NAVY RESPONSES TO FORENSICS RELATED COMMENTS FROM EPA ON DRAFT PHASE III RI QAPP, SITE 16 (EPA comments dated 20 SEP 2006)

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NCBC DAVISVILLE
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General EPA Comment No. 27:

Impacts to Allen Harbor Sediments; On the basis of the previously conducted Phase II Screening Level Ecological Risk assessment (SLER), the Work Plan de-emphasizes any potential impacts from Site 16 to Allen Harbor sediments. However, as noted in previous comments, while there may or may not be an unacceptable risk posed by the poly aromatic hydrocarbons (PAH) in Allen Harbor sediments, the data do not support the interpretation that the bulk of the PAH contamination is due to non-Site 16 activities. EPA's analysis suggests an alternative interpretation. Please see attached comments on the Forensic analysis. In general, the Navy has not provided enough information for EPA to agree with the Navy's conclusions, particularly with the impacts from the creosote operations from site 16 to the near-shore sediments.

The distribution pattern of PAH in the sediment (Figure 4-4 of the SLER) clearly shows an impact to the southwest and southern portions of the harbor from Seep 1 and the shoreline at Site 16. While marina dock pilings may contribute PAH to the harbor sediments, there has been no data directly linking the dock pilings with the observed PAH, let alone supporting an interpretation that they are the primary contributor of PAH to harbor sediments. An alternative explanation is needed. This is especially so when one considers the volumes of creosote that would have been used in the wood treating operation which was formerly operated at Site 16. This significant aspect of site history can not be overlooked. Historically, many pilings, telephone poles, etc. were treated at Site 16, a scant distance from the harbor. Additional evidence of the impact of past Site 16 activities can be seen from the concentrations of PAH around the north dock pilings and the southern dock pilings. If Site 16 were not the predominant contributor of PAH, then a much more uniform distribution of PAH around the southern and northern portions of the harbor and the marina dock should be expected. Instead, the concentrations are less (approximately 6 to 8 micrograms per kilogram) near the northern dock pilings, while higher concentrations (up to 16 to 18 micrograms per kilogram) are indicated along the southern dock pilings/shoreline. The relatively higher concentrations of PAH at the near-shore side of the marina dock is indicative of a concentration gradient which strongly suggests sediments are impacted to a greater degree from Site 16 than from the marina docks.

Additionally, while discharge of PAH along the southeast corner of the harbor has been ascribed to runoff inferred to be from non-Site 16 related vehicle traffic, etc., the PAH have also been attributed to storm drain discharge. However, to date, there has been no clear presentation of where this storm drain originates. It is not clear whether it collects only surface water runoff from Allen Harbor Road, or whether it actually also provides drainage from the North Central Area of Site 16, or for that matter, even from a portion of the railroad

spur area south of Davisville Road, where creosote soaked railroad ties exist. At a minimum, given the site topographic elevations, the storm drain would appear to run along Allen Harbor Road, from the south to north within Site 16, along the North-Central area. In any case, note that this entire area is within the confines of Site 16. Previous inspections of the North Central Area of Site 16 showed a concrete pipe at the northeast corner of Site 16 (southeast corner of the harbor) which could indicate contribution of drainage from that location.

In face of these issues, we agree that additional actions are necessary. The Navy is proposing a groundwater seep, piezometer survey of the harbor (12 sample locations). While this information will be useful, it is also possible that CVOC upwelling from groundwater is absorbed in organic matter in the sediment prior to discharging to the harbor water. Therefore, the Navy should supplement the proposed program with pore water samples from a number of locations in the near-shore environment using simple push-point (aka "Henry") samplers. To supplement the shoreline seep samples, pore-water samples may be collected in shallow water areas using an approach/grid pattern similar to that used in 2004 at Site 07. A relatively 'coarse' grid may be used as a first step. Applying "Triad" principles, identification of CVOC discharge areas through the initial round of pore-water samples may suggest the need to conduct additional phases of investigation (e.g., tighter grid spacing) in order to more accurately define the areas of plume discharge to surface water and sediment. Additionally, it would be of great benefit to provide a more definitive explanation/attribution for PAH in the sediment in the harbor. While a number of samples were collected during the Phase II SLER, additional samples should be collected and analyzed for PAH around the docks and shore line. Contributions from Site 16 can then be more clearly estimated, as well as the magnitude of any potential ecological or human health risks posed by the sediments. Additionally, a more accurate understanding of the storm drain network is clearly called for. This effort should identify and map the storm drain network and associated inputs including catch basin locations, potential points of infiltration into the storm drain network, points of discharge (e.g., into the harbor), and other pertinent information such as invert elevations and their relationship to water table depths. A detailed assessment of these features is needed, particularly at the northeast corner of Site 16, prior to ruling out contributions from that location as being from Site 16.

