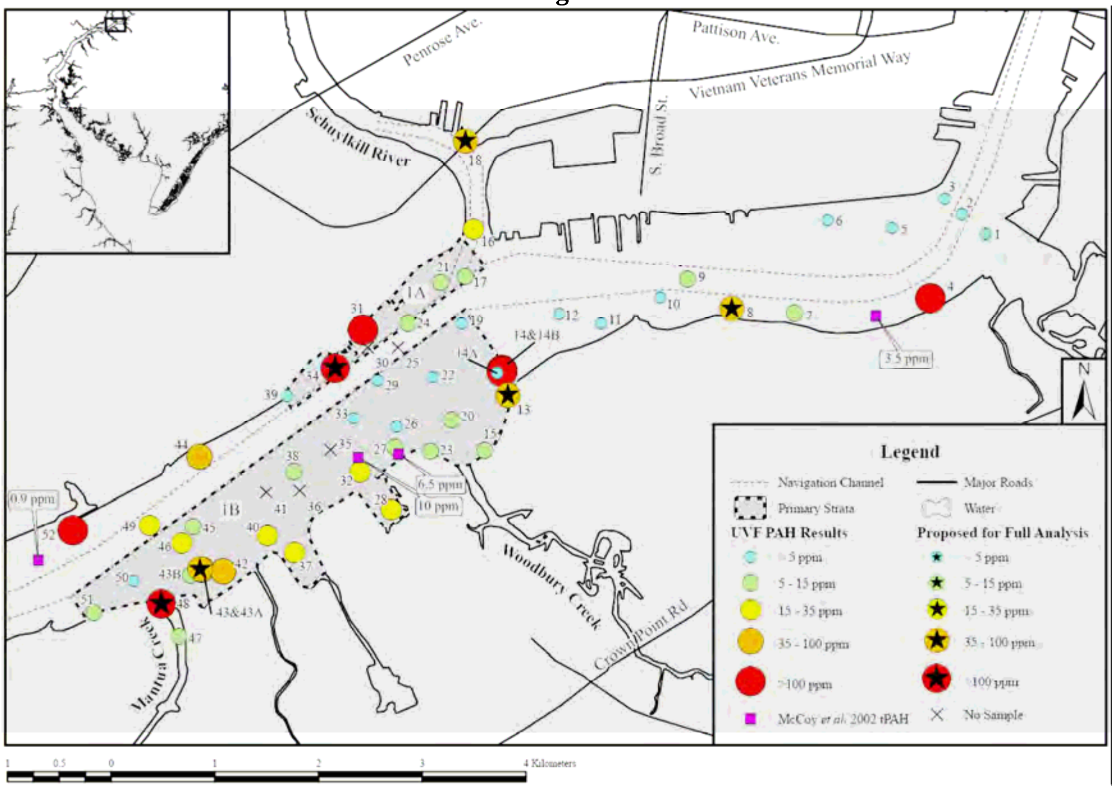
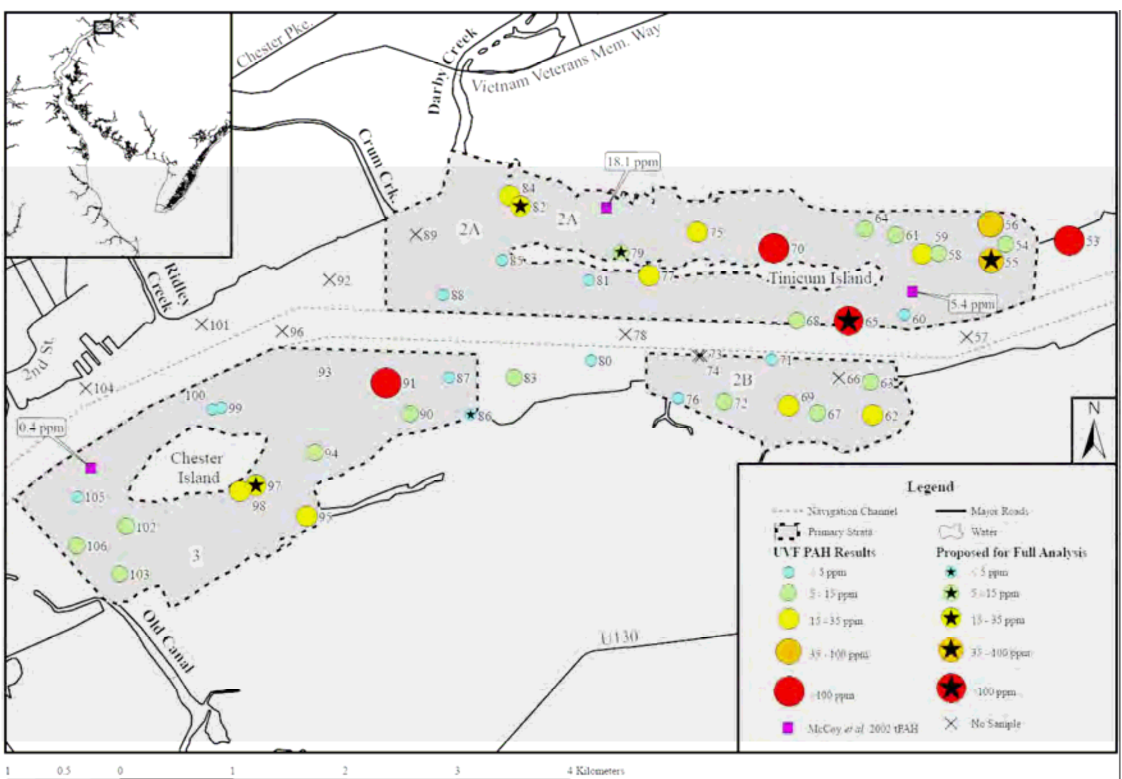


