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Section II
Stratus Creosote Report and Comments

1. Federal Register announcement of report and request for comments

[Federal Register: March 3, 2006 (Volume 71, Number 42)]
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DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

[I.D. 013006H]

Availability of Two Reports: Treated Wood in Aquatic Environments: Technical Review and Use Recommendations; and Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations

AGENCY: National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Commerce.

ACTION: Notice of availability; request for comments.

SUMMARY: NMFS is providing this notice in order to allow Federal and state agencies and the public an opportunity to review and provide comments on two reports, prepared for NMFS by an independent consulting firm, regarding the use of treated wood products in aquatic environments. The intent of the reports is to ensure NMFS is informed of relevant studies and recommendations when making decisions related to the use of treated wood in aquatic environments. This information may be used for future development or revision of NMFS treated wood-use guidelines. NMFS is soliciting public comment on whether the treated wood documents sufficiently summarize the existing body of knowledge concerning copper and creosote treated wood products,

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including the fate and transport of leached materials, the appropriate use of treated wood products, and the potential effects on living marine resources and their habitats. In addition to this public comment opportunity, the reports will also be subject to independent peer review.

DATES: Public comments must be received by 5 p.m., Pacific standard time May 2, 2006.

ADDRESSES: Comments on these reports may be submitted by mail to the National Marine Fisheries Service, 777 Sonoma Avenue, Suite 325, Santa Rosa, CA 95409, Attn: Water Quality Coordinator/Treated Wood Comments. Comments concerning the Treated Wood in Aquatic Environments report may be sent via facsimile to (301) 427-2538. Comments concerning the Creosote-Treated Wood in Aquatic Environments report may be sent via facsimile to (301) 427-2540. Comments may also be submitted electronically. For comments regarding the Treated Wood in Aquatic Environments report, please e-mail your comments to SWR.CopperWood@noaa.gov. For comments regarding the Creosote-Treated

swr.nmfs.noaa.gov/ or may be requested by calling or emailing the contact person listed below. Please include appropriate contact information when requesting the documents.

FOR FURTHER INFORMATION CONTACT: Joseph Dillon, Southwest Region Water Quality Coordinator at 707-575-6093 or by email, Joseph.J.Dillon@noaa.gov.

SUPPLEMENTARY INFORMATION: The purpose of the technical review documents is to present a summary of existing literature, prepared independently by Stratus Consulting, Inc. for NMFS, that analyzes the potential effects and mitigations for the use of treated wood products in aquatic environments. The documents focus on copper treated wood, primarily ammoniacal copper zinc arsenate (ACZA), as this is the most prominent material used on the west coast of the United States and in Alaska, and creosote treated products.

These products are being examined by NMFS to determine the risks

generated by their usage to the living marine resources that NMFS is responsible for managing. These include anadromous salmonids managed by NMFS under the Endangered Species Act (ESA), as well as other marine fishery resources including Essential Fish Habitat (EFH) as identified and described under Federal fishery management plans pursuant to Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). The use of treated wood in or near aquatic environments commonly requires a permit issued by the U.S. Army Corps of Engineers pursuant to the Clean Water Act and the Rivers and Harbors Act of 1899. Under the ESA, Federal agencies must consult with NMFS pursuant to section 7 of the statute to ensure that any action authorized, funded or carried out by the Federal agency does not jeopardize the continued existence of any threatened or endangered species or result in the destruction or adverse modification of designated critical habitat. Federal action agencies are also required by the Magnuson-Stevens Act to consult with NMFS on any action that may adversely affect EFH. In issuing this permit, the U.S. Army Corps of Engineers will have to conduct an EFH assessment pursuant to 60 CFR 600.920(e) to determine whether the proposed permitted action will adversely affect EFH.

Effects of treated wood that need to be examined under the ESA and Magnuson-Stevens Act regulations include direct, indirect, and cumulative effects. An example of direct effects includes the acute and sublethal impacts of copper and polycyclic aromatic hydrocarbons to salmonids and the EFH of managed species. An example of an indirect effect includes the adverse impacts to the prey base upon which ESA listed and EFH managed species depend. An example of a cumulative effect includes the impacts of multiple structures and contaminants in an area with or without additional loading from urban sources, historic mining, smelters, ships' hulls or any other source. The synthesis of these effects to habitat and to individuals, coupled with local environmental conditions and specific species of concern, defines the risk of a project proposing the use of treated wood.

Since the use of treated wood materials in situations that may expose aquatic ecosystems is widespread along the west coast of the United States and in Alaska, development of guidelines from the information presented in these reports should help to streamline the review of permitting processes as well as the permitting processes themselves. These reports may be used in the future to create new or update existing NMFS policies regarding treated wood.

Dated: February 27, 2006.

James W. Balsiger,

Deputy Assistant Administrator for Regulatory Programs,National Marine Fisheries Service.

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Section II

Stratus Creosote Report and Comments

2. Comments of David A. Webb, Administrative Director, Creosote Council III

CREOSOTE COUNCIL III

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May 2, 2006

National Marine Fisheries Service
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Attn: Water Quality Coordinator/Treated Wood Comments

Re: Comments on draft Stratus Consulting report entitled, *Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations* (Oct. 17, 2005)

Dear Sir:

On February 27, 2006 the National Marine Fisheries Service (NMFS) issued a notice, published at 71 Fed. Reg. 10957 (March 3, 2006), announcing availability of, and soliciting public comment on, two Stratus Consulting Inc. reports, each dated October 17, 2005, regarding use of treated wood in aquatic environments. One of those reports, *Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations* (hereinafter "*Technical Review*"), is the subject of these Creosote Council III ("Creosote Council") comments.[1]

The Creosote Council is the national, non-profit product stewardship organization for the U.S. creosote industry. Creosote is a highly beneficial, federally registered, industrial wood preservative used primarily for pressure treatment of railway ties, utility poles, and marine pilings. In addition to sponsoring all of the scientific studies that the United States Environmental Protection Agency (EPA) has required for reregistration of creosote under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the

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[1] The other Stratus Consulting report, confusingly entitled *Treated Wood in Aquatic Environments: Technical Review and Use Recommendations*, pertains primarily, if not exclusively, to waterborne wood preservatives, particularly CCA, ACZA, and ACQ.

Council often comments on federal or state legislative or regulatory matters that affect the nation's creosote producers, creosote wood treaters, or industrial/commercial users of creosote-treated wood products.

NMFS consideration of possible guidelines relating to use of creosote-treated wood in Pacific coastal aquatic environments, and specifically the technical review which the NMFS Southwest Regional Office engaged Stratus Consulting Inc. to conduct in connection with development of such guidelines, is a matter of substantial interest and concern to the Creosote Council. For the reasons discussed below, Stratus' supposedly independent and objective creosote *Technical Review* exceeds the proper bounds of a scientific analysis, reflects the NMFS Southwest Regional Office's own patent bias against use of creosote-treated wood, and contains numerous outcome-driven assertions and conclusions that are inaccurate, misleading, or scientifically unwarranted. As a result, the Stratus creosote *Technical Review* utterly fails to fulfill its stated objective, which NMFS indicated "was to establish a solid scientific basis from which guidance development and implementation could proceed." NMFS Statement of Work for Center for Independent Experts (CIE) at 2.

GENERAL COMMENTS

1. Draft Status of *Technical Review*

In response to the Creosote Council's concerns that the Stratus report be released in *draft* form for public review and comment, Dr. William T. Hogarth, Director of NOAA Fisheries, indicated in a February 2, 2005 letter to the Council that "*[d]rafts* of Stratus' treated wood summary documents will be released for public comment *prior to finalization*" (emphasis added). Similarly, Dr. Hogarth wrote to the Council on October 12, 2006, reconfirming that "NMFS will release the *draft* literature review and synthesis reports from Stratus for public comment" (emphasis added).

Despite Dr. Hogarth's written assurances to the Creosote Council, nothing on the face of the Stratus *Technical Review* of creosote-treated wood indicates that it is a draft. Instead, the creosote *Technical Review*, whose printed color cover is dated October 17, 2005, gives every appearance of being a final document. Further, the document is posted on the NMFS Southwest Regional Office's web site under "Items of Interest" without any indication that it is a draft, and the document is never referred to as a draft in the NMFS March 3, 2006 *Federal Register* notice. Even worse, the Council's understanding is that overly zealous NMFS personnel have been disseminating the creosote *Technical Review* to other federal agencies' personnel as if it were a final document rather than

cautioning that it is merely a draft and subject to revision following public comment and peer review.

Given that NMFS has submitted the creosote *Technical Review* for peer review, the document necessarily must be treated as a draft. *See* Office of Management and Budget (OMB), *Final Information Quality Bulletin for Peer Review* (Dec. 16, 2004), at 3 ("Peer review involves the review of a draft product by specialists in the field who were not involved in producing the draft."). To help rectify the misleading impression that NMFS and Stratus have created, the Creosote Council requests NMFS to promptly take the following actions: (i) stamp the cover and each page of the creosote *Technical Review* as a "DRAFT"; (ii) substitute the DRAFT-stamped document on the NMFS Southwest Regional Office web site and indicate that the draft creosote *Technical Review* is subject to public comment, peer review, and revision; (iii) publish a supplemental *Federal Register* notice clarifying that the October 17, 2005 creosote *Technical Review* is a draft, and subject to public comment, peer review, and revision; and (iv) advise all cognizant NMFS personnel that the creosote *Technical Review* is a draft document subject to public comment, peer review, and revision, that they must explain this fact whenever disseminating the draft, and that they may only disseminate the DRAFT-stamped version of the document.

2. Peer Review Procedures

The March 3 *Federal Register* notice states that the Stratus reports "will also be subject to independent peer review." 71 Fed. Reg. at 10958. More specifically, NMFS unilaterally determined—without any stakeholder input—that peer review of the Stratus creosote *Technical Review* (and the Stratus companion report on wood treated with waterborne preservatives) would be conducted by the Center for Independent Experts (CIE), which operates under the auspices of the Cooperative Institute for Marine and Atmospheric Science, a University of Miami–NOAA Fisheries joint institute. As a threshold matter, the Creosote Council believes that consistent with traditional peer review practices within the scientific community, NMFS should have sought stakeholder input in advance regarding subjects such as whether the CIE is the best suited organization to conduct an expert and independent peer review of the Stratus reports; what the specific experience and qualifications of the peer reviewers, and the pertinent conflict of interest considerations, should be for this particular peer review; and what the peer review process should entail. Instead, NMFS acted unilaterally in selecting CIE and devising the Statement of Work (including the Terms of Reference), so as to foreclose any stakeholder input.

The Creosote Council is especially concerned NMFS determined that the CIE peer review—which the Statement of Work describes as merely a "letter review"—should not be conducted in an open, transparent manner, and without any opportunity for stakeholder input directly to the peer reviewers, whose identities and qualifications still remain unknown to stakeholders and the public. NMFS apparently referred the Stratus reports to the CIE for peer review at least one month before they were released for public comment. Under the NMFS Statement of Work, each of the three (unidentified) members of the CIE peer review panel is to spend a maximum of only five days working individually on the project. There does not appear to be any opportunity for the peer reviewers to interact with each other, much less receive and consider comments from outside scientists, stakeholders, or the public. In fact, the Statement of Work requested that the peer reviewers' individual (non-consensus) reports be submitted to NMFS by April 14, 2006, more than two weeks prior to the May 2, 2006 deadline for public comments on the Stratus reports. As far as the Creosote Council knows, the CIE peer reviewers' reports (which presumably now have been forwarded to NMFS) have not yet been released to the public, and thus, the Council must hereby reserve (indeed, insist upon) a timely opportunity to comment on the CIE creosote peer review reports after NMFS finally makes them available.

CIE's procedures certainly allow for a peer review panel to conduct a meeting at which stakeholders can speak and/or submit written comments directly to the panel in connection with a NOAA-related issue, and to meet and confer in executive session following such a meeting, before each peer reviewer prepares his/her own independent report. *See, e.g.*, CIE's Groundfish Peer Review (reports describing CIE process utilized in that peer review are posted at www.rsmas.miami.edu/groups/cie/cierevlnks.htm.) The OMB *Final Information Quality Bulletin for Peer Review* states as follows:

> Public comments can be important in shaping expert deliberations. . . . there are situations in which public participation in peer review is an important aspect of obtaining a high-quality product through a credible process. . . .
>
> Public participation can take a variety of forms, including opportunities to provide oral comments before a peer review panel or requests to provide written comments to peer reviewers. Another option is for agencies to publish a "request for comment" or other notice in which they solicit public comment before a panel of peer reviewers performs its work.

OMB *Bulletin* at 21. Rather than utilizing any such open procedure here, NMFS mandated a limited, closed, paper procedure in which the anonymous peer reviewers are insulated from any outside criticisms of the Stratus reports, and apparently even the ability to confer with each other. This abbreviated "behind closed doors" peer review process might suit NMFS's purposes, but it violates the spirit of the OMB *Bulletin*. It strongly suggests that the NMFS Southwest Regional Office has attempted to rig the peer review process in order to obtain a quick rubber stamp of approval from the peer reviewers, not a fully informed, independent scientific evaluation of the Stratus reports.

3. NMFS Consideration Of Stakeholder Comments

The Creosote Council's understanding is that NMFS has contracted with Stratus to review stakeholder comments on the Stratus reports (such as these Creosote Council comments), and to prepare written responses to those comments. In addition to Stratus' review of the comments, the Creosote Council believes that it is extremely important for NMFS to review and consider all comments independently of Stratus. This is especially true for comments, like the Creosote Council's comments, which criticize the scope, content, and quality of the Stratus *Technical Review*. Of course, it also is important for both NMFS and Stratus to consider the peer review reports.

4. Nature and Utilization Of Potential NMFS Guidelines

As the Creosote Council noted in its September 13, 2005 letter to Dr. Hogarth, it is imperative for NMFS and its personnel, especially in the regional offices, to understand that any NMFS regional (or national) "guidelines" regarding use of, or issuance of permits for, creosote-treated wood in aquatic environments, must be regarded merely as non-binding guidance. Any such guidelines will *not* be regulations, will *not* have the force and effect of law, will *not* have to be utilized by NMFS personnel when consulted on particular types of projects or individual projects, and will *not*, as a matter of law, govern review or approval of permit applications by any federal, state, or local agency.

Further, while the Creosote Council acknowledges NMFS' consultative, permitting, and other functions under the Endangered Species Act and Magnuson-Stevens Act, the Council wishes to emphasize that through FIFRA, Congress has vested EPA with the primary authority to regulate the use of creosote, before, during, and after its application to wood products such as marine pilings. FIFRA's fundamental purpose is to protect health and the environment. Consistent with that mandate, EPA is nearing conclusion of a comprehensive, objective, non-biased, science-based FIFRA reregistration review of creosote (as well as conducting reregistration reviews of waterborne wood preservatives and numerous other pesticidal active ingredients). Under

reregistration or other FIFRA review processes, EPA will determine, at the appropriate time, what restrictions, if any, should be imposed in connection with use of creosote-treated wood in aquatic environments. Although the consultative and/or permitting activities of NMFS, the Fish and Wildlife Service, and the U.S. Army Corps of Engineers are important, they are ancillary to EPA's primacy regarding how use of creosote-treated wood should be regulated, including in aquatic environments.