Response to General EPA Comment 27:

EPA believes that the concentration gradient of PAHs indicates an impact to the southwestern and southern portions of Allen Harbor from Seep 1 and the shoreline at Site 16. This conclusion is based on Figure 4-8 of the final SLERA for Site 16. EPA believes there is "no data" linking the dock pilings with the PAHs in the sediments.

EPA should reconsider the PAH gradients in Allen Harbor. The concentrations in the southern end of Allen Harbor are generally higher around the marina pilings and storm water outfalls relative to the Site 16 shoreline and Seep 1. The concentrations of PAHs sampled next to the marina pilings are higher relative to samples collected in neighboring open water areas. For example, AH-29 (marina piling; EPAPAHs = 24 mg/kg) was higher than AH-32 (more open water area; EPAPAHs = 9.89 mg/kg), AH-33 (more open water area; EPAPAHs

= 12.1 mg/kg), and AH-45 (Site 16 shoreline EPAPAHs = 6.35 mg/kg). Thus, there are PAH gradients that indicate the marina pilings or operations around the marina are associated with PAHs in the sediments.

EPA further implies that there were large volumes of creosote releases from the Navy wood treating operations. Navy is not aware of any documentation that describes the volumes of creosote used at Site 16. Thus, there is no basis for EPA to conclude that the quantity of creosote is proportional to the potential impact. Navy conservatively approached the absence of historical information by sampling the area known to contain the highest levels of creosote derived PAHs on the site. The highest concentrations of PAHs measured were below 51 mg/kg for total EPA Priority Pollutant PAHs. As stated in the forensics results associated with the SLERA report (Appendix F), the PAHs in this area are 1) present at relatively low levels and 2) dissimilar to the PAH source signatures in the proximal sediment samples even after weathering is considered. Thus, the creosote impacts to subsurface soils appeared limited and the pathway to the sediments was incomplete.

EPA expressed an interest in additional information regarding the watershed serviced by the storm drains that Navy associated with the conveyance of PAHs to Allen Harbor. Navy will survey the system and generate maps illustrating the known inlets and outlets of this system in addition to any other relevant data that is uncovered during this investigation. Additional work is also planned for further evaluating PAHs from the marina and storm sewer systems.

General Comments on the Phase II Screening Level Ecological Risk Assessment of Site 16 at the Naval Construction Battalion Center (NCBC), Davisville, Rhode Island with particular attention to *Appendix B, Final Report, Environmental Forensic Investigation, Site 16 (Former Creosote Dip Tank and Fire Fighting Training Area)*

Comment No. 1:

Based on the difference between the PAH signature found in source-area soils and in the Harbor sediments, Navy concluded that no 'strong evidence' linked historic activities conducted at the Site 16 source areas to PAH impacts to Allen Harbor sediments. Creosote is a complex mixture often containing several hundred constituents, about 80% to 90% of which are PAHs, with the remainder consisting of phenolic compounds, N-, S-, and O-heterocyclic compounds, and amines. Consequently, the environmental behavior of creosote is determined by a number of processes and mechanisms. Before the potential contribution of PAHs from Site 16 to Allen Harbor sediments can be dismissed, the analytical results reported in the Environmental Forensic Investigation should be discussed in light of creosote fate and transport.

It is known that weathering of creosote is highly dependent on environmental conditions to which it is exposed. Upland, aerobic soils taken from the Site 16 source areas 1 and 2 (as shown on Fig. 1-2) are likely to be subjected to intermittent saturation by infiltrating meteoric water, whereas sediments from Allen Harbor are probably anaerobic and saturated with salt water. Differences in grain size, salinity, nature and composition of organic matter, microbial populations, availability of oxygen, temperature, and a number of other factors will affect the manner in which creosote weathers (Brooks, 2004). It is well known that weathering of creosote results in the loss of light PAHs (LPAH) (2- and 3-ring) due to their greater susceptibility to biodegradation, volatility, and aqueous solubilities, and yields a relative enrichment in heavy PAHs (HPAHs).