Figure 2
Screening Results

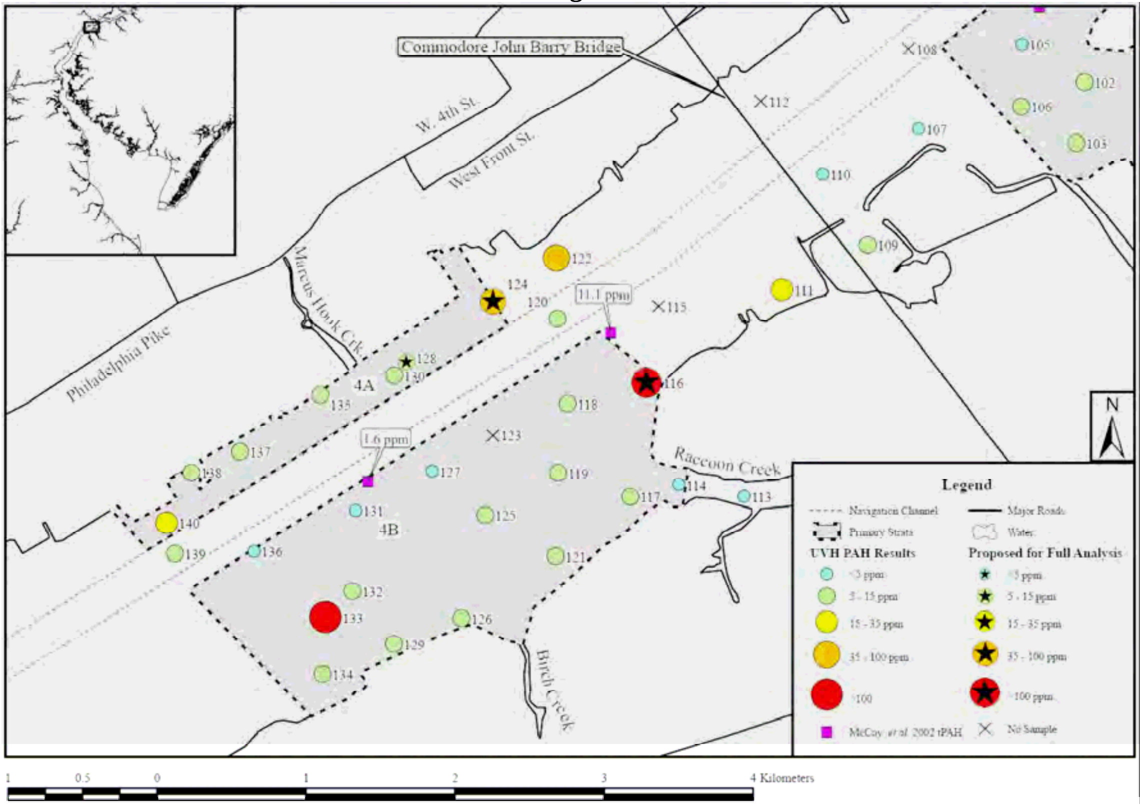


(a) Schuylkill River Area

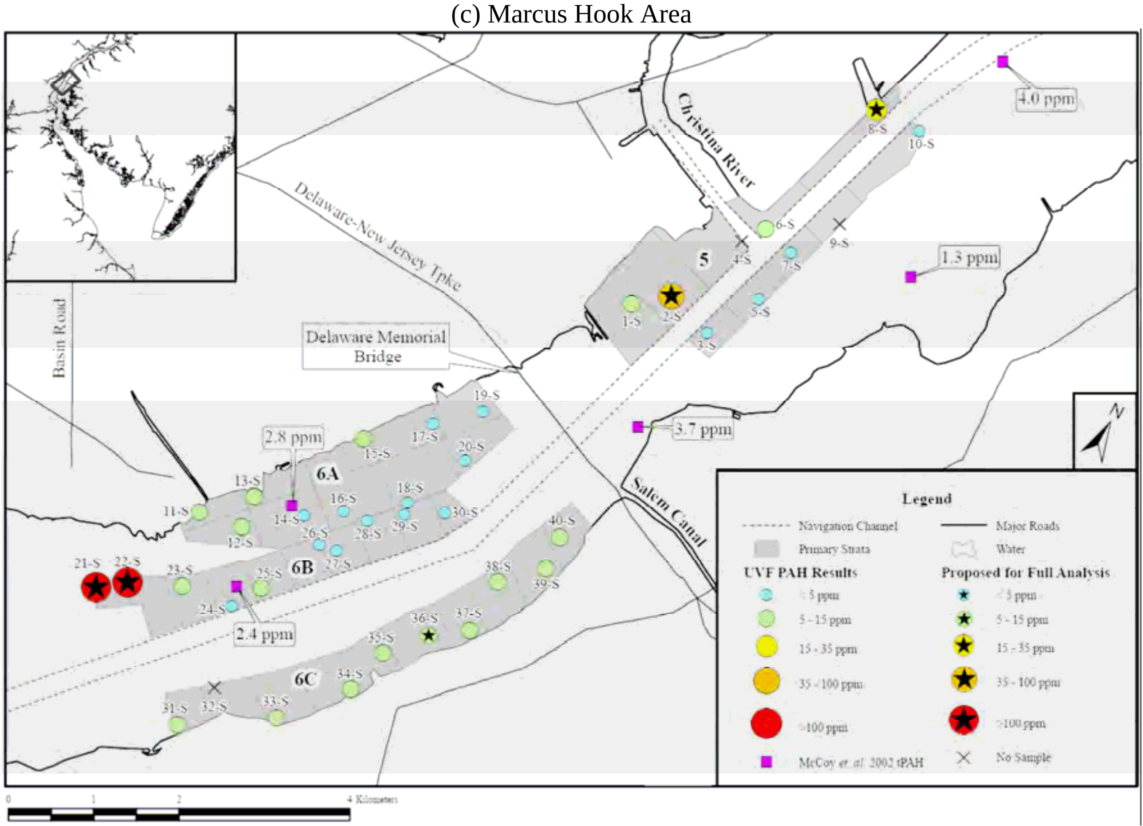


(b) Tinicum Island Area

Figure 2 (continued)
Screening Results

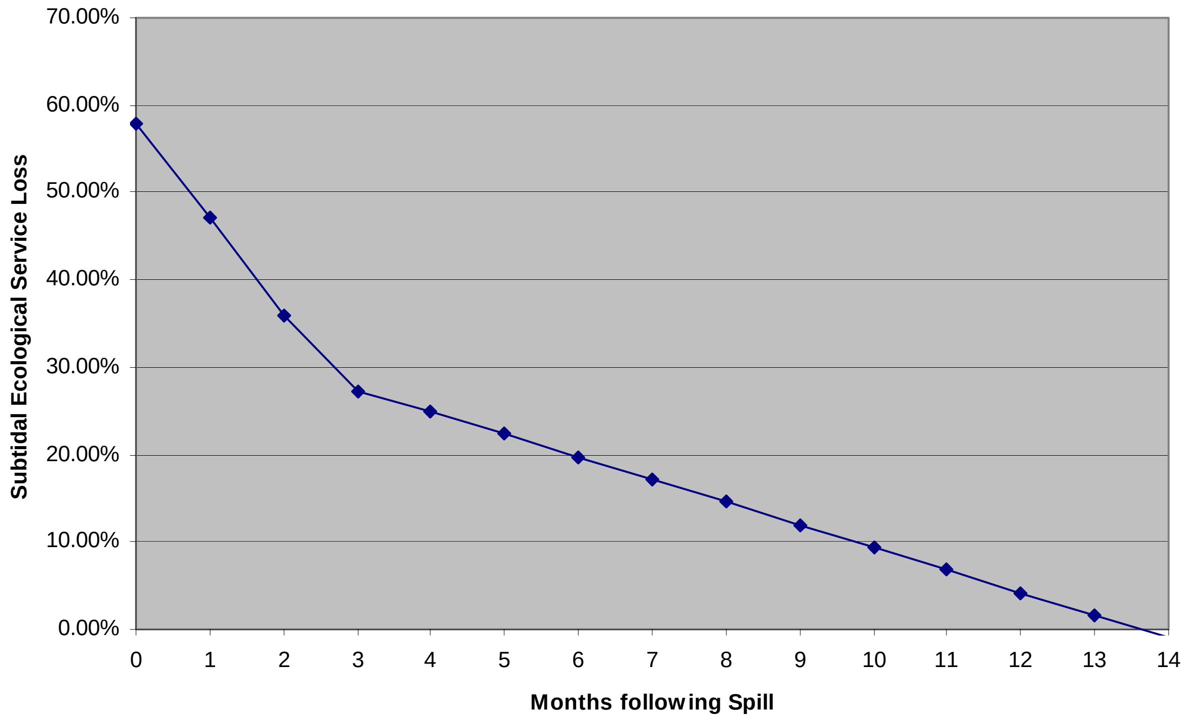


(c) Marcus Hook Area



(d) Christina River, Delaware Memorial Bridge

Figure 3
Projected Recovery Curve for Subtidal Injury



APPENDIX A

Comparison of Relationships Between Whole Sediment Chemistry and Sediment Toxicity Derived from Delaware River-Specific and National Data

To perform this comparison, we first obtained the complete toxicity and PAH chemistry data for the project from NOAA (Hartwell et al. 2001) and compared the incidence of toxicity in amphipod survival tests (Ampelisca abdita) to NS&T total PAH concentration.[33] Consistent with standard approaches for characterizing the incidence of toxicity, the 81 data points were divided into 8 groups (termed "concentration intervals"), sorted by increasing concentration. In Figure A-1, each group is represented by the NS&T total PAH concentration of the samples within it and the corresponding control-adjusted survival.[34] The toxic response seen at the highest concentration group, with a geometric mean of approximately 10 mg/kg dry weight (DW), is a control adjusted survival of 75 percent.[35]

These results were then compared to a database of matched sediment chemistry and toxicity data from sites located throughout North America (Field et al. 2002). The primary sources for the database include the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends Program (NSTP), U.S. Environmental Protection Agency's (U.S. EPA) Environmental Monitoring and Assessment Program (EMAP), Moss Landing Marine Laboratory (MLML, which compiled data for the state of California), State of Washington Department of Ecology's Puget Sound Database (SEDQUAL), and MacDonald Environmental Sciences' Biological Effects Database for Sediments. Many geographic areas along the Atlantic, Gulf, and Pacific coasts are represented in the database. Although the database includes information on a variety of toxicity endpoints, only data from the American Society for Testing Materials (ASTM) standard 10 day amphipod survival toxicity tests with Ampelisca abdita were used in the analyses discussed in this report. All of the candidate data sets included in the database were critically evaluated regarding consistency with established protocols, acceptable control survival, meeting of project data quality objectives, and verification of data accuracy as compared to source documents. Finally, the national data used in this comparison were limited to sediment samples with probable effects level quotients (PEL-Q) for

[33] For this analysis, we use the sum of non-alkyl PAHs from Hartwell *et al*. 2001. The 20 included compounds are naphthalene, biphenyl, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, dibenzothiophene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(e)pyrene, benzo(a)pyrene, perylene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)-perylene. Laboratory sediment samples from the Delaware River (November-December 2004 and September 2005) calculated a relative percent difference between the NS&T and non-alkyl PAH values of 10.5 percent (*i.e.* the non-alkyl is 10.5 percent higher than the NS&T value, weighted for value).

[34] The total PAH concentration is presented as the natural logarithm of the geometric mean of the samples within the group. The log transformation increases the signal to noise ratio in the dataset.

[35] The data set includes an outlier showing no toxicity at 127 mg/kg DW total PAH. National data sets consistently show substantial toxicity at such concentration levels. An isolated tarball, fragment of coal, or similar source of biologically unavailable PAHs may have been captured within the sample, thus resulting in high PAH concentrations but no toxicity. The sample was collected near a coal-fired power plant in the dredged portion of a ship turning basin. Other contaminants were found at relatively low concentrations in that sample (Hartwell *et al*. 2001). The use of a geometric mean reduces the impact of possible outliers.

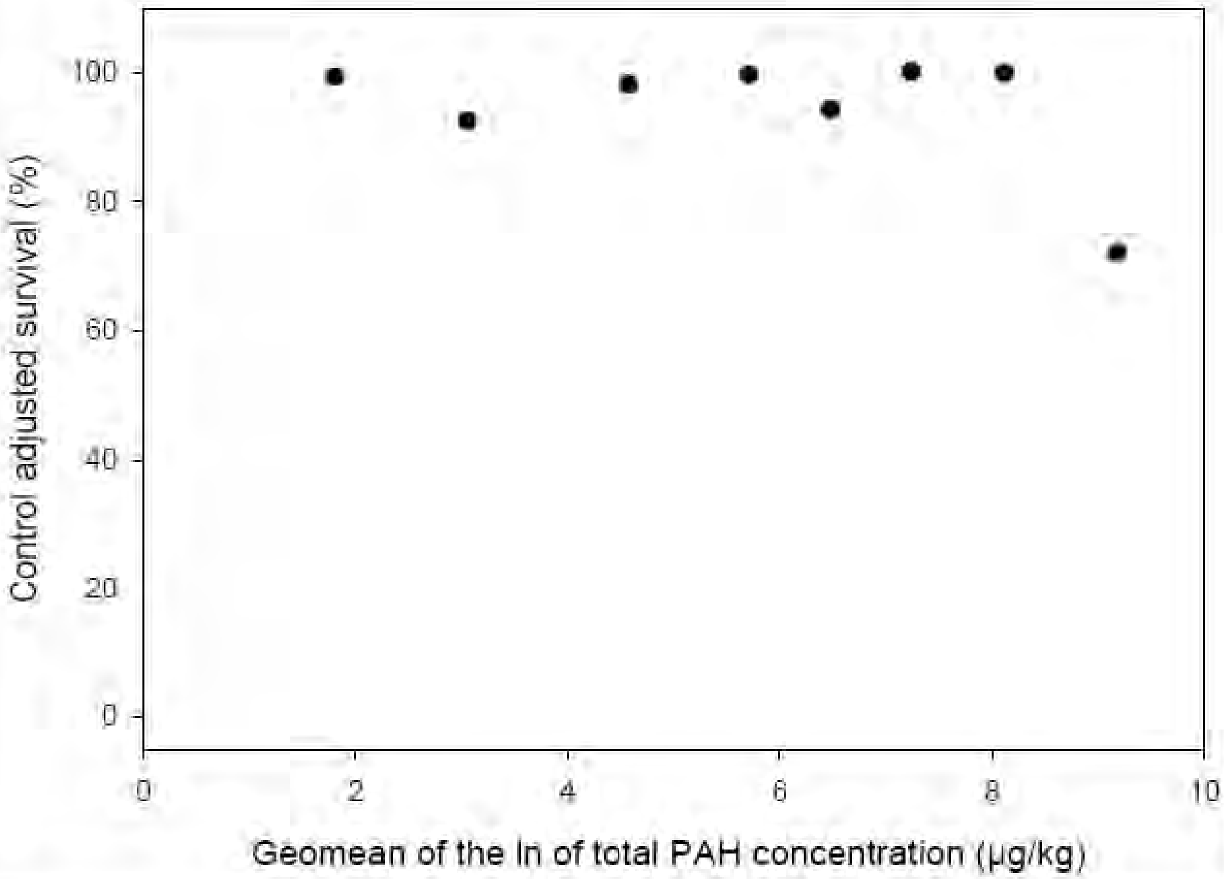
non-PAH contaminants less than 0.1, thereby limiting potential effects associated with other contaminants. We note that the whole sediment chemistry – toxicity relationships developed from these data have been shown to have good predictive ability at a variety of sites.