SECTION-BY-SECTION COMMENTS

Title of report — The title "*Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations*" is inaccurate since the creosote report (unlike the separate Stratus waterborne wood preservative report) does not make any specific recommendations regarding use of creosote-treated wood products in aquatic environments. Accordingly, the phrase "Use Recommendations" should be deleted from the title, which instead should be *Creosote-Treated Wood in Aquatic Environments: Technical Review*. Similarly, the penultimate sentence in section 1.1, which incorrectly asserts that Chapter 4 of the report includes "recommendations to minimize the environmental risks of toxic chemicals in aquatic environments" should be deleted.

Section 1.3 ("Types of Oil-borne Wood Preservatives") — The last sentence of the first paragraph asserts that "[t]o protect wood from these organisms, preservative formulations must be toxic to the wood-degrading organisms." This statement is incomplete at best. To be effective, wood preservative pesticides need only establish a zone of wood pest inhibition at susceptible sites on treated wood. Contrary to the Stratus creosote report, efficacy as a wood preservative does not depend on production of adverse effects in wood-degrading organisms. This distinction may be esoteric to some, but goes to lack of objectivity in the Stratus draft and suggests bias against wood preservative pesticides.

Section 1.4 ("Creosote Composition") — This section of the Stratus creosote *Technical Review* attempts to describe in summary fashion the composition of coal tar creosotes used to treat wood. The point of the section seems to be that despite an acknowledged composition that ranges widely and includes a large number and variety of components, the Stratus draft would take creosote to be a small collection of PAH compounds, primarily those regulated by EPA as carcinogenic. The main citation in the Stratus draft for this position is the World Health Organization (WHO) International Program on Chemical Safety (IPCS) document on Coal Tar Creosote (WHO, 2004). The Stratus draft points to the WHO document (and to a lesser degree on a 2000 publication by Eisler) as an authoritative source for a presentation on creosote physical properties and chemical composition. The draft goes on to state that the WHO publication includes

creosote compositional analyses from eight studies including creosotes from the United States, Britain, Germany, and the former Soviet Union.

It is quite unlikely that the WHO document includes analytical information developed on a North American creosote. Table 3 of the WHO document does present compositional information on eight creosote samples from around the world and claims that one of these eight is an AWPA P1 creosote. The source of this data is a Tar Industries Services report prepared in 1990 for an International Tar Conference. It is unlikely that the creosote analyzed for the 1990 International Tar Conference originated in North America or even conformed to AWPA specifications for P1/P13 creosote since complete compositional analysis of AWPA P1/P13 and P2 creosotes was not reported until 1994. Likewise, the Stratus draft merely acknowledges North American creosote and cites only EPA's summarization of North American creosote compositional data.

Actual compositional data for North American creosote are never presented in the Stratus draft. The absence of the most complete and reliable analytical characterization of creosote is more than an example of a mere omission of detail on a complex topic: it is a flaw in the foundation of the way the overall analysis was conducted. If an assessment of the environmental effects of creosote and creosote-treated wood is to be made on the basis of what is known about individual components of creosote, the lack of cogent comprehensive compositional information on creosotes detracts greatly from the validity of the assessment. This is the case with the Stratus draft assessment despite the availability of compositional and physical property analyses on certified samples of North American P1/P13 and P2 commercial creosotes.

The Creosote Council does not agree with the approach taken by Stratus to evaluate creosote risk by summing available information on the hazards of creosote components. However, once taken, that approach is susceptible to the uncertainty in quality and incompleteness of the analytical information relied upon by Stratus. Despite the assertion in the last sentence of section 1.4[2] in their analysis of creosote, Stratus moved quickly through the complexities and differences of creosote composition to reach a position of equating creosote with a select group of polyaromatic hydrocarbons (PAHs). The Stratus draft points out that EPA has classified 7 PAHs as probable human carcinogens (Group B2) but does not point out that the most recent and complete studies

[2] That "[w]hen considering the environmental impacts and toxicity of leached creosote in this report, we often will refer to the contaminants in leachate as 'PAHs' for simplicity, though we in fact mean 'PAHs, phenolics, heterocyclics, and other contaminants.'"

of creosote-exposed populations fail to show an association between creosote and cancer incidence (Wong and Harris, 2005, J Occup Environ Med 47:7, 683-97). Moreover, hazard assessment of complex mixtures must take into account the interactions of the components of the mixture. This was largely undone by Stratus in the present exercise.

Taken together, the points outlined above suggest that the Stratus draft report on creosote captured only a limited portion of the compositional information available on North American creosotes. There are at least two consequences to this: (1) the creosote hazard assessment offered by Stratus can be no more reliable than the Stratus view of what creosote actually is; (2) the creosote hazard (and risk) assessments of Dr. Kenneth Brooks which are based on assessment of actual creosote exposures are far more relevant and reliable than the assembled component assessment of Stratus.

Section 1.5 ("Creosote Regulations and Policies") — This section of the report is outside the scope of a technical review of scientific literature and should be deleted. Furthermore, the so-called regulatory discussion is highly selective, incomplete, and inaccurate. It reflects a pronounced bias against use of creosote and creosote-treated wood, which seriously undermines the credibility of the entire report.

The following additional comments relate to section 1.5:

(a) The reference to the "absence of federal guidelines" incorrectly implies that there is no federal regulation of creosote from the viewpoint of protecting the aquatic environment. As discussed in the General Comments above, the use of creosote, from both human safety and environmental viewpoints, is primarily and comprehensively regulated by EPA pursuant to FIFRA.

(b) The fact that nonprofessional use of creosote is "banned" in Europe, as it is in the United States, is irrelevant to use of commercially produced, creosote-treated wood products in aquatic environments.

(c) The assertion that "Table 1.4 provides some examples of creosote regulations and policies that *have been enacted* in the past few years and demonstrates the *consistency of approaches* toward creosote use in aquatic environments" (emphasis added) is inaccurate and misleading. For example, the New York creosote bill that Gov. Pataki carefully considered and then vetoed *twice* obviously is not a creosote-related regulatory measure that has been "enacted," and therefore should not have been included in the table. Further, the small number of agency policies identified in the table are not consistent with each other, much less representative of the vast majority of states and

local governments, which do not prohibit or restrict the use of creosote-treated wood in aquatic environments.

(d) Section 1.5 states that "[t]he U.S. EPA published a risk assessment, described below, that will be used by the agency to decide whether creosote will be re-registered as a pesticide." The Stratus creosote *Technical* review cites, quotes from, and comments on EPA's 2003 ecological effects risk assessment, but fails to explain that the document, which is part of EPA's FIFRA creosote reregistration review, is a *preliminary* risk assessment and subject to revision or refinement following EPA's consideration of public comments. *See* 68 Fed. Reg. 68042 (Dec. 5, 2003) (announcing availability of EPA's preliminary risk assessments on creosote, soliciting comment from interested parties, and explaining that revised risk assessments will be prepared). In addition to the Creosote Council and other interested parties, NMFS submitted extensive written comments on EPA's preliminary ecological effects risk assessment, including a summary of research and peer-reviewed references that NMFS deems relevant to EPA's reregistration review. Further, NMFS recently met with EPA to provide technical assistance in connection with the FIFRA reregistration review. In view of NMFS' direct input to EPA on creosote-related ecological effects issues, it serves no useful purpose, and is counterproductive, for the Stratus report to comment on the preliminary risk assessment.

Section 2 ("Models of PAH Leaching from Treated Wood and Environmental Exposure") — The Creosote Council endorses and supports the comments of Dr. Kenneth M. Brooks on this section of the Stratus draft report. The Council knows of no one with greater experience and insight in this area of science than Dr. Brooks.

Section 3.1 ("Toxic Components of Creosote") and **Section 3.3.3** ("Carcinogenesis") — The assertion in the second paragraph of section 3.1 that there is "little information concerning the interactive effects of creosote components" is incorrect. The most serious application of this misimpression by Stratus occurs in their description of carcinogenicity in section 3.3.3 of the draft. The Stratus draft points out that mechanisms of the chemical induction of cancer are similar in mammals and fish. In its review of the literature on this topic, Stratus focuses on studies in which a PAH, usually BaP, was dosed to fish (dose levels never stated) and internal organ tumors or genetic lesions are described. For purposes of these comments, the Council notes that in the Stratus draft report these effects are then ascribed to creosote. Stratus places heavy emphasis on biomonitoring specific enzyme induction products (CYP1A protein) as means of gaging carcinogenicity. While there is strong evidence about the activation of the AHH receptor and subsequent regulation of transcription and translation, the ultimate

outcome of this homeostatic sequence is not so well established, particularly with regard to neoplasia. The paragraphs below illustrate this point.

The hydrocarbon components of creosote do consist of planar fused ring compounds termed polyaromatic hydrocarbons (PAH), nitrogen and sulfur-containing hetereocyclic compounds and nitosubstituted aromatics. PAHs vary considerably in their biological activity. PAHs are indirect-acting or promutagens, meaning that genotoxicity is expressed following metabolic conversion of the PAH to an active species. The mechanism by which PAHs are thought to induce tumor formation is via interaction with genetic material within target cells; either frank mutagenicity or interference with normal genetic biology as a result of PAH-adduct formation with nuclear material. Photomutagenicity, or the property of enhancing the mutagenicity of non-ionizing radiation, has been reported for PAH mixtures and can account for the observation of a lack of mutagenicity in highly carcinogenic neutral PAH mixtures.[3] [4] The presence of PAH antimutagens has also been suggested to account for the difference in activity observed between isolated components of a PAH mixture and the intact mixture.[5]

The use of individual PAH components of a mixture, or any individual component, as a surrogate for the mix is fraught with possibilities for mistake. There is no validated method for tracking or otherwise characterizing the fate of mixtures of variable composition through the use of an indicator molecule. The National Research Council Report from the Board on Environmental Studies and Toxicology stated in their report on *Complex Mixtures – Methods For In Vivo Testing*,[6] indicator molecules have been used to assess mixtures based on the behavior of a constituent on the assumption that the behavior of the constituent is representative of the mixture. In judging this approach, the Committee cited the example of BaP. The committee reviewed independent research from six investigators, which collectively indicate that the BaP

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[3] Selby, C. P., et al., 1986. Chemical basis for photomutagenicity in synthetic fuels and correlation with carcinogenicity. Mut Res. 188:4, 287-299.

[4] Mahlum DD, 1983. Initiation/promotion studies with coal-derived liquids. J Appl Toxicol 3(1):31-34.

[5] Dasenbrock, C. et al., (1996) The carcinogenic potency of carbon particles with and without PAH after repeated intratracheal administration in the rat. Toxicol.Lett., 88: 1-3, pp 15-21.

[6] NRC, Complex Mixtures: Methods for In Vivo Toxicity Testing. National Research Council Committee on Life Sciences, page 13, National Academy Press, Washington, DC, 1988.

content of two complex mixtures, one of which was coal tar pitch volatiles, failed to correlate with the end points associates with that mixture. The National Research Council report concludes that BaP is at best is a crude indicator of the carcinogenic potential of complex mixtures. Direct testing of the role BaP can play in pulmonary carcinogenesis has demonstrated in inverse relationship between BaP and tumor formation. The relationship was also inversely dose-related, meaning that the greater the amount of BaP administered with the PAH mixture, the lower the incidence of lung tumors.

Environmentally and occupationally exposed cohorts have been examined for biomarkers of PAH exposure.[7 8 9 10] The majority of this work has concentrated on DNA adduct formation in circulating white blood cells or the presence of micronuclear bodies (MN) in white blood or other readily available cells. The work has shown the method to be characterized by great individual variability and subject to major change from nontarget influences. For example, the magnitude of the difference between the occupationally exposed and nonoccupationally exposed groups was small compared to as much as a 13-fold increase seen in the local general population between summer and winter heating. In the case of PAH biomarkers diet and personal habits such as smoking are considered important source of marker interference.[11 12] Surprisingly, DNA adduct formation and MN are not sensitive to cigarette smoking.

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[7] Eder, et al., (1999) Mutation Research, Vol. 424(1,2) pp. 249-261, Intraindividual variation of DNA adduct levels in humans.

[8] Jacob, et al., (1996) (Pure Appl. Chem., Vol. 68(2) pp, 301-8, The significance of polycyclic aromatic hydrocarbons as environmental carcinogens.

[9] Karahalil, et al., (1999) Mutation Research, Vol. 442(1) pp. 29-35, The micronucleus assay in exfoliated buccal cells: application to occupational exposure to polycyclic aromatic hydrocarbons.

[10] Kriek, et al., (1998) Mutation Research, Vol. 400(1,2) pp. 215-231, Polycyclic aromatic hydrocarbon-DNA adducts in humans: relevance as biomarkers for exposure and cancer risk.

[11] Kubiak, et al., (1999) Mutation Research, Vol. 445(2) pp 175-180, Biomarkers of carcinogenesis in humans exposed to polycyclic aromatic hydrocarbons.

[12] Lewtas, J. et al., (1997) Mutation Research, Vol. 378(1,2) pp. 51-63, Air pollution exposure – DNA adduct dosimetry in humans and rodents : evidence for non-linearity at high doses.

The carcinogenic/mutagenic effect of specific PAHs are not reliable indicators of the effect of PAHs in a complex mix like creosote. BaP or other specific PAHs are not reliable surrogates for biological activity of a complex hydrocarbon mixture containing PAHs.

Section 3.3.7 ("Other effects") — The reference to the work of Borthwick and Patrick (1982) should be amended to state that the work does not identify the nature (identity and purity) or source of the creosote used for testing and relied on the addition of an organic solvent to test system to facilitate introduction of the "creosote" test substance. The solvent greatly enhanced toxicity.

Section 3.4.2 ("Biological effects concentrations - sediment") — This section of the draft document should reflect the many source sources of PAHs in sediment, both natural and anthropogenic sources, that are not related to creosote or creosote-treated wood. A list of these sources and their PAH contribution to sediment can be found in the US Department of health and Human Services Agency for Toxic Substances and Disease registry (ATSDR) Toxicology Profile for Polycyclic Aromatic Hydrocarbons, Chapter 5, Potential for Human Exposure.[13]

Section 4.3 ("Laboratory and Field Studies") — The first paragraph of the conclusions to this portion of the draft report (section 4.3.5) states that

> the degree of PAH accumulation to sediment associated with these structures appears to be relatively minor in many settings, particularly in well-circulated waters and over time. PAH accumulation also appears to be relatively limited spatially (within approximately 10 meters of the structure) and has not generally been associated with measured, significant, biological effects except in close proximity to the structures. The duration of any biological effects also appears to become attenuated within several months of construction (the time period when leaching rates are likely to be highest).

In the paragraph which follows in the draft report the authors claim that several factors exist which suggest application of what they term the "precautionary principle." The first of these factors is the claim that aquatic species assessment was conducted at the community or population level rather than the individual level. The draft document also states that hazard assessment was conducted on tolerant life stages of aquatic organisms

[13] ATSDR Toxicology Profile for PAHs, US DHHS, Public Health Service, August, 1995.

rather than critical life stages. Following anything other than a "drive-by" (i.e., superficial) review of the extant literature, these statements are unsupportable. In looking at aquatic toxicity literature developed on creosote there are no less than 30 studies addressing effects on the aquatic plants (vascular and nonvascular), invertebrates of several species, crustaceans, and vertebrate species. These studies include laboratory investigations employing small numbers of a single species that in no way can be considered community or population studies but are in fact single specie bioassays. In addition there are well-documented field studies on creosote that do cover community effects but that also assess all life stages including critical life stages of target organisms. If this were not enough to establish a proper hazard assessment of creosote and creosote-treated wood, then the approach taken by Stratus could come into play: the approach of assessing creosote by evaluation of isolated PAH components. In this approach the number and variety of toxicity studies are nearly legion. In the realm of single PAH studies it is impossible not to find reports of Early Life Stage toxicity testing of aquatic species. Two easily located examples are:

Wassenberg and DiGiulio, (2004) Synergistic Embryotoxicity of Polycyclic Aromatic Hydrocarbon Aryl Hydrocarbon Agonists with Cytochrome P4501A Inhibitors in Fundulus heteroclitus, EHP, 112:17.