In addition, creosote leaches more readily in fresh water than in seawater, and the higher molecular weight constituents are more rapidly attenuated during transport. Numerous laboratory and field simulations of creosote releases have shown high retardation of the higher molecular weight compounds and relatively rapid downward transport of the lower molecular weight compounds (WHO, 2004). The forensic evaluation showed that "…pyrogenic PAHs in Site 16 creosotes possessed a characteristic PAH signature that was absent in Allen Harbor sediments." Is it possible that the presence of pyrogenic PAHs in site soils is due to local attenuation (e.g., sorption), while the more soluble constituents were leached and transported to harbor sediments via groundwater?

Different formulations are known to leach at different rates (Cooper, 1991). For example, Xiao et al. (2000, 2002) and others (Padma et al., 1998) report that phenanthrene leaches at a

rate higher than that predicted from its aqueous solubility – how might this observation affect the observed anthracene/phenanthrene (A0/P0) ratios shown in Appendix B, on Figure 10?

Please incorporate into the Forensic Report a discussion of these effects in the interpretation of data from site soils and harbor sediments. Please consider the effects of surface weathering on Site 16 soils and attenuation during transport – either overland, by surface flow (in solution and sorbed on particulates), and/or as solutes in groundwater on flow paths from the Site discharging into the Harbor – in comparisons of PAH signatures.

Response to Comment 1:

The literature cited by EPA demonstrates the complexity, fate, and transport of creosote derived chemicals in the environment. These references describe creosote as a material composed of approximately 160 compounds of which 80% are PAHs. The migration of creosote is dominated by the dissolution and evaporation of 2- and 3-ring PAHs. The remaining 4- to 6-ring PAHs are considered chemically stable and immobile except in particulate form. Importantly, these references establish that PAHs migrate from treated wood materials into adjacent sediments.

All of these findings are consistent with forensic results presented in the SLERA. For example, the creosote residuals contain low levels of 2-ring PAHs and reduced, but clearly identifiable, amounts of 3-ring PAHs (Figures 10a and 10b). The dominant creosote derived PAHs are 4- to 6-ring PAHs attributed to stable and stationary subsurface soil residues. Biodegradation has clearly occurred in the Site 16 soils (e.g., dominant isoprenoid hydrocarbons in sample S2-1 illustrated in Figure 12b); however, it did not significantly alter the PAH source signatures of hydrocarbon products (e.g., biodegraded kerosene in sample S2-1 plots with kerosene reference samples in Figure 11b) with much greater susceptibility to weathering than creosote. In short, the source signatures described in the report resist the forces of environmental weathering exhibited in the study area.

The weathering process has been extensively studied in many media. It is controlled by volatilization, dissolution (water-washing), and biodegradation. Volatilization is largely limited to 2-ring PAHs. Dissolution generally results in the preferential loss of 2- and 3-ring PAHs and less alkylated homologs (Neff 1979). Likewise, biodegradation expresses itself largely in the 2-ring PAH range. Numerous researchers have demonstrated the use of PAH signatures for source identification even under severe weathering conditions (Douglas 1996; Dupree and Ahrens 2002; Garrigues et al. 1995; Luca et al. 2005; Uhler and Emsbo-Mattingly 2006; Yunker et al. 1993; Wang et al. 1999; Zhang et al. 2005). The scientific literature demonstrates the widely accepted practice of PAH source identification consistent with the forensic analysis in the SLERA report.

Douglas, G., Bence, A., Prince, R., McMillen, S. and Butler, E. (1996) Environmental stability of selected petroleum hydrocarbon source and weathering ratios. ES&T 30: 2332-2389.

Dupree, C. and Ahrens M. (2002) Distribution of Polycyclic Aromatic Hydrocarbons (PAHs) in and Urbanised Estuary and Possible Implications for Source Apportionment. 2nd International Symposium on Contaminated Sediments.

Garrigues, P., Budzinski, H., Manitz, M., Wise, S. (1995) Pyrolytic and Petrogenic Inputs in Recent Sediments: A Definitive Signature through Phanthrene and Chrysene Compound Distribution. Polycyclic Aromatic Compounds 7: 275-284.

Luca, G., Furesi, A., Micera, G., Panzanelli A. Piu, P., Pilo, M., Spano, N., and Sanna, G. (2005) Nature, distribution and origin of polycyclic aromatic hydrocarbons (PAHs) in the sediments of Olbia harbor (Northern Sardinia, Italy). Marine Poll. Bull. 50: 1223-1232.