For marine amphipods, the 1997 NOAA dataset and the National Database are similar, with LC25 toxicity thresholds for the National data set of slightly more than 6 ppm versus the approximately 10 ppm threshold established for the Delaware River. Figure A-2 summarizes Delaware-specific (from Hartwell et al. 2001) and national data on the relationship between total PAH concentrations (log ppb dry weight) and control-adjusted amphipod survival (Ampelisca abdita).[36] As shown in the figure, there is good consistency between the Delaware-specific (open squares) and national (black circles) data sets. The relationship between total PAH concentrations and control-adjusted amphipod survival is strong and significant (r^2 = 0.84;). These results provide additional confirmation that the Delaware River dataset-based chemistry-toxicity relationships are reasonable. We used the local chemistry-toxicity relationship because it likely provides a more accurate representation of local sediment characteristics.

[36] The 1997 NOAA Study (Hartwell et al. 2001) uses a saltwater amphipod for all toxicity testing, regardless of source salinity. Samples were adjusted to an appropriate salinity for *Ampelisca abdita* for toxicity testing. Therefore, for comparability, we use the national dataset for *Ampelisca abdita*, rather than a freshwater amphipod such as *Hyalella azteca*.

Figure A-1

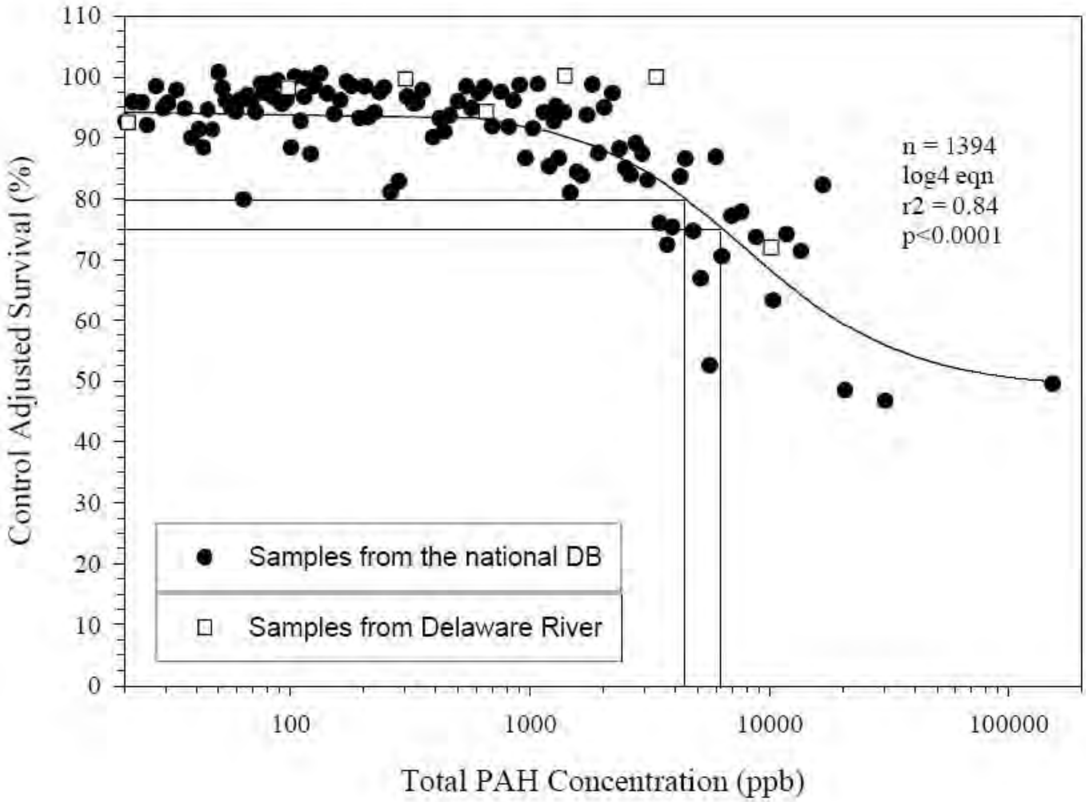
Control-adjusted Survival versus PAH concentration



Source: Hartwell et al. 2001

Figure A-2

Relationship between the geometric mean of the total PAH concentration (ppb DW) and the magnitude of of toxicity to the marine amphipod, Ampelisca abdita, in 10-d toxicity tests from two data sources: the national database and the Delaware River Assessment Area.



Reference conditions (mean PEL-Q <0.1)
n=824
Mean Control adjusted survival = 94%

APPENDIX B

Responsible Party "Fingerprinting" Analysis of Subtidal Sediment Samples Collected 10 Months after the *Athos* Spill

The following analytical summary covers the twenty Delaware River estuary sediment samples collected in mid-September 2005 (Table 1) that were received from the National Oceanic and Atmospheric Administration (NOAA). These sediment samples were analyzed by Geochemical and Environmental Research Group (GERG) at Texas A&M University for the polycyclic aromatic hydrocarbons (PAHs) listed in Table 2. The results from these sediment samples were compared to M/V *ATHOS* Tank Center 7 (TC7) fuel oil product samples collected in November 2004 and several subtidal sediment samples collected in December 2004 from “reference” sites in the Delaware River beyond the influence of the *Athos* oil spill. The subtidal reference sediments were collected up river of the spill near the Tacony Palmyra Bridge on December 10, 2004 and included SED-UL-01, SED-UL-02, SED-PTB-01, and SED-PTB-02. B&B Laboratories, an affiliate of TDI Brooks, analyzed the subtidal reference sediments and fuel oil product samples.

Several diagnostic parameters (Table 3) were calculated from the reference/oil mixture and sediment samples including C2D/C2P, C3D/C3P, and Pyrogenic/Petrogenic PAH, which are useful in differentiating petroleum sources. Figure 1 displays a histogram of the pyrogenic/petrogenic PAH ratio for the product and sediment samples and clearly shows that the sediments are characterized by an mixture of pyrogenic or combustion related PAH and “petrogenic” or petroleum related PAH, as would be expected from sediments in an urban estuary. The sediments do not show evidence of oiling, as evidenced by the high ratio values, relative to those of the *Athos* oil sample(s). Figure 2 displays a cross plot of C2D/C2P vs C3D/C3P for the reference, product and sediment samples. This ratio is important since it can be used as a petroleum source indicator in oiled samples. The ratio changes depending of the relative abundance of sulfur containing PAH (dibenzothiophenes) in petroleum, and can be used to differentiate between the *Athos* oil (which is enriched in dibenzothiophenes) and the background sediments which are relatively depleted in dibenzothiophenes. *Athos* oil in the sediments would result in the sediment samples clustering close to the *Athos* oil samples in the cross plot. Sample 48 is clearly an outlier in this data set with a C2D/C2P value greater than 1.0.

Using the C2D/C2P vs C3D/C3P cross plot, a model was generated to estimate the potential percentage of the TC7 (*Athos*) oil in the sediment samples. To develop the prediction model, the results for the subtidal reference samples were averaged and the TC7 oil was then mathematically added to the average reference. TC7 oil was added to increase the Total PAH concentration in the average reference sediment sample by 0.1, 0.5, 1, 2, 5, 10, 20, 30, 50, 75, and 100%. For example, the average Total PAH concentration for the subtidal reference samples was 3,923 ng/g. A mass of oil with a Total PAH concentration of 392 ng total was added to the average reference to increase the Total PAH concentration by 10%. While the Total PAH concentration increased by 10% in this example, the percent increase of the individual PAHs varied based on their relative distribution in the TC7 oil.

The C2D/C2P and C3D/C3P results were multiplied together to form a single diagnostic parameter. The C2D/C2P*C3D/C3P parameter and percent increase for each reference/oil mixture were used to develop a cubic multiple regression equation to predict the percent of TC7 oil in subtidal sediment samples (Table 1). The C2D/C2P*C3D/C3P result from each sediment sample was entered into the regression equation to estimate the potential percent increase due to TC7. The estimated percent increases for all samples were less than 10%. Considering the accuracy of the model based on the limited number of samples available, samples with a TC7 component of 10% or less should be considered indistinguishable from background. The one exception, was of sample 48 which had an estimated percentage of 16%. As shown in Figure 2, sample 48 which is clearly an outlier with a C2D/C2P value greater than 1.0, and should not be considered in this calculation.

Figure 3 further illustrates the differences shown in the cross plot between the PAH distributions in the sediments and the spilled *Athos* oil sample. The *Athos* oil sample contains an abundance of alkylated 2-, 3-, and 4- ring PAH (naphthalenes, fluorenes, phenanthernes, dibenzothiophenes, and chrysenes), while the sediments are dominated by the parent 4-, 5-, and 6-ring PAH.