Barron, et al., (2004) Evaluation of Fish Early Life Stage Toxicity Models of Chronic Exposures to Complex Polycyclic Aromatic Hydrocarbon Mixtures. Tox Sci 78: 60-67.

In the face of existing relevant publications and technical reports the conclusion that there is a need to invoke the "precautionary principle" is specious. Evocation of the Precautionary Principle under these circumstances is dangerously close to what Dr. Bernard Goldstein, Dean of the University of Pittsburgh Graduate School of Public Health, has recently described as abuse of the precautionary principle not warranted by toxicological science and risk assessment.[14]

Section 4.4 ("Factors to be Considered in Aquatic Risk Assessments") — The Creosote Council strongly objects to the final two paragraphs in the Stratus creosote *Technical Review*, which far exceed the proper boundaries of a scientific report and should be deleted in their entirety. Stratus sloppily asserts (without discussing Gov.

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[14] Goldstein, B., (2005) The Precautionary Principle: Is It a Threat to Toxicological Science?, International J of Toxicology, 25:3, 3-7.

Pataki's vetoes or the reasons for them) that the New York Legislature is an "agency" that has "begun replacing and restricting the use of creosote-treated wood." Then the report falsely generalizes that "regulatory agencies are increasingly recognizing that creosote treatments in marine environments can cause ecological harm under common enough circumstances that new structures should avoid the use of creosote-treated wood, and creosote should be isolated from the environment wherever it is used." The creosote *Technical Review* then concludes with the assertion—apparently Stratus' preordained conclusion—that "precautions to avoid creosote-treated wood where practical, and measures to isolate potential toxic effects appear to be justified," and recommends that "similar precautions be implemented by regulating agencies throughout the United States."

NMFS should not allow these and similar statements to be included in the Stratus creosote *Technical Review*. They not only are scientifically unwarranted, but also imply that Stratus, a private consulting firm, somehow has been delegated regulatory authority by NMFS (authority which NMFS itself for the most part does not possess) to determine whether creosote-treated wood should be allowed in aquatic environments, and if so, under what conditions. According to the March 3 *Federal Register* notice, "[t]he purpose of the technical review documents is to present a summary of existing literature, prepared independently by Stratus Consulting, Inc. for NMFS, that analyzes the potential effects and mitigations for the use of treated wood products in aquatic environments." 71 Fed. Reg. at 10958. The personal biases, opinions, and recommendations of the authors of the Stratus creosote *Technical Review* have no place in that document.

References —The Stratus creosote *Technical Review* contains a References Section, but it is unclear if the list of references cited in that section is coextensive with the creosote bibliography assembled by NOAA Fisheries for this project. The *Technical Review* could be improved by the addition of a master bibliography listing all references identified by NOAA Fisheries and stakeholders as well as those references identified by Stratus. The *Technical Review* should identify which of the citations in the master bibliography were actually cited in the Stratus *Technical Review*.

Sincerely,

David A. Webb
Administrative Director, Creosote Council III

cc: John H. Butala, D.A.B.T.
Lawrence S. Ebner, Esq.

Volume II

Section II

Stratus Creosote Report and Comments

3. Comments of Dr. Kenneth M. Brooks produced for the Western Wood Preservers Institute

Comments regarding Stratus Consulting's document

Creosote-Treated Wood in Aquatic Environments:
Technical Review and Use Recommendations

Produced for:

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March 6, 2006

Comments regarding Stratus Consulting's document

Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations

1. Introduction: Dr. Brooks discussed the creosote models and several publications he has produced with Dr. Fry and Ms. Susan Humphries of Stratus on numerous occasions. However, the interaction was far less intense than occurred during production of the Stratus waterborne report. The result is apparent in the two documents. It should be emphasized that the creosote model (Brooks, 1997) was produced using data that was available at that time. Creosote is a complex mixture containing many compounds. Sparacino's (1999) report of compounds representing >0.5% of the content of P1/P13 and P2 creosote produced in North America accounted for 95.9% (99 compounds) and 92.2% (129 compounds) respectively of the two mixtures. The most common compounds reported in commercially produced creosotes by Sparacino (1999) are summarized in Table 1. Stratus was made aware of this most recent and thorough creosote evaluation and why they chose to ignore it in favor of older documentation is uncertain.

The risk assessment and model of Brooks (1997) and subsequent evaluations of actual creosote treated wood projects (Brooks, 2000, 2003, 2004 and Goyette and Brooks, 1998, 2001) have focused on EPA's 16 priority pollutant parental PAH because their physicochemical properties and toxicology are well studied. This emphasis is not unique to predictions regarding the environmental response to creosote. Regulatory benchmarks, such as Washington States sediment quality criteria (WAC 173-204) focus on these priority pollutant PAH as do numerous attempts to define sediment quality values (Smith *et al.*, 1996; Ingersol *et al.*, 1996; Long *et al.*, 1995 and BCMWLAP, 2005).

Most analyses, including Brooks (1997) assume that the suite of PAH in creosote pressure treated wood is the same as the mixture in the raw oil. That is not true. Goyette and Brooks (1998) compared the composition of raw creosote oil used to treat the Sooke Basin piling with the suite of PAH expressed from the wood following treatment. Naphthalene, which represented 23.8% of new creosote oil was reduced to 10.6% of expressate after treatment. It was hypothesized that this most soluble of the PAH compounds in creosote was preferentially lost during post treatment steaming of the products. This is important because naphthalene is more soluble (32 mg/L) and bioavailable than other PAH indicating that studies using whole creosote oil in bioassays will likely overestimate the mixture's toxicity in comparison with the suite of PAH that migrate from creosote treated wood products into aquatic environments. Stratus was made aware of this information but chose to ignore its implication in their review.

Dr. Brooks acknowledges that the creosote risk assessment model is ten years old and that a significant body of information has accumulated to better inform the model since it was first written. Because of the complexity of both the preservative and receiving environments, numerous assumptions were and will continue to be necessary to estimate the environmental response to the use of these products. The model was built on worst case assumptions, a fact that Stratus has failed to acknowledge. Numerous studies and evaluations by others over the last 10 years have failed to identify significant flaws in the models which generally predict more PAH accumulating in sediments and much higher concentrations of dissolved PAH in the water column than are actually observed in the real world.

Table 1. Comparison of the percent, by weight of the total mixture, of North American P1/P13 and P2 with European Types B and C creosote oils. The percent composition of all 16 parental PAH and other organic compounds representing ≥ 0.5% of at least one creosote mixture as determined by Sparacino (1999) are provided.

Compound	North American P1/P13	North American P2	European Type B	European Type C
Naphthalene	9.0	8.0	5.3	0.1
Acenaphthene	6.1	6.6	4.4	2.0
Acenaphthylene	0.3	0.2	0.1	0.2
Fluorene	4.2	4.9	3.3	5.5
Phenanthrene	12.2	12.6	9.9	18.5
Anthracene	2.2	2.1	0.5	1.1
Sum of low molecular weight parental PAH (ΣLPAH)	**34.0**	**34.4**	**23.5**	**27.4**
Fluoranthene	6.8	6.5	4.3	9.8
Pyrene	6.0	5.7	2.8	6.3
Chrysene	1.5	1.5	0.1	0.1
Benz[a]anthracene	0.5	0.5	0.1	0.2
Benzo[b]fluoranthene	0.8	0.3	0.0	0.0
Benzo[k]fluoranthene	0.3	0.2	0.0	0.0
Benzo[a]pyrene	0.5	0.5	0.0	0.0
Benzo[e]pyrene	0.4	0.4	0.0	0.0
Ideno(1,2,3-c,d)pyrene	0.1	0.1	Not listed	Not listed
Benzo[ghi]perylene	0.05	0.05	Not listed	Not listed
Sum of high molecular weight parental PAH (ΣHPAH)	**16.95**	**15.75**	**7.3**	**16.4**
Total parental PAH (ΣPAH)	**51.0**	**50.2**	**30.4**	**43.8**
Acridine	0.2	0.1	0.5	1.1
Indene	0.9	0.7	Not listed	Not listed
Quinoline	0.8	0.8	Not listed	Not listed
2-Methylnaphthalene	5.1	4.6	8.0	0.3
1-Methylnaphthalene	2.3	2.1	4.5	0.2
1,1'-Biphenyl	1.2	1.2	2.1	0.1
1-Ethylnaphthalene	0.5	0.5	Not listed	Not listed
Dimethylnaphthalenes (1,3- & 2,6 plus 2 isomers)	1.9	2.1	0.4	0.0
Dibenzofuran	3.1	3.7	3.2	2.1
Methyldibenzofuran	0.7	1.3	Not listed	Not listed
Dibenzothiophene	1.3	Not listed	Not listed	Not listed
9H-Carbazole	1.2	1.2	0.9	1.4
Methylphenanthrene	0.7	0.7	Not listed	Not listed
2-Methylphenanthrene	0.8	0.8	Not listed	Not listed
4H-Cyclopental[def]phenanthrene	1.8	1.7	1.7	3.1
1-Methylphenanthrene	0.8	0.5	Not listed	Not listed
2-Phenylnaphthalene	0.5	0.5	Not listed	Not listed
Benzonaphthofuran + Azapyrene	0.6	0.6	Not listed	Not listed
Benzo(a)fluorene	0.9	0.9	0.5	1.0
Benzo(b)fluorene	Not listed	Not listed	0.5	1.1
2,3-Benzofluorene	1.1	1.1	Not listed	Not listed
Phenylmethylnaphthalene	0.5	0.4	Not listed	Not listed
Acepyrene	0.5	0.5	Not listed	Not listed
2,3-Benzanthracene	1.5	1.6	Not listed	Not listed
Dibenzocarbazole (isomer)		0.8	Not listed	Not listed
Other compounds > 0.5%	**28.7**	**28.3**		
Percent of mixture accounted for by those at > 0.5%	**79.7%**	**78.5%**	**52.4%**	**50.9%**
Compounds detected	**99**	**129**	**22**	**21**
Proportion of total mixture accounted for	**95.9%**	**92.25%**	**53.39%**	**55.09%**

models were not designed to precisely predict the environmental response, but rather to provide conservative estimates of the expected response. In response to the predictions made by the original creosote risk assessment model (Brooks, 1994), NMFS (1996) scientists predicted, based

on their own theoretical considerations, sediment PAH concentrations of 1,695 to 16,949 μg ΣPAH/kg dry sediment downstream from a single creosote treated piling. In fact, field studies have found concentrations ranging from non-detectable concentrations (Brooks, 2005) to a few tens of μg ΣPAH/g in the worst cases (Goyette and Brooks, 1998). At most sites, sediment concentrations have been <10 μg within a meter of the piling and in no case have significant biological effects been observed in macro-invertebrate communities. The reader is reminded that all of the epifaunal organisms inhabiting the pilings in the cover photograph settled there as sensitive larval stages – not as robust adults.

2. Specific comments: Stratus notes in the introduction that NMFS is ". . . .developing guidance on the use of treated wood in aquatic environments inhabited by NMFS trust resources. NMFS trust resources include commercially important marine species and their habitats, as well as threatened and endangered (T&E) marine species and their habitats." This includes all marine environments adjacent to the United States to a distance of 200 miles and those freshwaters used by several species and stocks, including salmon. By extension of the NMFS interpretations for salmon, this could include all anadromous species like menhaden, eels and shad. In other words, if, as the NMFS has proposed, this process leads to national guidance, the results may be applied to all marine waters and many freshwater systems with significant economic and social implications for the entire country. Restrictions on treated wood products should not be based on *effects per se* and/or *perceptions* that treated wood structures threaten aquatic resources. They should be based on empirically demonstrated adverse effects that threaten populations of these resources. The assertion in Stratus (2006) that NMFS manages T&E resources on an individual versus population basis is simply untrue. If that assertion were true, then mixed stock salmon fisheries would not be allowed because all of the T&E individuals returning to a small watershed could be captured in a single purse seine set . In addition, the stress imposed on individual T&E fish caught in hook and line fisheries far exceeds the stress (if any) imposed by the small amounts of polycyclic aromatic hydrocarbons released from creosote treated piling. Obviously, if NMFS was managing T&E stocks of salmon on an individual basis, no fishing of any kind would be allowed anywhere these stocks might be found, including the Pacific Ocean, Puget Sound and the Columbia River. Fishing has continued in all of these waters since the stocks were listed, making it obvious that NMFS has not managed T&E species on an individual basis.

- **Page 2-5, Non-detected compounds.** The most likely reason that HPAH were not reported in the Kang *et al.* (2003) study is for the same reason that they were not detected by Ingram *et al.* (1982). The concentrations of these highly insoluble compounds were less than detection limits at flow rates of 1.2 and 3.3 cm/sec. There is no basis for Stratus's assumption that they would have been detected in the absence of "volatilization, biodegradation, sorption to organic matter, or other route." Goyette and Brooks (1998) reported the results of dissolved PAH determinations in Sooke Basin by the Battelle Marine Science Laboratory in Sequim Washington using Semi-Permeable Membrane Devices (SPMDs). Four ring PAH were observed in concentrations of 0.002 to 0.61 ng/L (parts per trillion). The sum of the carcinogenic HPAH in tissues from mussels growing on the piling ranged between 0.39 and 3.92 ng/g (parts per billion) on day 14 following construction and were all below the method detection limit of 20 ng/g 1540 days following construction. The point being that all of this data suggests that HPAH were likely not observed at the flow rates examined by Kang *et al.* (2003) because their concentrations were exceeding low (below detection limits).

- **Page 2-5, Becker *et al.* (2001).** Brooks (2006) conducted leaching studies on CCA-C using TCLP tests of ground wood, TCLP tests of seven mm cubes, tests of 19 mm cubes (AWPA E11-907) and commodity size samples (2”x6”x24”) in static and dynamic tests. Loss rates using the small cubes were initially an order of magnitude higher (2.3 versus 22.61) than observed in the dynamic leaching studies. In large part this is believed to be associated with the high ratio of end-grain to surface-grain associated with the small samples (2:4) in comparison with the larger samples (0.00096) associated with a 16’ long 2”x6” plank. This problem is exacerbated when estimating environmental loss rates from oil-borne pressure treated wood because the open end grain provides a direct pathway for migration of the unfixed preservative into the diluent. Stratus (2006) acknowledged this problem.

- **Page 2-7, Xiao *et al.* (2002).** As a point of interest, Goyette and Brooks (1998, 2000) hypothesized that PAH, other than the more water soluble compounds such as naphthalene, migrated from the surface of the piling as microdroplets dislodged by currents and/or wave action. The Xiao *et al.* (2002) observation that loss rates were greatest in warm and turbulent water is consistent with this *particulate transport hypothesis.*

- **Page 2-8 Stratus Figure 2.2.** It is the long-term accumulations of PAH in sediments that constitute the primary risk to aquatic organisms associated with the use of creosote treated wood and the text on page 2-7 and Stratus’s Figure 2.2 are misleading. Figure 1 (from Brooks 2005a) describes, more fully, the results from Kang *et al.* (2004). Stratus was provided with a copy of the report and was aware of Kang *et al.* (2004). Note that PAH migration rates quickly converged to a single set of values following 10 days of immersion. It is the long-term migration rates that are important to predicting sediment concentrations of PAH, not short term rates as asserted by Stratus in Figure 2.2.