Neff, J. (1979) Polycyclic Aromatic Hydrocarbons in the Aquatic Environment. Applied Science Publishers Ltd., London, p 262.

Uhler, A. and Emsbo-Mattingly, S. (2006) Environmental Stability of PAH Source Indices in Pyrogenic Tars. Bull. Environ. Contam. Toxicol. 76: 689-696.

Yunker, M., Macdonald, R., Vingarzan, R., Mitchell, H., Goyette, D. and Sylvestre, S. (2002) PAHs in the Fraser River basin: a critical appraisal of PAH ratios as indicators of PAH source and composition. Org. Geochem. 33: 489-515.

Wang, Z., Fingas, M., Shu, Y., Sigouin, L., Landriault, M., and Lambert, P., (1999) Quantitative characterization of PAHs in Burn Residue and Soot Samples and Differentiation of Pyrogenic PAHs from Petrogenic PAHs-The 1994 Mobile Burn Study. ES&T 33:3100-3109.

Zhang, X., Tao, S., Liu, W., Yang, Y., Zuo, Q. and Liu, Z. (2005) Source Diagnostics of Polycyclic Aromatic Hydrocarbons Based on Species ratios: A Multimedia Approach. ES&T 39: 9109-9114.

Comment No 2:

As the Report indicates (e.g., Sec. 4.2), the three Reference Areas – Coggeshall Cove, Jamestown Island, and Fishing Cove – are not comparable (described as 'physically dissimilar') to Allen Harbor. It appears that none of the reference areas are as hydraulically restricted as Allen Harbor, so it is not obvious how the reference area results can be interpreted as being representative of the urban overprint on hydrocarbon composition in Allen Harbor sediments. Please clarify the rationale for the statement that these represent "ambient background" (Sec. 1, p. 3). Please include in this discussion a comparison of the reference areas and Allen Harbor with respect to depth of water, marine vehicular traffic, surrounding land use, sedimentation rates, circulation patterns, etc. It is not clear how the PAHs found in Allen Harbor sediments are related to those in the reference areas by a "…common ubiquitous source" without further explanation.

Response to Comment 2:

The relationship of Allen Harbor and the Reference Areas is likely governed by the tidal influx of suspended particulates from Narragansett Bay into Allen Harbor. Hydrocarbons that adhere to particles have a high propensity to settle out of the water column in low energy environments, like Allen Harbor. The narrow entrance to Allen Harbor helps trap particles by reducing the energy level of the water. In this way, hydrocarbons observed in the Reference Areas would be expected in Allen Harbor sediments. While the relative abundances of hydrocarbons (e.g. the PAH source signature) is expected to be similar in Reference Area and Allen Harbor sediments, the absolute abundance of PAHs will likely vary as a result of localized factors. These localized factors can include the flux of sand (effectively a dilution agent), hydrodynamics (higher concentrations could occur in areas of higher particle settling rates), and land use (runoff from more urbanized areas will contain higher levels of PAHs relative to residential or undeveloped areas). In summary, Allen Harbor exhibits a mixture of ubiquitous PAHs, like those observed in the Reference Areas, which is mixed with local landside and marina based inputs. The PAH concentration gradients and source signatures both suggest that the marina and storm water runoff represent the most significant sources of PAHs in Allen Harbor.

Comment No. 3:

Data from reference samples of former fire fighting training fuels, consisting of neat, combusted, and evaporated middle distillates, were incorporated into the Forensic Investigation. Given possible differences in creosote formulations and effects of weathering and segregation during transport (please see General Comment 1, above), the absence of reference materials demonstrating variability in the various PAH patterns (i.e., concentrations, and relative abundances) due to weathering of creosote seems to be a 'data gap.' Please explain why no weathered creosote samples were included in the reference materials.

Response to Comment 3:

Source samples 1-1 and 1-2 (Figures 8a and 8b) are weathered creosote. No data gap exists. No additional reference samples are necessary. EPA can find examples of weathered creosote in the references it cites in Comment 1. Additional reference materials can be found in the response to Comment 1.

Comment No. 4:

The transport of surficial material from the Site into proximal Allen Harbor sediments via the stormwater outfall pipe requires additional discussion. Where does this pipe originate? What area does it drain? Are there other outfall pipes, or a network of pipes across the Site? Please elaborate on the role of the stormwater outfall system at the Site, including details on the direction and extent of the pipe(s). What is the nature of the seeps? Are these natural, or are they also anthropogenic structures?