Table 1. List of Samples

Client Sample ID	GERG ID	Collection Date
8	C47250	9/13-9/14/2005
13	C47251	9/13-9/14/2005
18	C47252	9/13-9/14/2005
34	C47253	9/13-9/14/2005
43	C47254	9/15/2005
48	C47255	9/13-9/14/2005
55	C47256	9/13-9/14/2005
65	C47257	9/13-9/14/2005
79	C47258	9/13-9/14/2005
82	C47259	9/13-9/14/2005
86	C47260	9/13-9/14/2005
97	C47261	9/13-9/14/2005
116	C47262	9/13-9/14/2005
124	C47263	9/13-9/14/2005
128	C47264	9/13-9/14/2005
2-5	C47265	9/16/2005
8-5	C47266	9/16/2005
21-5	C47267	9/16/2005
22-5	C47268	9/16/2005
36-5	C47269	9/16/2005

Table 2. Target Compound List

Compound Name	Abbreviation	Compound Name	Abbreviation
Naphthalene	C0N	C3-Dibenzothiophene	C3D
C1-Naphthalenes	C1N	Fluoranthene	FLANT
C2-Naphthalenes	C2N	Pyrene	PYR
C3-Naphthalenes	C3N	C1-Fluoranthenes/Pyrenes	C1F/P
C4-Naphthalenes	C4N	C2-Fluoranthenes/Pyrenes	C2F/P
Biphenyl	BIP	C3-Fluoranthenes/Pyrenes	C3F/P
Acenaphthylene	ACEY	Benz(a)anthracene	BAA
Acenaphthene	ACE	Chrysene	C0C
Fluorene	C0F	C1-Chrysenes	C1C
C1-Fluorenes	C1F	C2-Chrysenes	C2C
C2-Fluorenes	C2F	C3-Chrysenes	C3C
C3-Fluorenes	C3F	C4-Chrysenes	C4C
Anthracene	C0A	Benzo(b)fluoranthene	BBF
Phenanthrene	C0P	Benzo(k)fluoranthene	BKF
C1-Phenanthrene/Anthracenes	C1P/A	Benzo(e)pyrene	BEP
C2-Phenanthrene/Anthracenes	C2P/A	Benzo(a)pyrene	BAP
C3-Phenanthrene/Anthracenes	C3P/A	Perylene	PERY
C4-Phenanthrene/Anthracenes	C4P/A	Indeno(1,2,3-c,d)pyrene	IND
Dibenzothiophene	C0D	Dibenzo(a,h)anthracene	DAH
C1-Dibenzothiophene	C1D	Benzo(g,h,i)perylene	BGP
C2-Dibenzothiophene	C2D		

Table 3. Diagnostic Ratios and Parameters of Polynuclear Aromatic Hydrocarbons

Parameter	Relevance in Environmental Samples
Total PAH	The sum of all PAH target analytes; includes 2- through 6-ring parent PAH and C1 - C4 alkyl-substituted PAH.
Perylene	A biogenic PAH formed during the early diagenesis in marine and lacustrine sediments; may be associated with terrestrial plant source precursors.
Total PAH less perylene	The sum of all PAH target analytes with the exception of perylene.
C2D/C2P	Ratio of C2 alkyl dibenzothiophenes (D) and C2 alkyl phenanthrenes (P) is a useful diagnostic source ratio for petroleum.
C3D/C3P	Ratio of C3 alkyl dibenzothiophenes (D) and C3 alkyl phenanthrenes (P) is a useful diagnostic source ratio for petroleum.
Pyrogenic PAH	The sum of combustion PAH compounds (fluoranthene, pyrene, chrysene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenz[a,h]anthracene, benzo[g,h,i]perylene, and indeno[1,2,3,-c,d]pyrene.
Petrogenic PAH	The sum of petrogenic PAH compounds (naphthalenes [C0 - C4], acenaphthene, acenaphthylene, fluorene [C0 - C3], phenanthrenes [C0 - C4], dibenzothiophenes [C0 - C3], chrysenes [C1 - C4], and fluoranthenes/pyrenes [C1 - C3]).
Pyrogenic/Petrogenic	The ratio of pyrogenic PAH compounds to petrogenic PAH compounds is useful for determining the relative contribution of pyrogenic and petrogenic hydrocarbons and in differentiating hydrocarbon sources.
Light PAH	The sum of lighter PAHs (2- to 3-ring PAH: naphthalenes [C0-C4], Biphenyl, Acenaphthylene, Acenaphthene, fluorenes [C0-C3], Anthracene, Phenanthrenes [C0-C4], dibenzothiophenes [C0-C3]
Heavy PAH	The sum of heavier PAHs (4-, 5-, and 6-ring PAH: Pyrene, Fluoranthenes [C0-C3], Benz(a)anthracene, Chrysenes [C0-C4], Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Perylene, Indeno(1,2,3-c,d)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene

Table 4. Estimated % Increase in PAH from TC7

Reference Samples	Total PAHs	C2D/C2P	C3D/C3P	(C2D/C2P)*(C3D/C3P)	Estimated % increase in PAH from TC7
SED-UL-01	2043	0.22	0.36	0.08	NA
SED-UL-02	533	0.27	0.26	0.07	NA
SED-PTB-01	2007	0.22	0.32	0.07	NA
SED-PTB-02	11109	0.11	0.14	0.02	NA
Product Samples					
Samp1 TC7 (B&B)	5648200	0.95	0.99	0.94	NA
Samp1 TC7 Dup (B&B)	5563800	0.95	1.05	1.00	NA
Sediment Samples					
8	10491	0.29	0.20	0.06	<10%
13	13500	0.13	0.07	0.01	<10%
18	32154	0.52	0.37	0.19	<10%
34	25134	0.57	0.29	0.16	<10%
43	5179	0.66	0.33	0.21	<10%
48	18472	1.05	0.40	0.42	15-20%
55	1813	0.24	0.17	0.04	<10%
65	19891	0.61	0.36	0.22	<10%
79	6841	0.32	0.23	0.07	<10%
82	25072	0.34	0.21	0.07	<10%
86	1481	0.28	0.18	0.05	<10%
97	6209	0.26	0.18	0.05	<10%
116	20304	0.51	0.30	0.15	<10%
124	11348	0.48	0.25	0.12	<10%
128	4018	0.39	0.23	0.09	<10%
2-5	6239	0.55	0.32	0.18	<10%
8-5	7447	0.62	0.26	0.16	<10%
21-5	14583	0.63	0.38	0.24	<10%
22-5	24715	0.61	0.41	0.25	<10%
36-5	4416	0.32	0.22	0.07	<10%

Cubic Regression Equation = $-5.04 + ((C2D/C2P*C3D/C3P) * 122.98) - ((C2D/C2P*C3D/C3P)^2 * 393.37) + ((C2D/C2P*C3D/C3P)^3 * 525.43)$