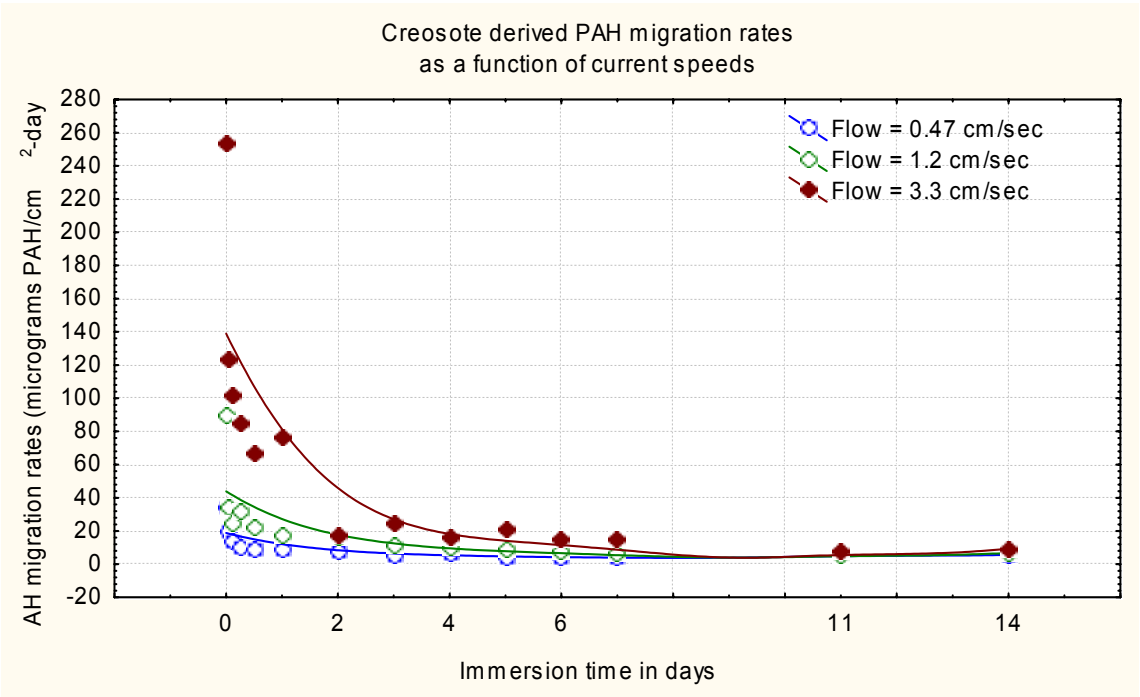

Figure 1. Creosote derived PAH migration rates from pressure treated wood (192 kg/m^3) into freshwater flowing at 0.47, 1.2 and 3.3 cm/sec (Data from Kang *et al.* (2004); graph from Brooks (2005a)).

- **Page 2-9, Whiticar *et al.* (1994) – *Concentrations of individual PAHs.*** As previously noted, naphthalene is a dominant PAH in creosote oil prior to treating. However, the high temperature, high humidity (steam) and low pressure environments used in the post treatment processing of creosote treated products preferentially removes more soluble and volatile naphthalene from the product; significantly reducing its presence in treated wood. The suite of PAH present in the pressure treated product is what migrates into the environment; not the suite of PAH found in creosote oil.

- **Page 2-11, (iv) Environmental factors – first paragraph.** Dr. Brooks agrees that theoretically, abraded wood particles would increase the leaching surface area from which creosote migrates to an aquatic environment. He also agrees that this can occur. However, he has surveyed dozens of creosote treated wood structures and has observed significant abrasion in only one instance at a pin piling on a personal use float. The abrasion was quickly and easily eliminated by installation of vertically placed HDPE wear strips within the intertidal zone. Stratus has presented no evidence substantiating abrasion as a common or significant problem associated with pressure treated wood. For this assertion to be credible, it must be based on something more than a perception.

  Epoxy is not, ". . .applied to cut ends of samples (in leaching studies) to minimize the effect of disturbance and abrasion as confounding factors." as asserted by Stratus. Epoxy is applied because laboratory studies unrealistically expose high end-grain in comparison with the surface grain. This unrealistically exposes the interior of cell walls to the diluent. Consider for example that one end (with exposed end-grain) of a piling is typically driven ten or more feet into the substrate and the other end is located above the receiving water. In the real world, the ratio of surface leaching area to exposed end-grain is therefore nearly infinite for piling. The procedure has nothing to do with abrasion.

- **Page 2-11, (iv) Environmental factors – second paragraph.** Wood preservatives are constantly being redistributed within lumber, timbers and pilings in response to diffusion gradients. Creosote migrating from near the surface of piling is constantly being replenished from deeper within the wood. This is the reason that historic assessments based on measuring the remaining preservative in pressure treated wood are of little value. In many cases, more preservative was observed at some depths after many years in service than was present at the time of treatment.

- **Page 2-12. Section 2.2.1. Model descriptions – Brooks CREOSS model.** A description of the assumptions used in constructing these *worst case models* was published in *Estuaries* (Brooks, 1996). In the near future, the creosote model will be revised to reflect the knowledge that has accumulated since it was first constructed and that model will be published in a peer reviewed journal.

  Unfortunately, there are no comprehensive studies describing PAH migration from creosote as a function of time, temperature, retention and salinity. These limitations are fully discussed in the Brooks (1997) introduction to the model. Algorithms describing the influence of each of these factors were segregated in the model's intermediate output because each factor was based on different studies and it was hoped that new data would be obtained to improve each algorithm. The PAH Migration Rate (M) is defined in Brooks (1997) as follows and Stratus's assertion that the model does not predict migration rates is erroneous. The model must predict migration rates in order to function.

$= (24.4 + 0.78*\text{temperature} - 0.55*\text{salinity})\exp^{(-\text{age in years}/10)}\exp^{(-\text{actual retention}/22.4 - 1)/2}$

- **Page 2-15, Section 2.2.2. Applicability and limitations of leaching rate models.** Dr. Brooks is unaware of what Stratus is referring to when the author(s) state that the risk assessment model asserts that different leaching rates are used for LPAH and HPAH. At page 26 of Brooks (1997) clearly states that, "For purposes of this model, we will assume that HPAH and LPAH migrate from the piling in the same proportions in which they are found in whole creosote." This statement is repeated several times in Brooks (1997). The model only predicts total PAH migration rates. Their proportion in water and sediments is then assumed to be equal to the proportion observed in the whole oil. The *Water Partition Coefficient* can be used to account for the low solubility of HPAH. Stratus did not specify where in Brooks (1997) it is asserted that different migration rates are used for LPAH and HPAH. If they will identify the statement's location, the statement will be removed. The source of data for developing each empirically derived algorithm are clearly identified in Brooks (1997). The basis for those algorithms that were developed in the absence of empirical data is also provided. The lack of specificity in the assertions made in this paragraph makes it difficult or impossible to respond.

- **Page 2-15, Section 2.2.2. Applicability and limitations of leaching rate models 2nd paragraph.** The empirical data from Xiao *et al.* (2002) has been incorporated in the Timber Bridge Model (Brooks, 2005) and will be incorporated in the next version of the creosote risk assessment model. However, as previously noted, it is expected to have little effect on sediment concentrations of PAH because the differences in PAH migration rates, as a function of flow speeds, converge to single values describing all flows within about 10 days.

- **Page 2-15, Section 2.2.2. Third and forth paragraph.** Dr. Brooks is confused by the Stratus comment that, "Regardless, it is unclear whether data from these studies were used to develop or calibrate the CREOSS model, or if the studies were cited for comparison." Brooks (1997) at Table 12, page 40, gives the data upon which the basic migration rate as a function of temperature and salinity was developed and the preceding text includes several paragraphs describing the results of the linear regression analysis upon which the algorithm is based. The availability of a comprehensive set of leaching studies on commodity size creosote treated wood products over a realistic real world range of temperatures, salinities and retentions, such as that reported by Brooks (2005b) for CA-B preservatives would enable development of a better model. However, data of that quality is not yet available for creosote. The question that should be asked by Stratus is, does Brooks (1997) lead to reasonable estimates of environmental concentrations of PAH in association with the use of creosote treated wood products. As will be seen in a later section of this response, the models do provide reasonable predictions and therefore, while the algorithms may not all be as well founded in empirical data as Dr. Brooks would like, the end result is useful (as acknowledged by Stratus).

- **Page 2-15, Section 2.2.2. Last paragraph.** It is unclear how Stratus concluded that Ingram *et al.* (1982) used WWPI BMPs in their study. These procedures were first developed in 1994, over a decade after the Ingram *et al.* (1982) study was conducted.

- **Page 2-16, First paragraph after Figure 2.4.** As previously noted, all of the models developed by Dr. Brooks are based on *worst case assumptions.* This was especially true for the Creorisk model because of the marginal dataset upon which it is based. However, as described in Table 12 of the model documentation, the algorithm was based primarily on Ingram *et al.*

(1982) and included data from Miller (1977) and Graham (date unknown). Given the paucity of high quality data, the over-prediction of PAH from creosote treated wood was intentional. A *Water Partition Coefficient* is provided to account for the low solubility of HPAH.

- **Page 2-17, Section 2.3.1, first paragraph.** The Creorisk Model (Brooks, 1997) was originally developed for use in harmonically driven current regimes typical of marine environments. Consistent with the worst case approach taken in these models, it estimates water column concentrations of PAH within half an hour either side of slack tide. The geometry is cylindrical around the piling in very poorly flushed environments. However, as current speeds increase, the PAH is forced into the downcurrent direction by a Geometry Factor. During these periods anticipated slow current speeds, turbulence is assumed to disperse PAH within the specified geometry. That geometry is defined by assuming a period of 12 hours and integrating a harmonic function having maximum amplitude equal to the maximum tidal speed observed on an exchange to mean low water (MLW) from t = -30 minutes to t = +30 minutes around slack tide. That integral is $0.0645*V_{maximum}$. During slack tide $\pm$ 30 minutes, turbulence is assumed to disperse migrating PAH into an ellipse equal to $0.0645*V_{maximum\ (cm/sec)}*1800$ seconds (30 minutes x 60 sec/min). Those who have done drifter studies in harmonically driven marine environments know that the drifters don't stop during slack tide. They move in random motions associated with eddy currents created as the tides change direction. There is no mechanistic basis for the approach taken. It is simply a model that is expected to provide minimum reasonable dilution volumes that are predictable in harmonically driven systems.

- **Page 2-19, last paragraph.** Stratus's conclusion that the transport is based on advection only is incorrect. The model discusses the small influence that molecular diffusion has on the dilution of PAH in the water column and exclusion of this as a factor is considered in keeping with the *worst case assumptions* driving development of the model. Diffusion is discussed at page 30 of Brooks (1997). Advection is not included in the determination of water column PAH concentrations because the highest concentrations are anticipated to occur within half an hour of slack tide when currents are exceptionally slow and chaotic. This is explained in detail in the model documentation. However, based on Stratus's inability to understand the text, it will be rewritten in the next version in a manner understandable by those unfamiliar with modeling. The model fully explains how advective transport is determined during sedimentation.

- **Page 2-20, first paragraph.** The pathway for developing the dilution factor in the Creorisk model is described at page 45 of Brooks (1997) under Model Output where it is stated that:

"Worst case scenarios occur within half an hyour of slack tide in areas where there are no steady state currents. **By integrating equation (2) from half an hour before slack tide to half an hour after slack tide we find that the average tidal speed during this period is 0.06451 x $V_{maximum}$." (Emphasis added)** Contrary to the comment by Stratus, the time is specifically identified.

- **Page 2-20, second paragraph.** Stratus states that, "In addition, dimensional analysis of the equation shows inconsistent units." Stratus did not query Dr. Brooks in this regard. The author incorrectly assumed that this could be worked through by those interested. Obviously that is not the case and the following text will be included in the model's next version.

$$PAH_{water}\ (ng/L) = WPC*10^6*2\pi*R_p*GF*M*1\ hour/[24\pi((1800*V_{model} + R_p)^2 - R_p^2)$$

Numerator

WPC = Water Partition Coefficient = non-dimensional
10^6 converts ml to liters and μg ΣPAH to ng ΣPAH = $(10^3 cm^3/L)*10^3 ng/\mu g$
2π is dimensionless
R_p = piling radius (cm)
GF = geometry factor which is dimensionless
M = PAH migration = $\mu g/cm^2$-day
1 hour = the time that PAH migrate (half an hour before to half an hour after slack tide)

Denominator

24 = 24 hours/day
π is dimensionless
1800 = seconds
V_{model} = cm/sec
R_p = cm/sec.

Combining these dimensions gives:

$$ng/L = \frac{cm^3*ng*cm*\mu g*hr}{L*\mu g*cm^2\text{-day}} \quad \frac{day*}{hr*((sec*cm/sec + cm)^2 - cm^2)} = hr\ cm^2$$

$$ng/L = \frac{cm^2*ng*hr}{L\text{-day}} \quad \frac{day}{hr\text{-}cm^2} = ng/L$$

For those who have not carefully reviewed or cannot understand the creosote risk analysis, this may seem somewhat obscure. However, the dimensions are correct and Stratus's comment is without merit.

- **Page 2-20, Last full paragraph.** The exclusion of post-deposition redistribution of sediment PAH associated with bioturbation and or mechanical disturbances such as erosion, turbulence during high current flows, propeller wash, etc. is intentional because it cannot be predicted. In addition, this would detract from the *worst case assumptions* upon which these models are based. For some reason, Stratus has refused to acknowledge at any place in their document Dr. Brooks' assertion that the models are based on *worst case assumptions.* Nor have they rebutted those assumptions other than to assert, without documentation in the form of empirical evidence, that abrasion of treated wood may significantly increase environmental loading of PAH.

- **Page 2-21, *Model predictions*, first paragraph.** Stratus asserts that, "The model predicts a water column concentration of 0.003 ppb total PAH. The volume of water containing this concentration and the length of time that this concentration persists are not specified, but it

appears that the concentration is an average that might not be representative of instantaneous concentrations at a particular location." As has been previously described in this critique, the model documentation clearly states that water column concentrations of PAH are predicted as an average during the period within half an hour either side of slack tide. The concentrations are predicted to be lower at other times as harmonically driven current speeds increase. The volume of water within which the concentration is predicted is precisely defined as a cylinder with radius equal to 1800 seconds * 0.0645*$V_{maximum}$. Thus the concentration is assumed to persist for one hour and if $V_{maximum}$ 2 cm/sec, the radius of the cylinder would be 2.3 meters.

- **Page 2-23, *Model predictions.*** It should be pointed out that Brooks (1997) includes an Excel™ spreadsheet useful for predicting the ΣTU described by Swartz *et al.* (1995). Furthermore, procedures for using this utility are provided on page 52 of Creorisk and an example is given in Table 16 on page 53. It is curious that Stratus failed to mention the availability of this in Brooks (1997).