Response to Comment 4:

Navy will further delineate the storm water drainage systems around the study area. The impact of the seeps to the Allen Harbor sediments appears minimal. The PAH concentration gradients proximal to the seeps is relatively low compared to other local sources, like the marina and storm water outfalls.

Comment No. 5:

It is stated in the Phase II Screening Level Ecological Risk Assessment (please see, for example, p. ES-1, Executive Summary, 4th paragraph, and elsewhere in the report) that "[C]oncentrations of chemicals in Allen Harbor were homogeneous" and that "…there is no real difference in concentrations close to shoreline areas relative to the other areas of Allen Harbor." The distribution of sample locations is clearly biased toward the south end of the Harbor (Figs. 2-2 and 2-3), with most of the AH sediment samples close to the shoreline (the Inner Harbor and Marina Areas) and relatively fewer samples in the Outer Area. Despite the limited number of forensic analyses overall, and particularly in the Outer Area, concentrations are <u>not</u> homogeneous.

In fact, the highest PAH concentrations are found in sediment samples along the south shore of the Harbor. From Table 5-3, it can be seen that the maximum concentrations of most of the individual PAHs occur at locations AH-49 (next to the stormwater outfall), AH-28, AH-29 (next to south dock), and AH-35 (adjacent to Seep 16-01). Figure C-2B shows the highest total PAH concentrations in AH-49 and AH-28. Most of the maximum concentrations of inorganics are near the docks (AH-17 and AH-29). Because the overall picture suggests that sediments closest to the site do, in fact, contain the highest concentrations of PAHs, and taking into account the uncertainties in PAH sources, segregation during weathering and leaching at the Site 16 source area, attenuation by different transport mechanisms, etc., the conclusion that the PAH impacts to Allen Harbor are not attributable to site activities is not well-supported.

Response to Comment 5:

The sampling plan was weighted towards the Inner Allen Harbor specifically for the purpose of detecting PAH impacts from candidate sources. The higher sampling resolution in this area was necessary for differentiating contributions from Site 16, marina, and storm sewer outfalls because these sources are in close proximity in the Inner Harbor.

The reference to PAH homogeneity refers to the limited range of PAH concentrations measured in the Allen Harbor; i.e., the concentrations generally fell between about 5 and 50 mg/kg. Forensically, all of the samples were dominated by plant waxes with lower levels of heavy residual petroleum and low level PAHs. Sample AH-49 was the principal exception. The relatively similar concentration and composition of these samples support the general

homogeneous description of Allen Harbor sediments.

EPA should reconsider the PAH gradients in Allen Harbor. The concentrations in the southern end of Allen Harbor are generally higher around the marina pilings and storm water outfalls relative to the Site 16 shoreline and Seep 1. The concentrations of PAHs sampled next to the marina pilings are higher relative to samples collected in neighboring open water areas. For example, AH-29 (marina piling; EPAPAHs = 24 mg/kg) was higher than AH-32 (more open water area; EPAPAHs = 9.89 mg/kg), AH-33 (more open water area; EPAPAHs = 12.1 mg/kg), and AH-45 (Site 16 shoreline EPAPAHs = 6.35 mg/kg). Thus, there are PAH gradients that indicate the marina pilings or operations around the marina are associated with PAHs in the sediments.

It is important not to confuse the high levels of PAHs observed at AH-49 with historical impacts from Site 16. AH-49 and AH-28 represent modern impacts from storm water. As stated previously, Navy will map the storm drainage system and further study the conveyance of PAHs to the outfall areas. It is anticipated from previous discussions with field personnel that the inlets for the storm sewers nearest AH-28 and AH-49 are associated with proximal roads and commercial parking lots.

Inspection of the sample location map clarifies several other issues. Samples AH-17, AH-29, and AH-35 were collected next to marina pilings. EPA incorrectly associated AH-35 with the Seep 16-01. Therefore, the overall picture portrayed in the forensic report is well supported. The marina pilings and storm sewer system are the most likely sources of PAHs in Allen Harbor.

Specific Comments:

Comment No. 6:

p. 6, Sec. 3. The text notes that total organic carbon (TOC) content of the harbor sediments was higher than TOC in the reference locations, but that the difference was not 'statistically significant.' What statistical test was used to establish this? Were other parameters characterizing the reference area samples and harbor sediments (e.g., EPAPAH or TPAH) also subjected to comparative statistical analysis? If so, please add this information to this section.