Figure 1. Pyrogenic/Petrogenic PAH Histogram for Product and Sediment Samples

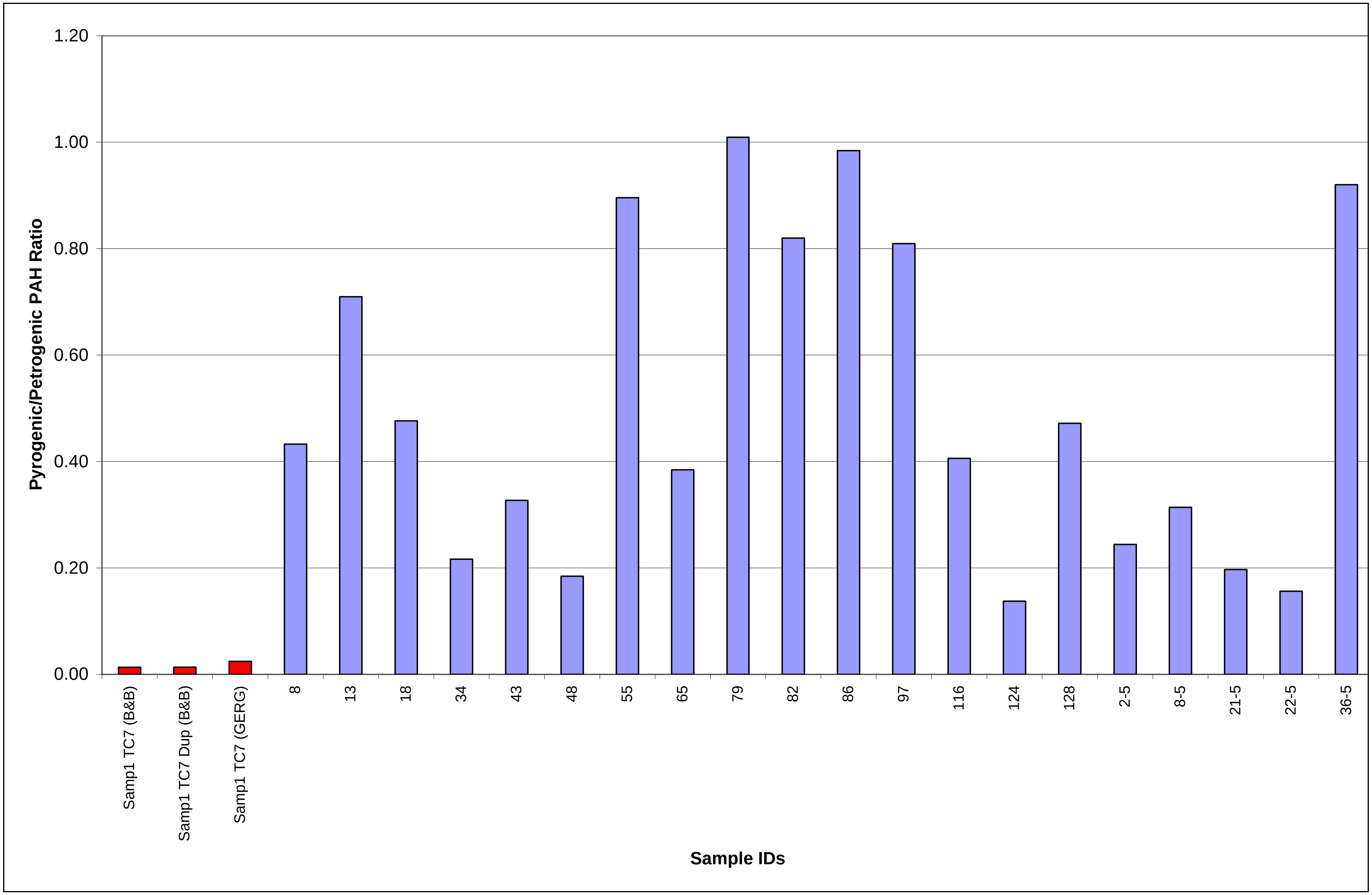


Figure 2. C2D/C2P vs C3D/C3P Source Ratio Plot

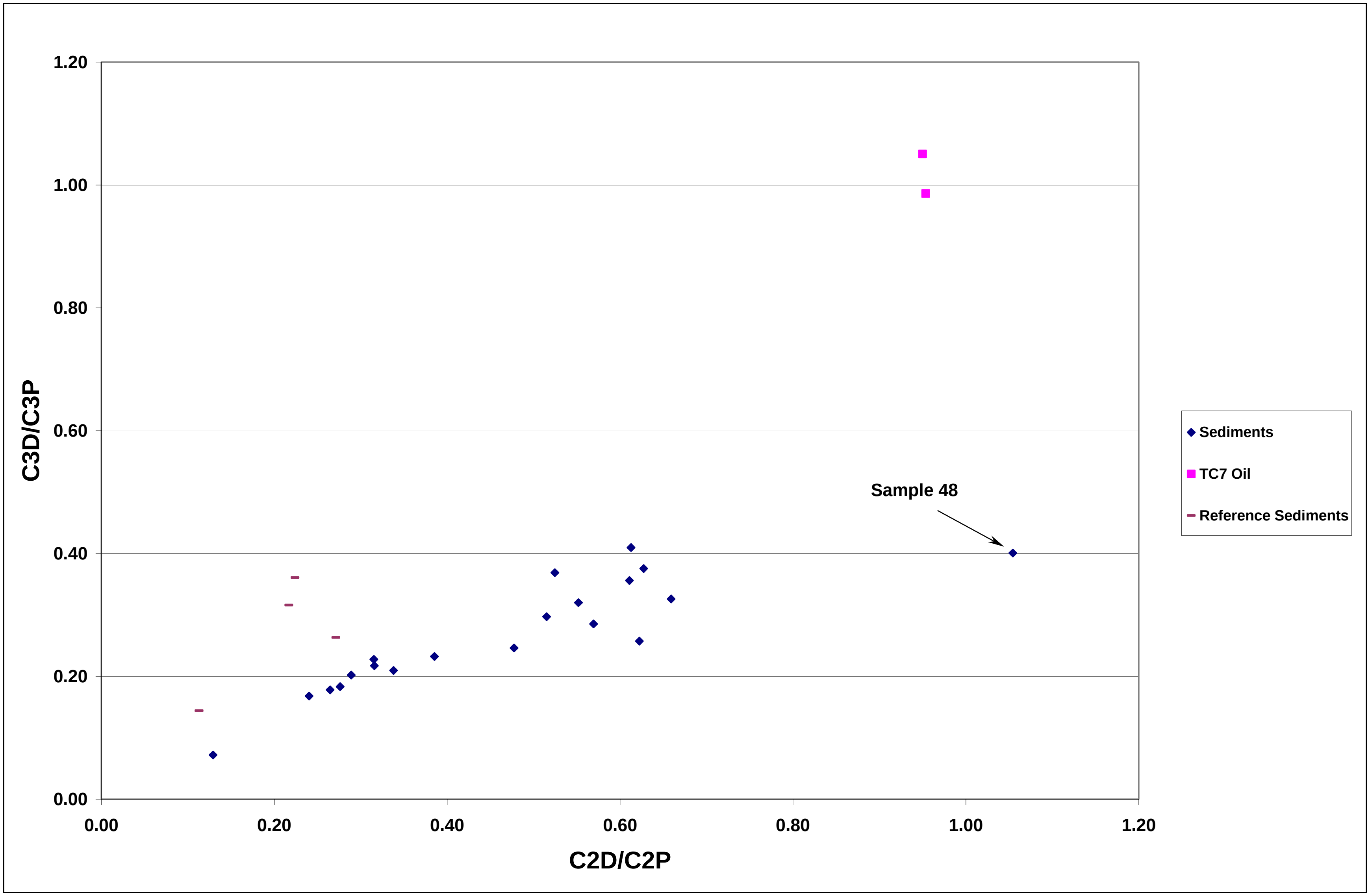
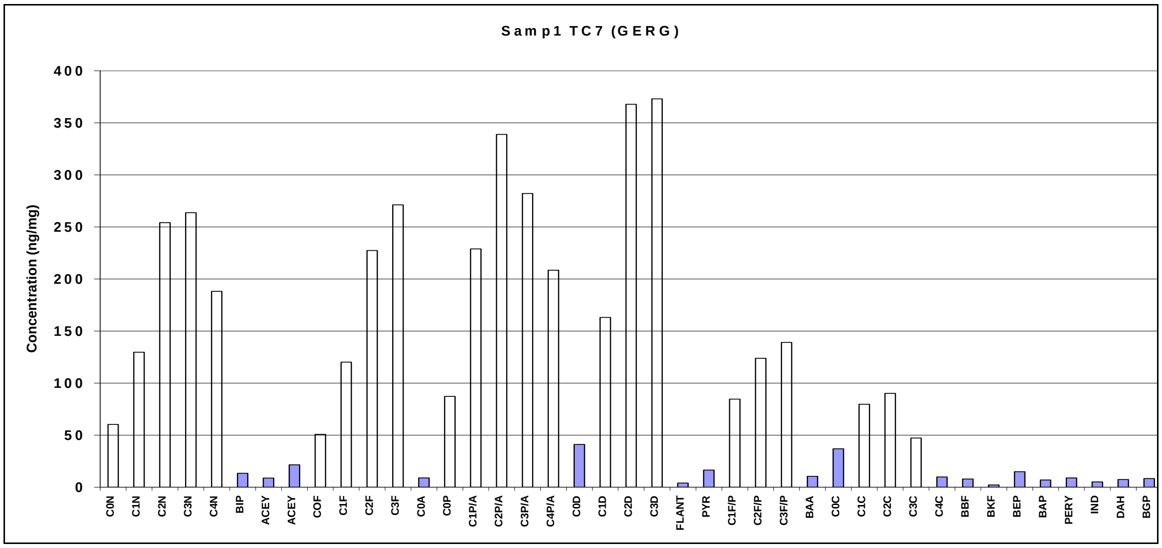
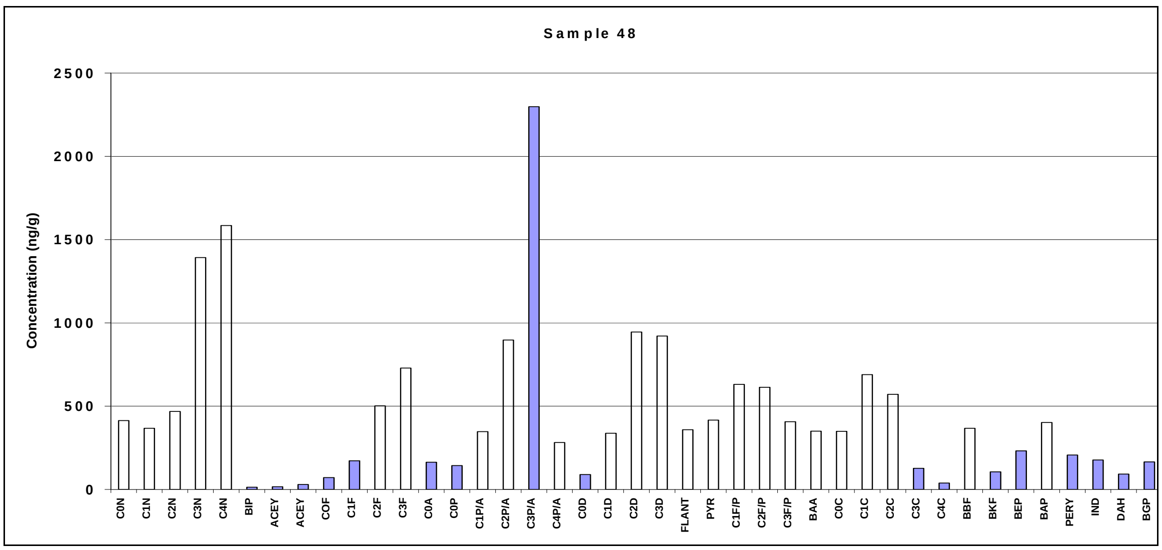
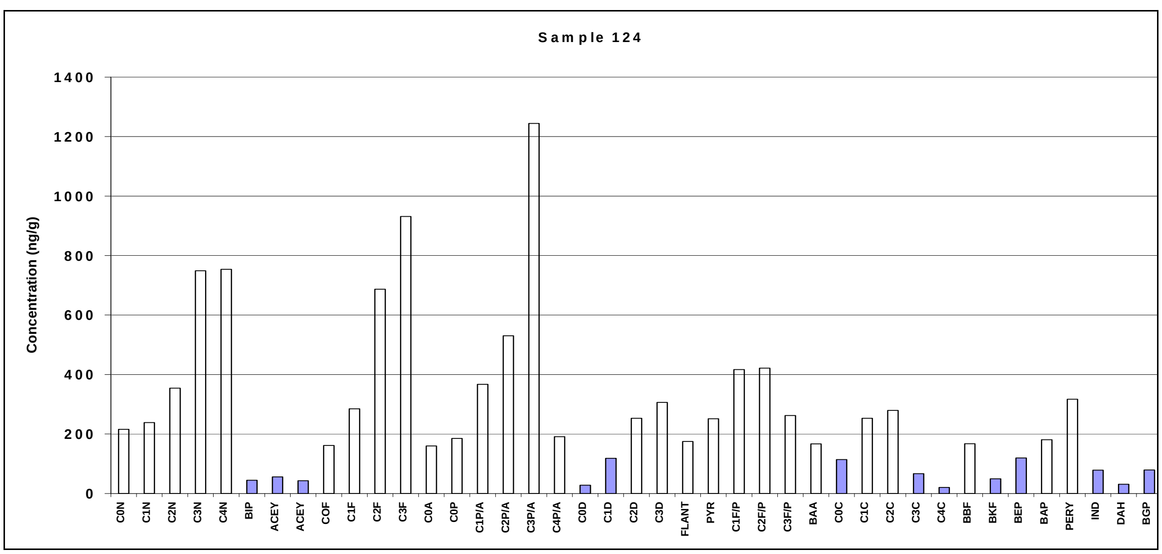