- **Page 2-26, (ii) Goyette and Brooks (1998, 2001), second paragraph.** Stratus asserts that, "In this study, the modeled total PAHs included all PAHs leached from creosote, but the measured total PAHs included only 17 measured PAHs potentially underestimating the total." This statement is incorrect. Most of the data used to estimate migration rates from creosote treated wood were taken from Ingram *et al.* (1982) and as stated at page 39 of Brooks (1997), "In each experiment, the leachate was examined at the end of three days for the presence of **15 major PAHs."** Emphasis added. The migration rates used in the Creorisk Model are based, in large part on the 15 PAHs that Ingram *et al.* (1982) was able to detect. Similar to the results of Xiao *et al.* (2000), they were not able to detect compounds heavier than benz(a)anthracene, The model assumes that the distribution of PAH within the migrating suite of compounds is similar to that found in creosote. This should not introduce significant errors because as seen in Table 1, priority PAH heavier than benz(a)anthracene comprise only 2% of creosote meeting AWPA Standard P2. Therefore, predicting total PAH migration based on the 15 compounds detected by Ingram *et al.* (1982) leads to a maximum error of 1/0.98 = 1.02 or 2 percent. However, the *particulate transport hypothesis* developed by Dr. Brooks suggests that the insoluble PAH do not dissolve in the water column, but are transported to sediments as microdroplets of PAH. If this is true then the 15 compounds detected by Ingram *et al.* (1982) likely do characterize the dissolved suite present in the receiving water. This is another example of inaccurate analysis and reporting by Stratus.

- **Page 2-26, (ii) Goyette and Brooks (1998, 2001), second paragraph.** One of the site selection criteria for Phase II of Environment Canada's creosote evaluation was that the site support a healthy macrobenthic community. Numerous potential sites were eliminated from consideration because they had historically been used for log storage. Initial site investigations indicated that the accumulated organic debris had resulted in anaerobic conditions and depauperate macrobenthic communities. Sooke Basin was chosen in part because the sediments were aerobic and supported a vibrant macrobenthos. Initial modeling indicated that the creosote treated dolphins would result in exceedances of adverse biological effects benchmarks due to the site's very slow currents and the dense clusters of treated pilings – despite the fact that the sediments were aerobic. Stratus has avoided reviewing the large biological databases including macrobenthic community assessments and bioassays included in Goyette and Brooks (1998,

2000) and Brooks (2000, 2003). This is curious because these data provide significant insight into the environmental response to creosote treated wood. Contrary to the assertion made by Stratus, the requirement for aerobic sediments and a healthy macrobenthic community is considered absolutely necessary for a worst case evaluation. Conducting the studies in anaerobic conditions with a depauperate macrobenthos would have denied any ability to detect biological effects.

- **Page 2-26, (ii) Goyette and Brooks (1998, 2000).** Figure 29 in Goyette and Brooks (1998) describes PAH as a function of depth in sediment cores. Concentrations declined exponentially as a function of depth. Why Stratus chose to ignore this section of the report and instead stated that, "Sediments above the RPD are oxic, which increases the rate of PAH breakdown, and sediment samples for PAH analysis were routinely collected from the top (0-2 cm) layer during the study." is curious and demonstrates a consistent trend to unsubstantiated criticisms rather than to accurately and completely reporting the results of many of the studies..

$$PAH_{\text{BMP dolphin as a function of sediment depth}} = 30.24*\exp^{-0.691*\text{sediment depth (cm)}} \qquad R^2_a = 0.998$$
$$PAH_{\text{WP dolphin as a function of sediment depth}} = 14.43*\exp^{-0.378*\text{sediment depth (cm)}} \qquad R^2_a = 0.983$$

- **Page 2-27, first paragraph.** During installation of the dolphins, the pile driver was anchored offshore to avoid contamination of sediments in the predetermined up- and down-current directions. The twelve creosote treated piling used to construct the two dolphins were also rafter there. Considering the amount of debris on the pile driver and the piling rafts located offshore from the dolphins, elevated PAH concentrations there were expected, but not considered indicative of the short or long-term environmental response to PAH derived from the structure, which was the purpose of the study. Dolphins are structures constructed of densely packed piling arranged like the poles in a teepee. The small area inside the dolphin was considered a *technozone* (European term) and it was not part of the study. PAH concentration inside the dolphin were not modeled and therefore the observed concentrations were not higher than model predictions as asserted by Stratus. The observed mean concentrations observed outside the interior of the dolphin were all lower than those predicted by the model.
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- **Page 2-27, first paragraph after Table 2.7.** The model makes predictions of the maximum PAH accumulation in sediments. Stratus's assertion that the concentrations reported in their Table 2.7,"occurred somewhat sooner than predicted, giving the appearance of model under-prediction earlier in the experiment followed by over-prediction later in the experiment" is unsupported. It is possible to numerically solve the infinite series presented in Equation 16 of Brooks (1997) to predict sediment concentrations as a function of time post installation. Brooks (2004) did that for the Sooke Basin data collected through day 1530. The results for a distance of 0.5 m downcurrent, normalized to the highest value reported, are provided in Figure 2. The normalized data for Day 14 is higher than the predicted value, but all other predictions are very close to predictions through Day 720 when it appeared that the concentrations peaked. These results suggested that during the first four years following immersion, the observed concentrations peaked slightly earlier and declined more quickly than was predicted by the model. This was particularly surprising because the sediments were anaerobic at that time and the model predicted much higher concentrations of PAH under the zero RPD conditions observed near the dolphins at the end of the study. The author is unaware of how Stratus could arrive at their stated conclusion as they did not present any supporting analysis.

- **Page 2-27, last paragraph.** Considering even the biased and selective way in which Stratus has used the available data, their conclusion that, "The results of these comparisons of modeled to measured PAH concentration data are not sufficient to make any specific quantitative conclusions about the accuracy of the model in predicting actual sediment concentrations" is curious. At the Westham Island Bridge (Stratus Table 2.6), the model predicted 0.56 μg ΣPAH/g dry sediment at 0.5 meters and the observed concentration was 0.17 μg ΣPAH/g. Similarly, the model predicted slightly higher concentrations at 2.0 m (0.17 predicted versus 0.03 μg/g observed) and 5.0 m (0.08 predicted versus 0.07 μg/g observed) than were actually observed. At Belcarra Bay the model predicted more PAH at one meter distance than was observed (9.0 predicted and 4.0 observed) at 3 and 5 meters distance the model predicted 5.5 and 4.0 μg/g and 10.0 and 8.5 μg/g were observed. In Sooke Basin the model predicted 24 μg ΣPAH/g dry sediment at 0.5 m distance and a mean of 16.1 μg ΣPAH/g were observed. Predicted values in Sooke Basin were generally higher than observed. Model predictions were not developed for the *Technozone* existing within the center of the dolphin. In Dr. Brooks' opinion, these results are excellent, especially when compared with the NMFS prediction of1,695 to 16,949 μg ΣPAH/g dry sediment downstream from a single piling. As explained in Brooks (1997), there is significant uncertainty in several of the algorithms used in the predictions due to a lack of empirical data. In addition, because the complexity of receiving environments, particularly harmonically driven marine environments, the models are based on worst case assumptions.

  Past models have only considered contributions of PAH from immersed portions of treated structures. Stormwater runoff from overhead structures also contributes PAH to receiving environments. Large industrial structures like those found at Belcarra Bay and the Westham Island Bridge contribute PAH from above the water. Recent rainwater runoff data generated by Oregon State University has allowed Brooks (2005a) to predict PAH loading from above water and immersed portions of treated wood structures. When that document completes peer review, the results will be incorporated in a new version of the creosote risk assessment model. Final judgment with respect to the reasonableness of the predictions make by the Creorisk Model will be left to other reviewers of the Stratus report and this response.

- **Contributions from overhead structures.** Contributions of PAH from overhead structurs are incorporated in the recently completed timber bridge model (Brooks, 2005a) produced for the U.S. Forest Service. Three wooden bridges were modeled and then assessed in that effort. Concentrations of PAH under and adjacent to the 53 year old Anderson Creek Bridge were predicted to range from 11.05 μg ΣPAH/g dry sediment within 15 cm of the 53 year old bridge's creosote treated bulkheads to 1.84 μg ΣPAH/g dry sediment at a distance of 20 m downstream. Observed concentrations steadily decreased from 1.59 μg ΣPAH/g under the bridge to 0.30 μg ΣPAH/g at 20 m downstream. Anderson Creek is a salmon spawning stream and the evaluation occurred in fall before winter rains increased typically low summer flows. The much lower sediment concentrations observed under the bridge in comparison with those predicted was likely associated previous annual high flows that diluted and redistributed the PAH downstream. In addition, sediments in the sandy-silt sediments under the bridge were aerobic, facilitating microbial catabolism of sedimented PAH.

  The Seabeck Lagoon Bridge was evaluated on October 19, 2004, 15 years after it was last reconstructed. Predicted sediment concentrations at this 183.5 foot long bridge spanning a poorly flushed tidal lagoon varied from 1.7 μg/g under the bridge to 3.87 μg ΣPAH/g at 3 m and

0.14 μg ΣPAH/g at 6 m downcurrent. Equal abundance and much higher diversity was observed under the bridge in comparison with the reference location.

- **Page 2-27, last paragraph.** Contrary to the assertion by Stratus to the contrary, both the number and density of pilings can be considered using the model of Brooks (1997), it simply takes more insight than was achieved by Stratus. It is unfortunate that they did not request that information if it was of concern to them.

- **Page 2-28, Section 2.3.3.** The author agrees with Stratus that aquatic systems are complex and difficult to model, but is reminded of a comment by Dr. Crawford Revie in considering future sea lice models in British Columbia. "Models don't have to be right to be useful." Dr. Brooks also agrees that environmental modeling of any kind is fraught with complexity and uncertainty. The models attempt to simplify this complexity by using *worst case assumptions.* For some reason, Stratus has failed to acknowledge this or to attack any of the assumptions because they do worst case. Field verification studies completed to date suggest that despite the uncertainties in many of the algorithms, the models *are useful.* Ultimately, their usefulness will be determined by experience and peer review.

- **Page 2-29, third full paragraph.** The next *incarnation* of the creosote risk assessment model will incorporate the results produced by Xiao *et al.* (2002) and Kang *et al.* (2004). This information was not available in 1997. It has been included in the Timber Bridge Model (Brooks 2005a). The data are of particular interest to Dr. Brooks they support his *particulate transport hypothesis* which has not yet been adequately tested.

- **Page 3-2, first paragraph.** Goyette and Brooks (1998) analyzed all sediment samples for 17 parental and 19 alkylated PAH plus dibenzofuran. The concentrations of alkylated PAH in Sooke Basin sediments under and near the creosote treated dolphins were very low. In the absence of definitive toxicity information and because the concentrations were so low, the data was included in the report's database, but was not analyzed. However, it is available for others to use.

- **Page 3-3, first paragraph.** Tissue PAH burdens in somatic and gonadal tissue were low throughout the *in-situ* mussel studies in Sooke. They were even lower in mussels growing directly on the Sooke Basin piling and on three creosote treated structures reported in Brooks (2003). The author is unaware of information supporting the assertion by Meador *et al.* (1995) that the "metabolic capacity" of PAH in bivalves is very limited.

- **Page 3-5, first paragraph.** As previously noted, the results of studies using whole creosote oil (Sved and Roberts, 1995) are useful for understanding the environmental responses to industrial spills but cannot be applied to the response to treated wood. Note that Sved and Roberts (1995) observed naphthalene comprising 21% of the resolvable PAH in their study of sediments contaminated with whole creosote oil. As previously noted, naphthalene is the most water soluble (and therefore bioavailable) PAH in creosote. However, Goyette and Brooks (1998) observed that much of the naphthalene present in the creosote oil used to treat the Sooke Basin BMP dolphins was absent in expressate from the treated piling. This is consistent with the frequent observation of high naphthalene in groundwater historically contaminated by discharging contaminated water flushed from retorts to unlined ponds at treating plants.

- **Page 3-13, second paragraph.** Stratus's statement regarding the in-situ mussel bioassay in Sooke Basin is misleading. Mussels growing within 15 cm of the newly installed piling grew significantly more slowly than those at further distances. However, all of the following important information was intentionally or unintentionally excluded by Stratus:

  - Note that Battelle found only 22.9 ng dissolved ΣPAH/L at a distance of 0.25 m from the downcurrent side of the dolphin and that the sum of toxic units (ΣTU) determined using the method of Swartz *et al.* (1995) was 0.031.

  - Mussel tissue PAH concentrations were very low at all times. Prior to placement in the test, mussel tissues held 16.15 ± 2.2 ng ΣPAH/g wet tissue. Tissue concentrations were highest on Day 14 following construction (47.0 to 68.1 ng/g) in comparison with 44.1 ± 8.1 ng/g at the open control. On Day 384, tissue concentrations of PAH were lowest immediately adjacent to the BMP piling (8.29 ± 0.85 ng/g) in comparison to 11.1 ± 1.2 ng/g at the open control.

  - On Day 185, mussel condition factors were higher at all treated wood stations (0.200 ± 0.009 to 0.244 ± 0.036) than at the open control (0.177 ± 0.035).

  - Mussel survival was 79 ± 0.7% at the BMP 0.5 m station, which was not significantly different from the open control (80 ± 4.5). Mussel survival was higher at other stations near the BMP dolphin varying between 88 ± 6% at 2.0 m to 81 ± 7.9% at 10 m and it was highest (88.7 ± 5.6%) at 0.5 m from the weathered piling in comparison with the control cohorts. These are all exceptionally high survival rates at the end of one year with no indication of toxicity associated with PAH released from the creosote treated wood..

  - While Stratus emphasized that mussels grew significantly slower near the piling, they failed to report that the final valve lengths for the three replicate cohorts of 100 mussels at each station was 59.3 ± 2.4 mm immediately adjacent to the BMP piling and 64.2 ± 0.9 mm adjacent to the weather piling dolphin in comparison to 69.5 ± 0.8 mm at the open control. This growth, which was achieved over the winter months, was exceptional for all of the cohorts..

  - Lastly, Stratus failed to report that no significant differences were observed in development of eggs to the trochophore stage in reproductive studies involving all of the cohorts of mussels..

A more holistic assessment of this data would have concluded that mussels survived and grew exceptionally well in all cohorts evaluated in Sooke Basin; that they bioconcentrated small amounts of PAH during the first 14 days; but that they effectively catabolized PAH after that leading to lower values in the mussels growing on the piling than was observed before the test began and tissue burdens in mussels growing on the piling were lower than observed at the open control. No significant adverse effects were observed in any of these cohorts. The fact that the large number of animals evaluated (300 at each distance) enabled the detection of small differences in their lengths at the end of 384 days is also noteworthy.

- **Page 3-14, first paragraph.** It should once again be emphasized that the suite of PAH in whole creosote oil is not the same as the suite migrating from pressure treated wood. If studies

are intended to assess the biological or environmental response to the pressure treated wood product, then they need to use expressate from the wood, which will contain much less naphthalene that the raw oil. Otherwise, these studies are comparing apples and oranges.

- **Page 3-15, Table 3.1.** Note that all of the biological effects concentrations reported in this table are 100 to 6000 times greater than the maximum of 30 ngΣPAH/L measured at Sooke Basin. Low concentrations of dissolved PAH associated with the creosote treated piling was further substantiated by the low concentrations of PAH observed in mussels growing directly on the treated structures and by the fact that all of the 124 taxa representing the 4,236 invertebrates collected in six 0.0225 m^2 samples from creosote treated piling in Puget Sound settled there as sensitive larval stages.