Response to Comment No. 6:

The Navy has consulted with the key author of the Phase II SLERA, EA Engineering, Science, and Technology (Dr. Daniel Hinckley) who indicates that a standard t-test would have been performed to compare harbor versus reference area TOC samples (the null hypothesis would have been that the difference between the means was zero, using an alpha value of 0.05).

Comment No 7:

p. 10, Sec. 4.4. The 2nd bullet states that "[T]he pyrogenic PAHs in Source Area 1 creosotes shared a distinctive enrichment of anthracene that was absent in the proximal Allen Harbor sediments." The data in Table A-2 indicate that the highest concentrations of anthracene are reported from samples at the south end of AH adjacent to Site 16 (e.g., AH-49, at 814 μg/kg; AH-28, 792 μg/kg; AH-35, 693 μg/kg) while samples from the Outer Harbor area report considerably lower concentrations (e.g., AH-06, 86 μg/kg; AH-08, 181 μg/kg, and AH-11, 177 μg/kg). Please explain this apparent contradiction. Also, please see General Comment 5, above, regarding the distribution of PAH concentrations.

Response to Comment 7:

The enrichment discussed in this section refers to the concentration of anthracene relative to phenanthrene. The relative abundance of anthracene to phenanthrene is usually low; i.e., about 0.2 (Stout et al., 2004). The enrichment of anthracene relative to phenanthrene requires chemical refining (Rhodes, 1945). Creosote products are manufactured at a tar refinery and some contain ratios of anthracene to phenanthrene greater than one. When these creosotes are observed in the environment (e.g., abraded marina piling debris), they mix with ambient sediments and result in the cumulative anthracene to phenanthrene ratio to be in the 0.5 to 2.0 range (approximate).

The pyrogenic PAHs in Source Area 1 creosotes shared a distinctive enrichment of anthracene *relative to phenanthrene* that was absent in the proximal Allen Harbor sediments.

Rhodes, E.O., "The Chemical Nature of Coal Tar," in National Research Council Committee. Chemistry of Coal Utilization. ed: H. H. Lowry United States: John Wiley & Sons, Inc.; 1945.

Stout, S.A., Uhler, A.D., and Emsbo-Mattingly, S.D. (2004) Comparative Analysis of Background Anthropogenic Hydrocarbons in Surficial Sediments from Nine Urban Waterways. Environ. Sci. & Technol. 38: 2987-2994.

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Brooks, K. M., 2004. Polycyclic Aromatic Hydrocarbon Migration from creosote-treated railway ties into ballast and adjacent wetlands, USDA Forest Service Research Paper FPL-RP-617, Madison WI. 53 pp.

Cooper, P.A. 1991. Leaching of Wood Preservatives from Treated Wood in Service. Prepared for Public Works Canada, Ottawa, Ontario. January 1991.

Crawford, D. M., and De Groot, R. C., 1996. Evaluation of new creosote formulations. Forest Products laboratory, USDA Forest Service Technical Report.

WHO, 2004. Coal Tar Creosote. From Concise International Chemical Assessment Document 62, First draft prepared by Drs Christine Melber, Janet Kielhorn, and Inge Mangelsdorf, Fraunhofer Institute of Toxicology and Experimental Medicine, Hanover, Germany. Published under the joint sponsorship of the United Nations Environment Programme, the International Labour Organization, and the World Health Organization, and produced within the framework of the Inter-Organization Programme for the Sound Management of Chemicals. World Health Organization, Geneva, 2004.

Tiruponithura V. Padma, Robert C. Hale, and Morris H. Roberts, Jr., 1998, Toxicity of water-soluble fractions derived from whole creosote and creosote-contaminated sediments. *Environmental Toxicology and Chemistry*: 1998, No. 17(8), pp. 1606–1610.

Xiao, Y., J. Simonsen, and J.J. Morrell. 2000. Laboratory Simulation of Leaching from Creosote Treated Wood in Aquatic Exposures. IRG/WP 00-50157. International Research Group on Wood Preservation. Prepared for the 31st Annual Meeting, Kona, HI, 14-19 May.

Xiao, Y., J. Simonsen, and J.J. Morrell. 2002. Effect of Water Flow Rate and Temperature on Leaching from Creosote-Treated Wood. Research Note FPL-RN-0286. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.