Figure 3. Product and Sediment Sample Histograms







Appendix C - Potential Toxicity Report

Appendix D - Field Sampling Plan for Sept 2005 Sediment Data Collection

Appendix E - Field Data Report for Sept 2005 Sediment Sampling

Appendix F - Equilibrium Partitioning Analyses Performed by Rick Greene

Appendix G - Whole Sediment Toxicity and Chemistry Reports Provided by DNREC

Appendices C-G available upon request

APPENDIX H

HEA Calculations

ATHOS AQUATIC TWG - PRELIMINARY HEA

PRELIMINARY HEA CALCULATION - SUMMARY

Injury Parameter	**Value**	**Source/Notes**
Injury Area: Acres with Subtidal Oiling	412	Subtidal Zones adjacent to Heavily Oiled Shoreline (to 18' depth contour)
Background Service Loss	9.90%	Hartwell *et al*. 2001, Mid-river region
Duration of Injury	14 Months	
Recovery Curve Shape	Linear	Non-continuous at Month 3
Discount Rate	3%	Standard rate used in NRDA
Anchor Points	**Service Loss**	(*Athos*-related Injury)
Month 1 (Day 19)	51%	Triad Sample at Tinicum
Month 3 (Day 83)	28%	Triad Sample at Tinicum
Month 10 (Day 295)	10%	September 2005 Sediment Sampling Results

HEA RESULTS

Annual Loss (nominal)		
2004	21.0	Service acre years (SAYs)
2005	72.0	SAYs
2006	0.1	SAYs
Annual Loss (discounted, year 2006)		
2004	22.3	Discounted SAYs (DSAYs)
2005	74.2	DSAYs
2006	0.1	DSAYs
Quantification of Loss	96.6	DSAYs

Days After Spill	Uncorrected Service Loss	*Athos*-Attributed Service Loss	Acres	Date	Daily Loss	Days After Spill	Uncorrected Service Loss	*Athos*-Attributed Service Loss	Acres	Date	Daily Loss
0	67.8%	57.9%	412	26-Nov-04	238.7	54	48.4%	38.5%	412	19-Jan-05	158.7
1	67.5%	57.6%	412	27-Nov-04	237.2	55	48.1%	38.2%	412	20-Jan-05	157.2
2	67.1%	57.2%	412	28-Nov-04	235.7	56	47.7%	37.8%	412	21-Jan-05	155.7
3	66.8%	56.9%	412	29-Nov-04	234.2	57	47.3%	37.4%	412	22-Jan-05	154.3
4	66.4%	56.5%	412	30-Nov-04	232.7	58	47.0%	37.1%	412	23-Jan-05	152.8
5	66.0%	56.1%	412	1-Dec-04	231.3	59	46.6%	36.7%	412	24-Jan-05	151.3
6	65.7%	55.8%	412	2-Dec-04	229.8	60	46.3%	36.4%	412	25-Jan-05	149.8
7	65.3%	55.4%	412	3-Dec-04	228.3	61	45.9%	36.0%	412	26-Jan-05	148.3
8	65.0%	55.1%	412	4-Dec-04	226.8	62	45.5%	35.6%	412	27-Jan-05	146.9
9	64.6%	54.7%	412	5-Dec-04	225.3	63	45.2%	35.3%	412	28-Jan-05	145.4
10	64.2%	54.3%	412	6-Dec-04	223.9	64	44.8%	34.9%	412	29-Jan-05	143.9
11	63.9%	54.0%	412	7-Dec-04	222.4	65	44.5%	34.6%	412	30-Jan-05	142.4
12	63.5%	53.6%	412	8-Dec-04	220.9	66	44.1%	34.2%	412	31-Jan-05	140.9
13	63.2%	53.3%	412	9-Dec-04	219.4	67	43.8%	33.9%	412	1-Feb-05	139.5
14	62.8%	52.9%	412	10-Dec-04	217.9	68	43.4%	33.5%	412	2-Feb-05	138.0
15	62.4%	52.5%	412	11-Dec-04	216.5	69	43.0%	33.1%	412	3-Feb-05	136.5
16	62.1%	52.2%	412	12-Dec-04	215.0	70	42.7%	32.8%	412	4-Feb-05	135.0
17	61.7%	51.8%	412	13-Dec-04	213.5	71	42.3%	32.4%	412	5-Feb-05	133.5
18	61.4%	51.5%	412	14-Dec-04	212.0	72	42.0%	32.1%	412	6-Feb-05	132.1
19	61.0%	51.1%	412	15-Dec-04	210.5	73	41.6%	31.7%	412	7-Feb-05	130.6
20	60.6%	50.7%	412	16-Dec-04	209.1	74	41.2%	31.3%	412	8-Feb-05	129.1
21	60.3%	50.4%	412	17-Dec-04	207.6	75	40.9%	31.0%	412	9-Feb-05	127.6
22	59.9%	50.0%	412	18-Dec-04	206.1	76	40.5%	30.6%	412	10-Feb-05	126.1
23	59.6%	49.7%	412	19-Dec-04	204.6	77	40.2%	30.3%	412	11-Feb-05	124.7
24	59.2%	49.3%	412	20-Dec-04	203.1	78	39.8%	29.9%	412	12-Feb-05	123.2
25	58.8%	48.9%	412	21-Dec-04	201.6	79	39.4%	29.5%	412	13-Feb-05	121.7
26	58.5%	48.6%	412	22-Dec-04	200.2	80	39.1%	29.2%	412	14-Feb-05	120.2
27	58.1%	48.2%	412	23-Dec-04	198.7	81	38.7%	28.8%	412	15-Feb-05	118.7
28	57.8%	47.9%	412	24-Dec-04	197.2	82	38.4%	28.5%	412	16-Feb-05	117.3
29	57.4%	47.5%	412	25-Dec-04	195.7	83	38.0%	28.1%	412	17-Feb-05	115.8
30	57.0%	47.1%	412	26-Dec-04	194.2	84	37.9%	28.0%	412	18-Feb-05	115.4
31	56.7%	46.8%	412	27-Dec-04	192.8	85	37.8%	27.9%	412	19-Feb-05	115.1
32	56.3%	46.4%	412	28-Dec-04	191.3	86	37.7%	27.8%	412	20-Feb-05	114.7
33	56.0%	46.1%	412	29-Dec-04	189.8	87	37.7%	27.8%	412	21-Feb-05	114.4
34	55.6%	45.7%	412	30-Dec-04	188.3	88	37.6%	27.7%	412	22-Feb-05	114.0
35	55.3%	45.4%	412	31-Dec-04	186.8	89	37.5%	27.6%	412	23-Feb-05	113.7
36	54.9%	45.0%	412	1-Jan-05	185.4	90	37.4%	27.5%	412	24-Feb-05	113.3
37	54.5%	44.6%	412	2-Jan-05	183.9	91	37.3%	27.4%	412	25-Feb-05	113.0
38	54.2%	44.3%	412	3-Jan-05	182.4	92	37.2%	27.3%	412	26-Feb-05	112.6
39	53.8%	43.9%	412	4-Jan-05	180.9	93	37.2%	27.3%	412	27-Feb-05	112.3
40	53.5%	43.6%	412	5-Jan-05	179.4	94	37.1%	27.2%	412	28-Feb-05	111.9
41	53.1%	43.2%	412	6-Jan-05	178.0	95	37.0%	27.1%	412	1-Mar-05	111.6
42	52.7%	42.8%	412	7-Jan-05	176.5	96	36.9%	27.0%	412	2-Mar-05	111.2
43	52.4%	42.5%	412	8-Jan-05	175.0	97	36.8%	26.9%	412	3-Mar-05	110.9
44	52.0%	42.1%	412	9-Jan-05	173.5	98	36.7%	26.8%	412	4-Mar-05	110.5
45	51.7%	41.8%	412	10-Jan-05	172.0	99	36.6%	26.7%	412	5-Mar-05	110.2
46	51.3%	41.4%	412	11-Jan-05	170.6	100	36.6%	26.7%	412	6-Mar-05	109.8
47	50.9%	41.0%	412	12-Jan-05	169.1	101	36.5%	26.6%	412	7-Mar-05	109.5
48	50.6%	40.7%	412	13-Jan-05	167.6	102	36.4%	26.5%	412	8-Mar-05	109.1
49	50.2%	40.3%	412	14-Jan-05	166.1	103	36.3%	26.4%	412	9-Mar-05	108.8
50	49.9%	40.0%	412	15-Jan-05	164.6	104	36.2%	26.3%	412	10-Mar-05	108.4
51	49.5%	39.6%	412	16-Jan-05	163.2	105	36.1%	26.2%	412	11-Mar-05	108.1
52	49.1%	39.2%	412	17-Jan-05	161.7	106	36.0%	26.1%	412	12-Mar-05	107.7
53	48.8%	38.9%	412	18-Jan-05	160.2	107	36.0%	26.1%	412	13-Mar-05	107.4