Page 3-18, last paragraph and page 3-19. Much of the NMFS emphasis on setting a 1.0 µg ΣPAH/g standard has been based on the work of NMFS scientists Johnson *et al.* (1994) and Horness *et al.* (1998). The following critique was supplied to Stratus but no mention of the problems in these papers is presented in their report. They are provided here for information to other reviewers. These two papers are considered together because they both relied on essentially the same data. Both papers also relied heavily on the assertion that observance of a biochemical response to PAH implies physiological impairment. The inappropriateness of this assertion is discussed in Brooks (2003b). Enzyme induction is a sign of physiological response – not necessarily a sign of stress or physiological impairment.

The most significant flaw in Johnson *et al.* (1994) and Horness *et al.* (1998) is that they significantly underestimated sediment PAH exposure – at least in Elliott Bay where they reported 10 mg ∑PAH/kg in contrast to Department of Ecology (WDOE 1995) reports of 111.3 to 593 µg ∑PAH/g. Johnson *et al.* (1994) and Horness *et al.* (1998) reported 6 µg ∑PAH/g) in the Duwamish Waterway and 90 µg ∑PAH/g in Eagle Harbor. In reality, Eagle Harbor sediments contain as much as 6,461 mg ∑PAH/kg (Swartz *et al.*, 1989) and the Puget Sound Environmental Atlas (PSWQA, 1992) indicated sediment ΣPAH levels at numerous locations in the Duwamish Waterway >21 µg ΣPAH/kg. In general, higher contaminant concentrations are found in shallow nearshore areas associated with Seattle's intensely urbanized upland and with numerous waterfront docks and industrial facilities. Concentrations of ∑PAH decline in the middle and outer reaches of Elliott Bay (PSWQA, 1992). Sediments in these Puget Sound industrial areas also contain high levels of PCBs and metals. Misitano *et al.* (1994) reported much higher concentrations of both high and low molecular weight PAH in these areas than reported by Johnson *et al.* (1994) and Horness *et al.* (1998).

Juvenile English sole (*Pleuronectes vetulus*), which were the subject of Johnson *et al.* (1994) and Horness *et al.* (1998), are found in shallow water in the intertidal zone where sediment concentrations of all contaminants are highest. As they grow, English sole move into deeper water, but tend to seasonally migrate from deep water in the winter to shallow water in the spring. In British Columbia, English sole are known to make extensive migrations of at least 700 miles (Hart, 1973). The point is that English sole in Elliott Bay and the Duwamish Waterway are exposed to a variety of sediment conditions including ∑PAH concentrations that greatly exceed (by one to two orders of magnitude) those described in these two reports.

Both papers are based on the assumption that the English sole subjected to histopathological examination were exposed to a single sediment concentration of ∑PAH. That simply is not true and while the study does suggest a correlation between exposure to ∑PAH

(and the mix of other contaminants found in these industrial areas) and hepatic lesions, it is not appropriate to attempt to quantify the degree of exposure without significant additional study and documentation of the actual PAH exposure experienced by the fish. Furthermore, while the intermediate metabolites of some high molecular weight PAH can create chromosomal lesions, some metals and other organic compounds found in these contaminated sediments are also associated with cancer. Correlation analysis can never be used as unequivocal evidence of a cause and effect relationship. Both reports are analogous to examining chemical plant workers for signs of disease in their locker rooms and collecting air samples at the same time. Most responsible researchers would not assume that the low concentrations of chemical in the locker room was responsible for any observed disease.

To summarize, Johnson *et al.* (1994) and Horness *et al.* (1998) noted some of these problems in their own work. The authors suggested that the results warranted a closer look at the protectiveness of existing sediment quality criteria. Lastly it is important to note that the author's could not demonstrate any adverse effect on the population of English sole in their study. Poston (2001) summarizes other critical reviews of these papers.

- **Page 3-19.** Stratus has not presented a defensible argument for a sediment effects concentration of 1 ppm ΣPAH as a reasonable screening value for use in the evaluation of potential creosote applications. To the best of the author's knowledge no jurisdiction, anywhere in the world has adopted the sediment standard or screening level proposed by NMFS Northwest Science Center. Such standards must be applied to all activities. In this case, a sediment standard of 1.0 μg ΣPAH/g would essentially shut down all sewage treatment plant outfalls; all stormwater discharges to surface waters; and many industrial discharges. The implications of uniformly applying a standard that is exceeded naturally in some areas to all activities in North American would likely be to shut down modern society. Application of this standard to only treated wood is arbitrary and this author believes that based on the lack of empirical evidence, it should also be considered arbitrary..

- **Page 4-2, Section 4.2 Risk Assessments Using PAH Leaching Models.** Stratus is in error in reporting that the recommendations of Brooks (1995) were based on a TOC of 1.9%. The text on page 7 of Brooks (1995) clearly states that the PAH predictions were based on a TOC of 1.0 percent. The rationale for reducing the input from 1.9% to 1.0% in making recommendations for the Columbia River is discussed in the paper. It appears that Stratus did not read the report.

- **Page 4-3, first paragraph after Table 4.1.** Both Poston (2001) and Brooks (1997) rely on the ΣTU methodology of Swartz *et al.* (1995) to assess water column toxicity. Stratus did not present any convincing arguments in Chapter 3 that would discredit the work of Swartz *et al.* (1995).

- **Page 4-3, second paragraph.** Stratus has presented no information suggesting that the numerous benchmarks described in Table 3.2. are inadequate to protect biological resources. In addition, Stratus has ignored the exceptionally large bioassay and benthic community databases reported in Goyette and Brooks (1998, 2000) and in Brooks (2000 and 2003a). Washington State proposed changes in its marine PAH SQC after publication of the NMFS describing *effects per se* at ΣPAH concentrations <1.0 μg ΣPAH/g. The proposed revisions will decrease the SQC

for HPAH from 960 to 900 μg ΣHPAH/g TOC and increase the SQC for LPAH from 370 to 593 μg ΣLPAH/g TOC (WDOE, 1999). The proposed change will increase the sum of the two classes 1,330 to 1,493 μg/g. For sediments containing one percent TOC that equates to a SQC of 14.93 μg ΣPAH/g dry sediment – not the 1.0 μg/g proposed by the Northwest Science Center.

Washington State is also developing freshwater sediment quality criteria. Table 3-11 of Michelsen (2003) gives as an example, a freshwater PAH SQC of 6.6 μg LPAH/g dry sediment and an HPAH SQC of 31.0 μg/g. The total is 37.9 μg ΣPAH/g, which is far above the 1.0 μg/g proposed by the Northwest Science Center.

British Columbia (BCMWLAP, 2005) has recently defined sediment quality criteria for managing contaminated sites. This document includes *Sediment Quality Criteria for Sensitive Contaminated Sites (SedQC$_{SCS}$).* These sensitive sites include habitats used by endangered or threatened species, or species of special concern under the Canadian *Species at Risk Act.* The SedQC$_{SCS}$ for PAH includes 7 LPAH and 6 HPAH. The stipulated suite of PAH includes phenanthrene, fluoranthene, pyrene, chrysene and benzo(a)anthracene – the most abundant PAHs found in sediments near creosote treated structures. The newly adopted TPAH value in British Columbia is 10 μg ΣPAH/g dry sediment – not 1.0 as has been proposed by NMFS.

Goyette and Brooks (1998) contained a detailed evaluation of the efficiency and protectiveness of the numerous sediment quality benchmarks available at that time based on a very large database consisting of a suite of sediment bioassays with same sample chemistry. They found that the Washington State SQC and the mean of the TEL and PEL were both protective and efficient.

The development of SQC by Washington State and other jurisdictions has been based on careful deliberation and documentation and none of the evolving criteria are consistent with the Northwest Science Center's standard of 1.0 μg ΣPAH/g. Stratus has been very selective in its discussion of sediment effects and regulatory criteria. Their conclusion that the NMFS recommended sediment quality criterion of 1.0 μg ΣPAH/g is an appropriate benchmark is no better substantiated in their document than it has been by the Northwest Science Center. Almost none of this information is provided in the Stratus Report.

- **Page 4-3, last paragraph.** Stratus's assertion that, "Depending on the specific field application, the laboratory-based leaching models appear to be more likely to under-predict than over-predict leaching under field conditions, . . ." is based on conjecture with no empirical evidence supporting it. To the contrary, the field verification studies of Goyette and Brooks (1998, 2000) and Brooks (1997 and 2005a) indicate generally lower concentrations of PAH in the water column and in sediments near creosote treated structures than are predicted by the model. A credible report by Stratus would have relied more on a thorough review instead of their selective review and it would have documented empirical evidence supporting the numerous unsubstantiated assertions made in their document.

- **Page 4-5 and 4-6.** The report of Katz (1998) indicated that average dissolved PAH concentrations near the Navy pier when bilge water was being discharged was 1.1 μg/L (N = 36). The Navy stopped discharging bilge water and removed 50% of the creosote treated piling. Concentrations of dissolved PAH then declined by an order of magnitude to 0.12 μg/L at the piers and 0.06 μg/L at non-NAVSTA sites. It is agreed that some low and intermediate weight PAH migrating from creosote treated wood are dissolved in the water. At Sooke Basin, concentrations of dissolved PAH within 25 cm of the six piling dolphins varied between 0.018

and 0.031 mg/L in comparison with a concentration of 0.013 μg/L at the open control. Dr. Brooks was a navy carrier pilot for 20 years and spent time on carriers in San Diego Bay. He has seen the oil sheens associated with the discharge of bilge water from ships. He has also seen the very dense assemblages of creosote treated piling at Navy piers in the 1960's and 1970's. An alternate and more rational assessment of the Katz (1998) results would be that ending bilge water discharges was primarily responsible for the decrease in dissolved PAH at the NAVSTA because with half the creosote treated piling still in place, the increase in dissolved PAH was only 0.06 μg/L above background.

- **Page 4-7, first paragraph.** Sediment samples reported in Goyette and Brooks (1998) were carefully collected from the upper 2.0 cm of the sediment column in accordance with recommendations in the Puget Sound Estuary Protocols (PSEP, 1996). Why Stratus would assert that they were collected at the "top 2.0 to 2.5 cm" is unclear.

- **Page 4-7, Table 4-2.** It is unclear where Stratus got the values used in Table 4-2. A single sample was collected inside the BMP dolphin next to one of the six closely spaced piling on Day 384. The concentration of PAH was 30.8 μg ΣPAH/g not 47.4. On Day 14, the mean PAH concentration at 0.5 m from the BMP dolphin was 7.86 μg ΣPAH/g – not 105 μg/g. Sediment PAH was measured at 105 μg/g at the Weathered Piling (WP) dolphin on Day 14. However, high concentrations were not observed there on other days (14.1 μg/g was observed on Day 180 and 10.8 μg/g on Day 384) or at other distances (the concentration at 2.0 m distance on Day 14 at the WP dolphin was 2.9 μg ΣPAH/g). The anomalously high sample was most likely associated with pile driving and dolphin fabrication. A more rigorous review by Stratus would have reported the above relationships.

  The mean sediment PAH concentration at 0.5 m distance from the BMP dolphin on Day 180 was 8.8 μg/g (not 14.4 or 17.8) and it increased to 18.9 μg/g on Day 384. Numerous other errors are evident in Table 4-2 of the Stratus Report. Stratus has over-emphasized the high sediment concentration of PAH observed in the Sooke Basin study and overstated concentrations at the BMP dolphin. This is the dolphin that should be emphasized because it is BMP piling that are being used today, at least on the west coast.

  Figure 2, 3 and 4 are provided to better place the PAH concentrations observed in the Sooke Basin Study in better perspective. Note in Figure 2, that 3 samples were collected at the BMP site that exceeded 30 μg ΣPAH/g. One of those was from inside the dolphin and the other two were both at 0.5 m distance. One additional sample was observed with a concentration of 18 μg/g and the remaining samples were all $\leq$ 10 μg/g. The results of sampling an offshore transect (where the pile driver was anchored) on Day 384 are provided on the right side of Figure 2. Note that while sediments collected next to the piling had 69.3 μg ΣPAH/g, the oil was restricted only to that area and the concentration was 2.85 μg/g at a distance of 2.0 m and it was essentially at background at 5.0 and 10 m (0.68 and 0.66 μg ΣPAH/g). Figures 3 and 4 are histograms describing the frequency of observation of classes of PAH concentrations to put Stratus's review in better perspective.

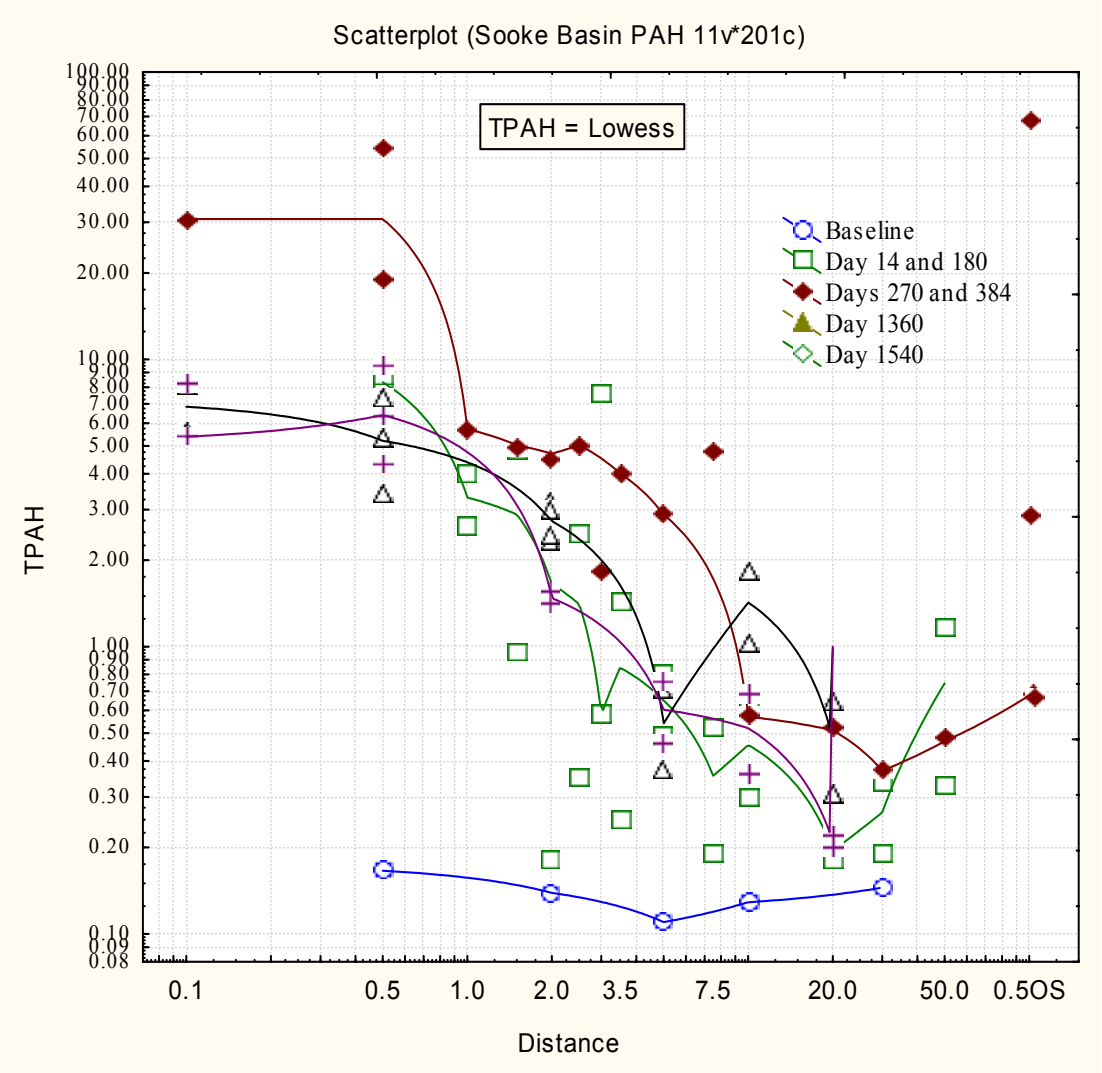

Figure 2. Summary results describing ΣPAH concentrations in surficial (0 – 2 cm) sediments as a function of distance from the Sooke Basin creosote treated dolphins.