Days After Spill	Uncorrected Service Loss	*Athos*-Attributed Service Loss	Acres	Date	Daily Loss
108	35.9%	26.0%	412	14-Mar-05	107.0
109	35.8%	25.9%	412	15-Mar-05	106.7
110	35.7%	25.8%	412	16-Mar-05	106.3
111	35.6%	25.7%	412	17-Mar-05	106.0
112	35.5%	25.6%	412	18-Mar-05	105.6
113	35.5%	25.6%	412	19-Mar-05	105.3
114	35.4%	25.5%	412	20-Mar-05	104.9
115	35.3%	25.4%	412	21-Mar-05	104.6
116	35.2%	25.3%	412	22-Mar-05	104.2
117	35.1%	25.2%	412	23-Mar-05	103.9
118	35.0%	25.1%	412	24-Mar-05	103.5
119	34.9%	25.0%	412	25-Mar-05	103.2
120	34.9%	25.0%	412	26-Mar-05	102.8
121	34.8%	24.9%	412	27-Mar-05	102.5
122	34.7%	24.8%	412	28-Mar-05	102.1
123	34.6%	24.7%	412	29-Mar-05	101.8
124	34.5%	24.6%	412	30-Mar-05	101.4
125	34.4%	24.5%	412	31-Mar-05	101.1
126	34.3%	24.4%	412	1-Apr-05	100.7
127	34.3%	24.4%	412	2-Apr-05	100.4
128	34.2%	24.3%	412	3-Apr-05	100.0
129	34.1%	24.2%	412	4-Apr-05	99.7
130	34.0%	24.1%	412	5-Apr-05	99.3
131	33.9%	24.0%	412	6-Apr-05	99.0
132	33.8%	23.9%	412	7-Apr-05	98.6
133	33.8%	23.9%	412	8-Apr-05	98.3
134	33.7%	23.8%	412	9-Apr-05	97.9
135	33.6%	23.7%	412	10-Apr-05	97.6
136	33.5%	23.6%	412	11-Apr-05	97.2
137	33.4%	23.5%	412	12-Apr-05	96.9
138	33.3%	23.4%	412	13-Apr-05	96.5
139	33.2%	23.3%	412	14-Apr-05	96.2
140	33.2%	23.3%	412	15-Apr-05	95.8
141	33.1%	23.2%	412	16-Apr-05	95.5
142	33.0%	23.1%	412	17-Apr-05	95.1
143	32.9%	23.0%	412	18-Apr-05	94.8
144	32.8%	22.9%	412	19-Apr-05	94.4
145	32.7%	22.8%	412	20-Apr-05	94.1
146	32.7%	22.8%	412	21-Apr-05	93.7
147	32.6%	22.7%	412	22-Apr-05	93.4
148	32.5%	22.6%	412	23-Apr-05	93.0
149	32.4%	22.5%	412	24-Apr-05	92.7
150	32.3%	22.4%	412	25-Apr-05	92.3
151	32.2%	22.3%	412	26-Apr-05	92.0
152	32.1%	22.2%	412	27-Apr-05	91.6
153	32.1%	22.2%	412	28-Apr-05	91.3
154	32.0%	22.1%	412	29-Apr-05	90.9
155	31.9%	22.0%	412	30-Apr-05	90.6
156	31.8%	21.9%	412	1-May-05	90.2
157	31.7%	21.8%	412	2-May-05	89.9
158	31.6%	21.7%	412	3-May-05	89.5
159	31.5%	21.6%	412	4-May-05	89.2
160	31.5%	21.6%	412	5-May-05	88.8
161	31.4%	21.5%	412	6-May-05	88.5
162	31.3%	21.4%	412	7-May-05	88.1
163	31.2%	21.3%	412	8-May-05	87.8
164	31.1%	21.2%	412	9-May-05	87.4
165	31.0%	21.1%	412	10-May-05	87.1
166	31.0%	21.1%	412	11-May-05	86.7
167	30.9%	21.0%	412	12-May-05	86.4
168	30.8%	20.9%	412	13-May-05	86.0
169	30.7%	20.8%	412	14-May-05	85.7
170	30.6%	20.7%	412	15-May-05	85.3
171	30.5%	20.6%	412	16-May-05	85.0
172	30.4%	20.5%	412	17-May-05	84.6
173	30.4%	20.5%	412	18-May-05	84.3
174	30.3%	20.4%	412	19-May-05	83.9
175	30.2%	20.3%	412	20-May-05	83.6
176	30.1%	20.2%	412	21-May-05	83.2
177	30.0%	20.1%	412	22-May-05	82.9
178	29.9%	20.0%	412	23-May-05	82.5
179	29.8%	19.9%	412	24-May-05	82.2
180	29.8%	19.9%	412	25-May-05	81.8
181	29.7%	19.8%	412	26-May-05	81.5
182	29.6%	19.7%	412	27-May-05	81.1
183	29.5%	19.6%	412	28-May-05	80.8
184	29.4%	19.5%	412	29-May-05	80.4
185	29.3%	19.4%	412	30-May-05	80.1
186	29.3%	19.4%	412	31-May-05	79.7
187	29.2%	19.3%	412	1-Jun-05	79.4
188	29.1%	19.2%	412	2-Jun-05	79.0
189	29.0%	19.1%	412	3-Jun-05	78.7
190	28.9%	19.0%	412	4-Jun-05	78.3
191	28.8%	18.9%	412	5-Jun-05	78.0
192	28.7%	18.8%	412	6-Jun-05	77.6
193	28.7%	18.8%	412	7-Jun-05	77.3
194	28.6%	18.7%	412	8-Jun-05	76.9
195	28.5%	18.6%	412	9-Jun-05	76.6
196	28.4%	18.5%	412	10-Jun-05	76.2
197	28.3%	18.4%	412	11-Jun-05	75.9
198	28.2%	18.3%	412	12-Jun-05	75.5
199	28.2%	18.3%	412	13-Jun-05	75.2
200	28.1%	18.2%	412	14-Jun-05	74.8
201	28.0%	18.1%	412	15-Jun-05	74.5
202	27.9%	18.0%	412	16-Jun-05	74.1
203	27.8%	17.9%	412	17-Jun-05	73.8
204	27.7%	17.8%	412	18-Jun-05	73.4
205	27.6%	17.7%	412	19-Jun-05	73.1
206	27.6%	17.7%	412	20-Jun-05	72.7
207	27.5%	17.6%	412	21-Jun-05	72.4
208	27.4%	17.5%	412	22-Jun-05	72.0
209	27.3%	17.4%	412	23-Jun-05	71.7
210	27.2%	17.3%	412	24-Jun-05	71.3
211	27.1%	17.2%	412	25-Jun-05	71.0
212	27.0%	17.1%	412	26-Jun-05	70.6
213	27.0%	17.1%	412	27-Jun-05	70.3
214	26.9%	17.0%	412	28-Jun-05	69.9
215	26.8%	16.9%	412	29-Jun-05	69.6