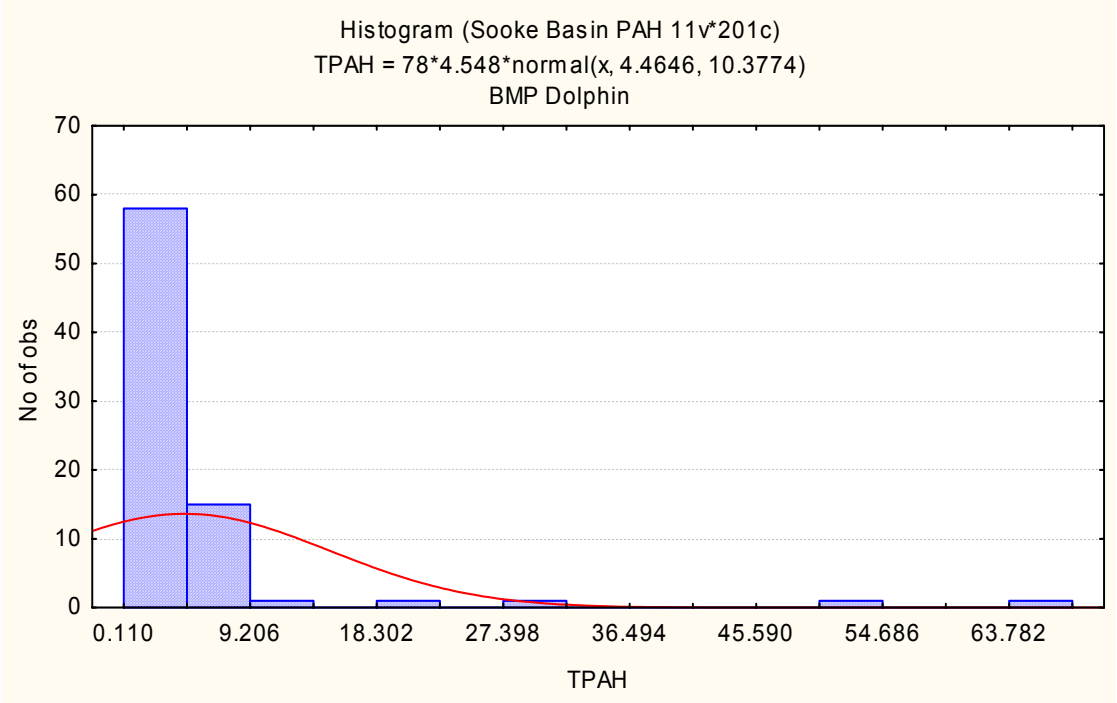

Figure 3. Frequency of observation of PAH concentrations at the Sooke Basin Best Management Practices (BMP) dolphin. Data from Goyette and Brooks (1998, 2000)

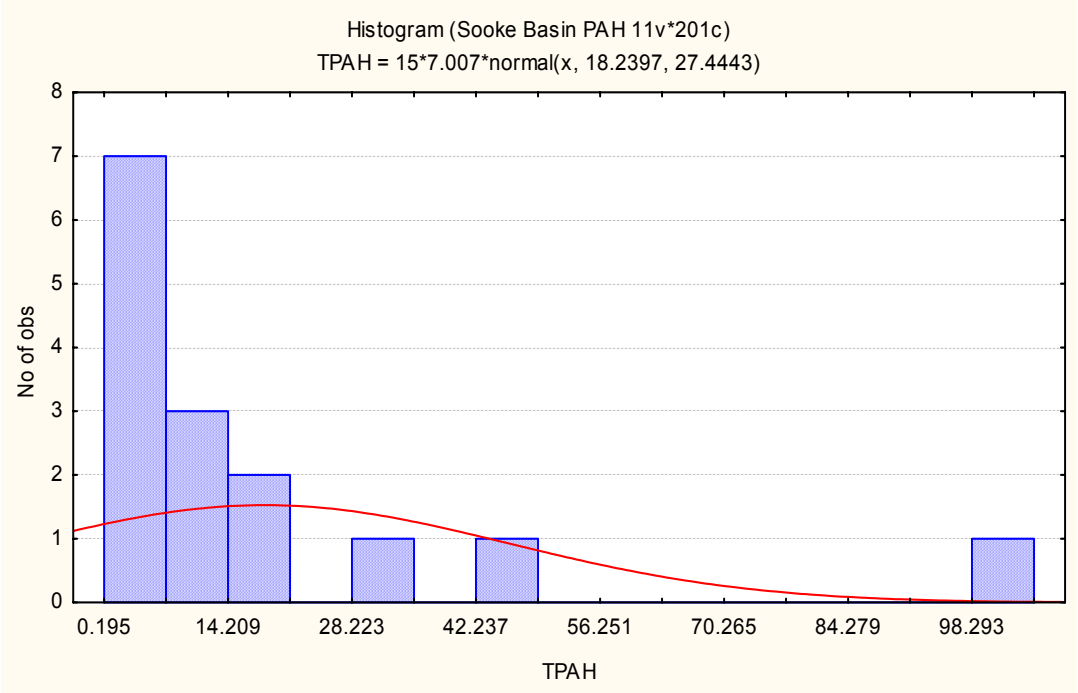

Figure 4. Frequency of TPAH concentrations observed in sediments at the Sooke Basin Weathered Piling dolphin. Data from Goyette and Brooks (1998, 2000)

Environmental studies are fraught with variability and it is important to put that in proper context. For instance, sediment concentrations of 7.6 and 20.0 μg ΣPAH were recorded 5.0 m from the Mechanical Control dolphin on Day 14. There were no creosote treated piling or sources of PAH other than the pile driver at this site. It should be also noted that Stratus was provided with all of the Sooke Basin data.

- **Page 4-9, first paragraph.** Stratus asserts that "elevated PAH concentrations remaining over a year after installation and extending up to 50 m from the pilings." That statement is not true. Table 2 describes sediment data collected at the 30 and 50 m stations from the BMP dolphin on Day 384, together with concentrations for the Mechanical Control and Open Control sites on the same day. Concentrations were highest at the Mechanical Control site, where there were only untreated Douglas fir piling, and lowest at the Open Control. PAH concentrations at distances ≥30 m from the BMP dolphin were intermediate. However, the null hypothesis that the three means were equal was not rejected.

Table 2. a) Surficial (0 to 2.0 cm depth) sediment ΣPAH concentrations observed at distances ≥ 30 m from the BMP dolphin and at the Mechanical Control (MC) and Open Control sites in Sooke Basin on Day 384. b) Analysis of variance assessing the significance of differences in mean ΣPAH concentrations at the three sites.

Breakdown Table of Descriptive Statistics (Sooke Basin PAH)
N=14 (No missing data in dep. var. list)

Site	TPAH DAY 384 >29 m Means	Confidence -95.000%	Confidence +95.000%	TPAH DAY 384 >29 m N
BMP	0.434	0.317	0.551	5.000
MC	0.500	0.008	0.992	6.000
OC	0.203	0.067	0.340	3.000
All Grps	0.413	0.229	0.597	14.000

Analysis of Variance (Sooke Basin PAH)
Marked effects are significant at p < .05000

Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
TPAH DAY 384 >29 m	0.179	2.000	0.090	1.141	11.000	0.104	0.865	0.448

- **Page 4-9, first bullet.** As shown in the preceding paragraphs, Stratus misrepresents the results of the Sooke Basin study in this bullet. True, that sample was elevated on that Day 14. However, the concentration of the ΣPAH was high only at that location on that particular day. To put this result in perspective, Stratus should have noted that the concentration was 2.9 μg/g at 2.0 meters on the same day and it was 15.9 μg/g and on Day 180 and 16.1 μg/g on Day 384. The surrounding data strongly suggests that a piece of debris from the pile driving operation was included in the Day 14 sample and that this concentration did not characterize conditions at other locations near the WP dolphin on the same day or on following days. The Stratus assertion is a misuse of the data.

- **Page 4-9, last bullet.** This statement is misleading. Mussel tissue burdens of PAH were low at all times in the Sooke Basin study. They were significantly higher in mussels at the 0.5 m station on Day 14 in comparison with mussels at the Open Control. Differences in body burdens of PAH were not significantly different among the five cohorts on Day 185 and they were significantly lower in mussels grown adjacent to the BMP pilings when compared with control mussels on Day 384. Protocols for these *in-situ* bioassays are clearly detailed in the report and it is puzzling that Stratus concluded that the mussels that grew slightly slower were in contact with contaminated sediments. In fact, the mussel cages were placed at a depth of 1.5 meters or about 8 to 9 meters above the sediments, which they were never in contact with.

- **Page 4-10, last paragraph.** The Fort Worden site is not, "A long wharf" as described by Stratus. As noted in Table 1 of Brooks (2003a), this wharf consists of 801 Class "A" creosote treated piling packed into an area of 2,115 m^2 and it was chosen because it is one of the densest assemblages of creosote treated piling, located in a rural area away from other sources of PAH, that the author could find in the Pacific Northwest. In addition to the piling, the wharf's deck is supported by a numerous creosote treated beams and cross braces. The sample referred to by Stratus was collected in the center of the densest cluster of tightly packed piling that could be negotiated within this complex. The mean of the three samples collected there was 27.6 μg ΣPAH/g and the next highest sample collected at Fort Worden contained 17.57 μg ΣPAH/g. This represents yet another instance in which Stratus has described results in a non-representative way. A more balanced summary by Stratus would have included the fact that when normalized to sediment organic carbon, not a single sample collected within the Fort Worden complex was greater than the Washington State SQC or that the number of macrobenthic taxa immediately adjacent to the creosote treated wave fence was equal to or greater than observed at either of two reference locations and that the abundance of macrofauna was three to six times higher at all distances within 7.5 m of the creosote treated structures at Fort Worden when compared with these reference stations.

- **Page 3-14, 4.3.5 Conclusions.** All researchers agree that creosote migrates in small quantities from pressure treated wood and that it can accumulate in sediments and Dr. Brooks agrees with the first paragraph of Stratus's conclusions. However, despite a century and a half of high usage in transportation and marine systems across America, there are few records of environmental damage created by the use of creosote treated wood structures.

- **Page 3-14, 4.3.5 Conclusions, second paragraph.** The Precautionary Principle, as stated in Article 15 of the Rio Declaration (UNCED) is, "*the precautionary approach should be widely applied and that, where there are* ***threats of serious or irreversible damage****, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* The first paragraph of Stratus's conclusions indicates that they found no threats of serious or irreversible damage associated with the use of creosote treated wood products. Despite the uncertainties inherent in managing any human activity, including the use of wood that has been preserved using creosote, there is a great deal known regarding the migration, transport and fate of creosote derived PAH. As shown in the papers reviewed by Stratus, there are a number of tools available including risk assessment models and production and construction *Best Management Practices,* to enable society to effectively and deliberately manage the use of these commodities. These resources significantly reduce the need for a

precautionary approach leading to USACE denials, based on advice from NMFS, of the public's right to use these minimally impacting, inexpensive and renewable wood products for projects constructed where federal permits are required. It is puzzling that NMFS and Stratus invoke the *precautionary approach* to the use of treated wood products, for which the environmental risks and their management are well characterized, in favor of alternative materials such as concrete, steel and plastic, for which similar detailed knowledge is not available. Based on conversations with Dr. Fry (personal communication), in which he expounded at length on the significant risks associated with the use of steel and plastic products in aquatic environments, it is puzzling that none of this information was included in the final version of the Stratus report. Because of the lack of information, it is these products to which the *precautionary approach* should be applied.

- **Page 3-14. 4.3.5. Conclusions, second paragraph.** Stratus states that, "First, the above studies typically have evaluated responses at the community level (e.g., the benthic invertebrate studies) or to tolerant life stages (e.g., adult oysters and mussels)." Most benthic invertebrates have planktonic larval stages that recruit into sediments or onto treated piling as more sensitive larvae or juveniles. Therefore, the composition of these communities integrates environmental effects at nearly all life stages. Stratus completely ignored the inventory of invertebrate communities resident on creosote treated piling that were presented in Brooks (2003a). The Stratus statement also ignores the results of the mussel (*Mytilus edulis edulis*) reproductive bioassays that found no significant differences in development to the trochophore stage as a function of distance from the BMP dolphin. As previously noted, NMFS does not manage listed salmon stocks at the individual level. If they did, there would be no mixed stock or hook and line fisheries allowed anywhere in the Pacific Ocean, particularly near the Columbia River or in Puget Sound, Washington.

  Lastly, most of the pressure treated wood risk assessments have been conducted in worst case environments involving slow moving bodies of water and high densities of treated wood. However, Brooks (2000) assessed the risks associated with bridges treated with pentachlorophenol crossing salmon spawning streams in Washington State and Oregon and Brooks (2005a) assessed sediment PAH concentrations under the creosote treated Anderson Creek Bridge in Washington State. Anderson Creek is also a salmon spawning stream. Sediment concentrations of pentachlorophenol and/or PAH were well below any biological effects concentration at all of these sites – even within 15 cm of piling and/or bulkheads supporting the bridges. Stratus did not discuss any of these studies, even though they were provided copies of them. The studies are important because they directly assess conditions in salmon spawning streams and demonstrate a lack of effects. Why Stratus chose to ignore reports directly assessing effects in salmon spawning streams is puzzling.

- **Page 4-14, Section 4.4 Factors to be Considered in Aquatic Risk Assessments.** The first sentence in this section, asserting that, ". . . .PAHs that leach from creosote-treated wood have the potential to accumulate in abiotic media and aquatic biota and to cause toxicity to biota." is misleading. While the potential may exist, of all the reports reviewed by Stratus, the only case in which adverse biological effects were observed was in sediment bioassay tests conducted within ca. 0.65 m of the Sooke Basin dolphin. No adverse effects were observed in macrobenthic communities in any of the other studies or in bioassays at any site other than Sooke.

- **Page 4-15, second and fifth bullets.** Dr. Brooks agrees that site specific risk assessments should be conducted where current speeds are <1.0 cm/sec (first bullet). With respect to creosote, site specific risk assessments should also be conducted where sediment redox is negative or where the reduction oxidation potential discontinuity is < ~1.0 cm. WWPI (2002) provides specific guidance for when a site specific risk assessment is required. Based on the results of Brooks (2000 and 2005a) there is no reason to arbitrarily require a site specific risk assessment for the use of creosote treated wood in areas where the larvae and/or juveniles of T&E species are found. Imposition of this requirement should only be based on empirical evidence demonstrating a real risk in these situations.

- **Page 4-15 and 4-16, remaining bullets.** The remaining bullets should be applied to all construction activities and commodities – not just to pressure treated wood.