Days After Spill	Uncorrected Service Loss	*Athos*-Attributed Service Loss	Acres	Date	Daily Loss	Days After Spill	Uncorrected Service Loss	*Athos*-Attributed Service Loss	Acres	Date	Daily Loss
216	26.7%	16.8%	412	30-Jun-05	69.2	270	22.1%	12.2%	412	23-Aug-05	50.4
217	26.6%	16.7%	412	1-Jul-05	68.9	271	22.0%	12.1%	412	24-Aug-05	50.0
218	26.5%	16.6%	412	2-Jul-05	68.5	272	22.0%	12.1%	412	25-Aug-05	49.7
219	26.5%	16.6%	412	3-Jul-05	68.2	273	21.9%	12.0%	412	26-Aug-05	49.3
220	26.4%	16.5%	412	4-Jul-05	67.8	274	21.8%	11.9%	412	27-Aug-05	49.0
221	26.3%	16.4%	412	5-Jul-05	67.5	275	21.7%	11.8%	412	28-Aug-05	48.6
222	26.2%	16.3%	412	6-Jul-05	67.1	276	21.6%	11.7%	412	29-Aug-05	48.3
223	26.1%	16.2%	412	7-Jul-05	66.8	277	21.5%	11.6%	412	30-Aug-05	47.9
224	26.0%	16.1%	412	8-Jul-05	66.4	278	21.4%	11.5%	412	31-Aug-05	47.6
225	25.9%	16.0%	412	9-Jul-05	66.1	279	21.4%	11.5%	412	1-Sep-05	47.2
226	25.9%	16.0%	412	10-Jul-05	65.7	280	21.3%	11.4%	412	2-Sep-05	46.9
227	25.8%	15.9%	412	11-Jul-05	65.4	281	21.2%	11.3%	412	3-Sep-05	46.5
228	25.7%	15.8%	412	12-Jul-05	65.0	282	21.1%	11.2%	412	4-Sep-05	46.2
229	25.6%	15.7%	412	13-Jul-05	64.7	283	21.0%	11.1%	412	5-Sep-05	45.8
230	25.5%	15.6%	412	14-Jul-05	64.3	284	20.9%	11.0%	412	6-Sep-05	45.5
231	25.4%	15.5%	412	15-Jul-05	64.0	285	20.8%	10.9%	412	7-Sep-05	45.1
232	25.3%	15.4%	412	16-Jul-05	63.7	286	20.8%	10.9%	412	8-Sep-05	44.8
233	25.3%	15.4%	412	17-Jul-05	63.3	287	20.7%	10.8%	412	9-Sep-05	44.4
234	25.2%	15.3%	412	18-Jul-05	63.0	288	20.6%	10.7%	412	10-Sep-05	44.1
235	25.1%	15.2%	412	19-Jul-05	62.6	289	20.5%	10.6%	412	11-Sep-05	43.7
236	25.0%	15.1%	412	20-Jul-05	62.3	290	20.4%	10.5%	412	12-Sep-05	43.4
237	24.9%	15.0%	412	21-Jul-05	61.9	291	20.3%	10.4%	412	13-Sep-05	43.0
238	24.8%	14.9%	412	22-Jul-05	61.6	292	20.3%	10.4%	412	14-Sep-05	42.7
239	24.8%	14.9%	412	23-Jul-05	61.2	293	20.2%	10.3%	412	15-Sep-05	42.3
240	24.7%	14.8%	412	24-Jul-05	60.9	294	20.1%	10.2%	412	16-Sep-05	42.0
241	24.6%	14.7%	412	25-Jul-05	60.5	295	20.00%	10.1%	412	17-Sep-05	41.6
242	24.5%	14.6%	412	26-Jul-05	60.2	296	19.92%	10.0%	412	18-Sep-05	41.3
243	24.4%	14.5%	412	27-Jul-05	59.8	297	19.83%	9.9%	412	19-Sep-05	40.9
244	24.3%	14.4%	412	28-Jul-05	59.5	298	19.75%	9.8%	412	20-Sep-05	40.6
245	24.2%	14.3%	412	29-Jul-05	59.1	299	19.66%	9.8%	412	21-Sep-05	40.2
246	24.2%	14.3%	412	30-Jul-05	58.8	300	19.58%	9.7%	412	22-Sep-05	39.9
247	24.1%	14.2%	412	31-Jul-05	58.4	301	19.49%	9.6%	412	23-Sep-05	39.5
248	24.0%	14.1%	412	1-Aug-05	58.1	302	19.41%	9.5%	412	24-Sep-05	39.2
249	23.9%	14.0%	412	2-Aug-05	57.7	303	19.32%	9.4%	412	25-Sep-05	38.8
250	23.8%	13.9%	412	3-Aug-05	57.4	304	19.24%	9.3%	412	26-Sep-05	38.5
251	23.7%	13.8%	412	4-Aug-05	57.0	305	19.15%	9.3%	412	27-Sep-05	38.1
252	23.7%	13.8%	412	5-Aug-05	56.7	306	19.07%	9.2%	412	28-Sep-05	37.8
253	23.6%	13.7%	412	6-Aug-05	56.3	307	18.98%	9.1%	412	29-Sep-05	37.4
254	23.5%	13.6%	412	7-Aug-05	56.0	308	18.90%	9.0%	412	30-Sep-05	37.1
255	23.4%	13.5%	412	8-Aug-05	55.6	309	18.81%	8.9%	412	1-Oct-05	36.7
256	23.3%	13.4%	412	9-Aug-05	55.3	310	18.73%	8.8%	412	2-Oct-05	36.4
257	23.2%	13.3%	412	10-Aug-05	54.9	311	18.64%	8.7%	412	3-Oct-05	36.0
258	23.1%	13.2%	412	11-Aug-05	54.6	312	18.56%	8.7%	412	4-Oct-05	35.7
259	23.1%	13.2%	412	12-Aug-05	54.2	313	18.47%	8.6%	412	5-Oct-05	35.3
260	23.0%	13.1%	412	13-Aug-05	53.9	314	18.39%	8.5%	412	6-Oct-05	35.0
261	22.9%	13.0%	412	14-Aug-05	53.5	315	18.30%	8.4%	412	7-Oct-05	34.6
262	22.8%	12.9%	412	15-Aug-05	53.2	316	18.22%	8.3%	412	8-Oct-05	34.3
263	22.7%	12.8%	412	16-Aug-05	52.8	317	18.13%	8.2%	412	9-Oct-05	33.9
264	22.6%	12.7%	412	17-Aug-05	52.5	318	18.05%	8.1%	412	10-Oct-05	33.6
265	22.5%	12.6%	412	18-Aug-05	52.1	319	17.96%	8.1%	412	11-Oct-05	33.2
266	22.5%	12.6%	412	19-Aug-05	51.8	320	17.88%	8.0%	412	12-Oct-05	32.9
267	22.4%	12.5%	412	20-Aug-05	51.4	321	17.79%	7.9%	412	13-Oct-05	32.5
268	22.3%	12.4%	412	21-Aug-05	51.1	322	17.71%	7.8%	412	14-Oct-05	32.2
269	22.2%	12.3%	412	22-Aug-05	50.7	323	17.62%	7.7%	412	15-Oct-05	31.8

Days After Spill	Uncorrected Service Loss	*Athos*-Attributed Service Loss	Acres	Date	Daily Loss
324	17.54%	7.6%	412	16-Oct-05	31.5
325	17.45%	7.6%	412	17-Oct-05	31.1
326	17.37%	7.5%	412	18-Oct-05	30.8
327	17.28%	7.4%	412	19-Oct-05	30.4
328	17.20%	7.3%	412	20-Oct-05	30.1
329	17.11%	7.2%	412	21-Oct-05	29.7
330	17.03%	7.1%	412	22-Oct-05	29.4
331	16.94%	7.0%	412	23-Oct-05	29.0
332	16.86%	7.0%	412	24-Oct-05	28.7
333	16.77%	6.9%	412	25-Oct-05	28.3
334	16.69%	6.8%	412	26-Oct-05	28.0
335	16.60%	6.7%	412	27-Oct-05	27.6
336	16.52%	6.6%	412	28-Oct-05	27.3
337	16.43%	6.5%	412	29-Oct-05	26.9
338	16.35%	6.4%	412	30-Oct-05	26.6
339	16.26%	6.4%	412	31-Oct-05	26.2
340	16.18%	6.3%	412	1-Nov-05	25.9
341	16.09%	6.2%	412	2-Nov-05	25.5
342	16.01%	6.1%	412	3-Nov-05	25.2
343	15.92%	6.0%	412	4-Nov-05	24.8
344	15.84%	5.9%	412	5-Nov-05	24.5
345	15.75%	5.9%	412	6-Nov-05	24.1
346	15.67%	5.8%	412	7-Nov-05	23.8
347	15.58%	5.7%	412	8-Nov-05	23.4
348	15.50%	5.6%	412	9-Nov-05	23.1
349	15.42%	5.5%	412	10-Nov-05	22.7
350	15.33%	5.4%	412	11-Nov-05	22.4
351	15.25%	5.3%	412	12-Nov-05	22.0
352	15.16%	5.3%	412	13-Nov-05	21.7
353	15.08%	5.2%	412	14-Nov-05	21.3
354	14.99%	5.1%	412	15-Nov-05	21.0
355	14.91%	5.0%	412	16-Nov-05	20.6
356	14.82%	4.9%	412	17-Nov-05	20.3
357	14.74%	4.8%	412	18-Nov-05	19.9
358	14.65%	4.8%	412	19-Nov-05	19.6
359	14.57%	4.7%	412	20-Nov-05	19.2
360	14.48%	4.6%	412	21-Nov-05	18.9
361	14.40%	4.5%	412	22-Nov-05	18.5
362	14.31%	4.4%	412	23-Nov-05	18.2
363	14.23%	4.3%	412	24-Nov-05	17.8
364	14.14%	4.2%	412	25-Nov-05	17.5
365	14.06%	4.2%	412	26-Nov-05	17.1
366	13.97%	4.1%	412	27-Nov-05	16.8
367	13.89%	4.0%	412	28-Nov-05	16.4
368	13.80%	3.9%	412	29-Nov-05	16.1
369	13.72%	3.8%	412	30-Nov-05	15.7
370	13.63%	3.7%	412	1-Dec-05	15.4
371	13.55%	3.6%	412	2-Dec-05	15.0
372	13.46%	3.6%	412	3-Dec-05	14.7
373	13.38%	3.5%	412	4-Dec-05	14.3
374	13.29%	3.4%	412	5-Dec-05	14.0
375	13.21%	3.3%	412	6-Dec-05	13.6
376	13.12%	3.2%	412	7-Dec-05	13.3
377	13.04%	3.1%	412	8-Dec-05	12.9

Days After Spill	Uncorrected Service Loss	*Athos*-Attributed Service Loss	Acres	Date	Daily Loss
378	12.95%	3.1%	412	9-Dec-05	12.6
379	12.87%	3.0%	412	10-Dec-05	12.2
380	12.78%	2.9%	412	11-Dec-05	11.9
381	12.70%	2.8%	412	12-Dec-05	11.5
382	12.61%	2.7%	412	13-Dec-05	11.2
383	12.53%	2.6%	412	14-Dec-05	10.8
384	12.44%	2.5%	412	15-Dec-05	10.5
385	12.36%	2.5%	412	16-Dec-05	10.1
386	12.27%	2.4%	412	17-Dec-05	9.8
387	12.19%	2.3%	412	18-Dec-05	9.4
388	12.10%	2.2%	412	19-Dec-05	9.1
389	12.02%	2.1%	412	20-Dec-05	8.7
390	11.93%	2.0%	412	21-Dec-05	8.4
391	11.85%	1.9%	412	22-Dec-05	8.0
392	11.76%	1.9%	412	23-Dec-05	7.7
393	11.68%	1.8%	412	24-Dec-05	7.3
394	11.59%	1.7%	412	25-Dec-05	7.0
395	11.51%	1.6%	412	26-Dec-05	6.6
396	11.42%	1.5%	412	27-Dec-05	6.3
397	11.34%	1.4%	412	28-Dec-05	5.9
398	11.25%	1.4%	412	29-Dec-05	5.6
399	11.17%	1.3%	412	30-Dec-05	5.2
400	11.08%	1.2%	412	31-Dec-05	4.9
401	11.00%	1.1%	412	1-Jan-06	4.5
402	10.92%	1.0%	412	2-Jan-06	4.2
403	10.83%	0.9%	412	3-Jan-06	3.8
404	10.75%	0.8%	412	4-Jan-06	3.5
405	10.66%	0.8%	412	5-Jan-06	3.1
406	10.58%	0.7%	412	6-Jan-06	2.8
407	10.49%	0.6%	412	7-Jan-06	2.4
408	10.41%	0.5%	412	8-Jan-06	2.1
409	10.32%	0.4%	412	9-Jan-06	1.7
410	10.24%	0.3%	412	10-Jan-06	1.4
411	10.15%	0.3%	412	11-Jan-06	1.0
412	10.07%	0.2%	412	12-Jan-06	0.7
413	9.98%	0.1%	412	13-Jan-06	0.3
414	9.90%	0.0%	412	14-Jan-06	0.0