- **Pages 4-16 and 4-17.** It is uncertain how the actions of a very few of the thousands of federal, state and local jurisdictions that use and/or permit the use of pressure treated wood has to do with the science of this subject. At this point Stratus leaves science and enters the realm of politics – leaving the door open for others to respond. It is curious that Stratus has not included comments and responses from the U.S. Forest Service regarding the use of pressure treated wood. That agency's Forest Products Laboratory has far more expertise and credibility than NMFS in understanding and predicting the environmental response to pressure treated wood and yet Stratus failed to solicit their comments or those of the hundreds of port authorities that continue to use pressure treated wood to advantage.

- **Page 4-17, last paragraph.** At page 4-14, Stratus concludes that, " . . . and has not generally been associated with measured, significant, biological effects except in close proximity to the structures." As previously stated, even this statement is misleading in that biological effects have generally not been detected and where they have, they have been associated with a proliferation of life on and around the piling. How Stratus uses even their own conclusion to assert in the last paragraph of their report that, ". . . . ., and environmental levels of contaminants originating from creosote-treated wood are often toxic, precautions to avoid creosote-treated wood where practical, and measures to isolate potential toxic effects appear to be justified." is incomprehensible.

Conclusion. Dr. Brooks has seldom encountered a scientific review that has been as poorly written and biased as this document. Despite Stratus's selective extraction of material and misrepresentation of the results of numerous studies, even their own review does not substantiate the conclusions reached. In the end, because empirical evidence did not support the desired conclusions, they reverted to a political argument in asserting that because a few jurisdictions have institute restrictions that others should follow. It should be emphasized that standards in a democratic society must be uniformly applied. Restrictions on a single commodity are not justified. If NMFS feels that a sediment PAH criterion of 1.0 μg ΣPAH/g is needed, they should submit their proposal to EPA for consideration. Obviously a standard of 1.0 μg ΣPAH/g, if applied equally to all activity, would essentially shut down all societies. No stormwater discharges, no atmospheric deposition associated with fireplaces or electrical power generation, no sewage treatment plant discharges, etc. The pressure treated wood industry has a right to be treated equally with other elements of society and the application of this standard to only

pressure treated wood cannot be viewed as anything but arbitrary. If such a standard is applied universally within America, then certainly, the treated wood industry would have to comply.

The lack of scientific rigor and the bias evident in this report means that other reviewers will be forced to examine the volumes of available literature to achieve a true perspective. In that regard, it is unfortunate that Dr. Brooks has not submitted some of his numerous studies to journals for peer review and publication. The basic model for CCA-C Brooks (1996) was peer reviewed and published as have Brooks (2000a, 2000b, 2004b). Brooks (2005a) is in-review. An effort will be made in the near future to submit other key publications. From that perspective, the Stratus report has been valuable in that it points out sections of Brooks (1997) that need amplification to assist those unfamiliar with modeling and environmental risk assessment.

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Section II

Stratus Creosote Report and Comments

4. Transmittal by Chris Risbrudt of the Forest Service

United States Department of Agriculture
Forest Service
Forest Products Laboratory
One Gifford Pinchot Drive
Madison, WI 53726-2398
Phone: 608 231-9200
Fax: 608 231-9592
TDD: 608 231-9544

File Code: 4000
Date: April 26, 2006

NOAA Fisheries, Water Quality Coordinator, Treated
Wood Comments
National Marine Fisheries Service
777 Sonoma Avenue, Suite 325
Santa Rosa, CA 95409

Dear Water Quality Coordinator:

I am respectfully submitting the attached comments on behalf of the USDA Forest Service concerning two documents that have been posted in the Federal Register by the National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NMFS).

We understand NMFS is in the process of developing guidelines for the appropriate use of preservative-treated wood in aquatic environments. As part of this process, NMFS contracted with a consulting firm to interpret the existing science on preservative leaching and environmental impacts and to make recommendations to NMFS on guidelines for appropriate use. The consulting firm produced two reports, which have been posted to allow comments by the public, as well as by Federal and state agencies.

Forest Service scientists have reviewed the reports and have noted that the recommendations have the potential to significantly impact construction projects conducted by the Forest Service and other government agencies. In several cases, the recommendations in the reports do not appear to be well-supported by the relevant science. We have enclosed a review that summarizes our primary concerns with the content and recommendations in the reports. Thank you for your time and consideration.

Sincerely,

/s/ Robert J. Ross (for)
CHRIS RISBRUDT
Director

Enclosure

cc: Robert J Ross
Stan Lebow

Gordon E Blum

Volume II

Section II

Stratus Creosote Report and Comments

5. Memo from Stan Lebow, PhD, of Forest Service to Chris Risbrudt that contain Forest Service comments

Date: April 26, 2006

To: Dr. Christopher Risbrudt, Director
USDA Forest Service, Forest Products Laboratory
1 Gifford Pinchot Dr.
Madison, Wisc. 53726-2398

From: Stan Lebow, PhD., Research Forest Products Technologist

Subject: Comments on Stratus Consulting Reports on use of Preservative-Treated Wood in Aquatic Environments

Background

The National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NMFS), is in the process of developing guidelines for the appropriate use of preservative-treated wood in aquatic habitats that are, or have been, utilized by threatened or endangered species. NMFS is primarily concerned about the impacts of copper released from waterborne preservatives and of polyaromatic hydrocarbons (PAHs) released from creosote-treated wood. The purpose of the proposed guidelines is to identify the types of construction projects that present acceptable risks and those that might warrant further study. To assist with developing these guidelines, NMFS contracted with Stratus Consulting to interpret the existing science on preservative leaching and environmental impacts and to make recommendations to NMFS on guidelines for appropriate use. The task included comparing treated wood to alternative construction materials such as concrete, steel, and plastic.

The Forest Service shares NMFS's desire to utilize construction materials in a manner that is compatible with our natural resources. To that end, the Forest Service has conducted and/or funded studies on the environmental impacts of preservative-treated wood. These studies have indicated that treated wood can be used for most Forest Service construction projects without posing unreasonable risks to the environment. Recommendations in the Stratus Consulting reports appear to offer a more restrictive view of appropriate uses for preservative-treated wood. If these Stratus-proposed recommendations are incorporated into NMFS guidelines, construction projects proposed by the Forest Service and other government agencies could be significantly impacted.

General Comments

Perhaps the most notable weakness of the reports is the apparent disconnect between the science presented in the bodies of the reports and the recommendations listed in the conclusions. A specific example is Recommendation #4 (page 7-4) of the report on waterborne preservatives (a similar recommendation is made on page 4-15 of the creosote report). The authors appear to be recommending that any treated-wood construction project, regardless of project size or stream flow, require a site-specific ecological risk assessment if the location is defined as part of critical habitat for NOAA Trust Resources. It is notable that, because the majority of Pacific Coast

rivers, streams, and estuaries are considered critical habitat, adoption of this recommendation would require site-specific risk assessment for the majority of construction projects in or above water. Recommendation #4 appears to directly conflict with the authors' conclusions elsewhere in the report, that concerns are limited to projects involving large volumes of treated wood or poor water circulation (see page 7-1, for example). In fact, the recurring theme among the studies and models evaluated by Stratus is that small- to medium-sized construction projects in (or above) moving water do not rise to a level of concern that warrants further study. More specifically, the U.S. Army Corp of Engineers modeled the impacts of ACZA- and CCA-treated wood and concluded that no adverse impacts were likely to occur if average flows exceeded 1.0 cm per second and fewer than 100 piles were involved in a construction project. Using more conservative models, NMFS conducted a simulation with structures involving 300, 100, or 24 piles. Their models indicated acceptable copper concentrations in all scenarios involving 24 piles, or with current speeds in excess of 10 cm per second. Thus, blanket recommendations that all projects in areas designated as critical habitat require a site-specific biologic assessment appear to be unfounded.

The impact of implementing such recommendations on Forest Service construction projects alone could be substantial. Most Forest Service construction projects utilize much smaller volumes of treated wood than those modeled and often do not have any treated wood in direct contact with water. They are also typically constructed over well-circulated water. Requiring a full risk assessment in these situations would appear to be unnecessarily burdensome and an inefficient use of time and resources. The Stratus recommendation appears additionally incongruous because earlier in the text the authors point out the negative impact of a similar approach in a NOAA Fisheries Northwest Region draft guidance document. The following excerpt is copied verbatim from page 6-15 of the Stratus waterborne preservatives report:

"The draft guidance includes the statement that "While this guidance contains recommendations on project design and construction, in most settings, a site specific assessment will be needed to determine if the use of treated wood will be consistent with adequate protection of species covered by the ESA and the MSA, their prey base and habitat." This statement is significant because the desire to avoid a formal consultation for a treated wood project can lead an applicant to use alternative materials such as steel or concrete, even if the proposed use of treated wood products would not have exceeded water column or sediment guidelines."

Thus, it appears that the authors are well aware of costs associated with requiring unnecessary site-specific risk assessments.

It is also troubling that although the reports provide suggested parameters to evaluate in site-specific assessments, little guidance is offered on interpreting the results of those evaluations. This raises the concern that the suitability of treated wood for a specific application will remain unresolved even after the considerable time and expense of conducting an assessment.

Another area of the waterborne preservatives report that warrants comment is Chapter 5, Alternative Materials. The information presented in this chapter is inadequate to allow comparison of relative risks and benefits of alternative construction materials. The authors do briefly note that concrete, steel, and plastic products all contain and emit compounds that are

potentially harmful to aquatic organisms. However, there is no attempt to model or quantify the rate of release of these components or their potential environmental concentrations. Thus, it is not possible to consider the risk associated with the alternatives relative to that of preservative-treated wood. Based on the Stratus reports, it appears that the science on environmental impacts of alternative materials is less advanced than that for treated wood. The lack of data on the alternatives is significant considering that the primary criticism of treated wood in the Stratus reports appears to be the degree of uncertainty associated with the existing models. If similar logic is applied to the alternative materials, this lack of environmental data should lead to a recommendation of a site-specific biological assessment for any project using any materials in any area designated as critical habitat. Any other recommendation would be difficult to defend based on the state of the science of the alternative materials relative to treated wood. The practical impact of Stratus Recommendation #4, then, may be to require a site-specific assessment for all construction projects regardless of the building material, size of project, or site conditions. This type of outcome would hinder the Forest Service's ability to build the infrastructure needed to access its lands for either forest management or public recreation purposes.

The Stratus waterborne preservatives report does present some information on the cost of treated wood piles relative to concrete, steel, and plastic piles, but the information does have some limitations. A small but important point is that the report uses a typical maximum service life of 15 years for treated-wood piles. Service life data are notoriously difficult to obtain, and in this case the 15-year value—apparently obtained from personal communication—is substantially below that expected by the treating industry and below that predicted by Forest Service exposure tests. The cost comparison also neglects an important consideration for many Forest Service construction projects that are in remote locations with limited vehicular access: The Stratus report notes that the heavier alternative materials are slightly more expensive to install but does not acknowledge that the difference in installation costs increases for remote locations. In locations without vehicular access, construction with alternative materials may simply be impractical. The economic comparison also does not include the cost of purchase or installation of any construction members other than piles. Piles compose only a small fraction of the volume of treated wood used in many construction projects, and particularly Forest Service projects. Most treated-wood members used in construction (joists, stringers, beams, and decking) are oriented horizontally. The cost of these members made of treated wood is generally lower than the cost of these members made of alternative materials, but an even greater difference is found in the ease and cost of installation. As mentioned above, the cost of installing heavier materials in remote locations can be prohibitive.

The lack of information provided for members other than piles in the Stratus reports is also a concern in the biological impact assessment. Neither report addresses release of preservative components from treated wood above water, even though this use constitutes the greatest volume of treated wood. Past publications and correspondence from NMFS (the 2004 Slopes III document, for example) indicate that NMFS is concerned with releases from all parts of a treated-wood structure, including those not in contact with water. Release of preservative from above-water members is primarily a function of precipitation. Because precipitation varies seasonally and geographically, estimation of preservative release from wood used above water is complex. Still, the value of the Stratus reports and their recommendations is diminished by the

lack of data on contributions from a major portion of treated-wood structures. Although data on leaching from precipitation is limited in comparison to leaching rate data for submerged wood, some data are available, and the reports should be expanded to incorporate above-water members of both treated wood and non-wood materials.

In both reports, the authors convey the impression that previous studies and models are likely to underestimate actual rates of preservative release from in-service structures. In the report on waterborne preservatives, the authors expend considerable effort (see Table 2.5, for example) expounding on the theory that laboratory leaching trials are likely to underestimate leaching from treated wood in service. Although some of the authors' points may be valid, they are largely speculative. For example, no evidence supports the theory that static-renewal leaching procedures underestimate leaching rates. In essence, these tests are actually flow-through tests conducted in steps, and they will reach similar values if the test is carried to completion. There are numerous other reasons why laboratory tests may actually overestimate in-service leaching. First, many past laboratory studies have used samples with small dimensions and/or a high proportion of end-grain. These types of samples are intended to accelerate leaching and shorten the test period. By intent, these types of samples will overestimate release rates from commodity-size material in service. Forest Products Laboratory researchers have found that specimens treated in the laboratory may actually have a higher rate of preservative leaching than wood treated by commercial treaters. There are several reasons for this. First, laboratory treatments often use a "full cell" process with a lengthy initial vacuum, lengthy pressure period, and no final vacuum. This type of process is used to improve the uniformity of preservative penetration within the sample and minimize variability between treatment groups. However, the full cell treatment also maximizes uptake of preservative solution. Commercial treaters, in contrast, have the goal of using the minimum amount of preservative required while still meeting the treatment standards. Commercial treaters use an abbreviated initial vacuum, a short pressure period, and a lengthy final vacuum. As a result, commercial treatments typically deliver only about two-thirds the amount of solution that is delivered with a laboratory full cell treatment. In a recent Forest Products Laboratory study, leaching from laboratory-treated deck boards was compared to that of commercially treated deck boards purchased from several suppliers. In each case, less preservative leached from the commercially treated deck boards than from the laboratory-treated deck boards. Commercial treaters have extensive experience in using their equipment to minimize use of preservative and provide a clean surface. In many cases, laboratory researchers are less familiar with treating processes and may not achieve ideal treatment conditions. A common flaw with laboratory treatments is that researchers rapidly dry the specimens immediately after treatment. This rapid re-dry does not allow fixation reactions to proceed and may also result in surface deposition of preservatives on the specimens.

Laboratory tests may also overestimate in-service leaching when the tests are conducted using commercially treated specimens. Laboratory trials are often conducted with deionized water, which can cause higher rates of leaching of some types of preservatives than those found with natural waters. Leaching tests also assume full exposure of the product to the leaching medium, whether water immersion or simulated rainfall. However, in actual structures, much of the wood is only partially exposed to weather because it is protected by decking or other parts of the structure above it. Finally, laboratory tests are typically conducted until the rate of preservative release reaches a relatively stable level and then discontinued. The final release rate noted in the

laboratory trial is then assumed to remain constant for the life of the product and is used to estimate long-term leaching. This assumption of constant release for an indefinite period is an overestimate because as the preservative is depleted from the wood, leaching rate will gradually decline. Thus, most published estimates of long-term release and environmental accumulation tend to overestimate long-term leaching.

In the creosote report, the authors claim (see bottom of page 4-3) that the models reviewed in the report are more likely to under-predict than over-predict PAH leaching under field conditions. This claim appears to directly conflict with the authors' own review of those same models earlier in the report. On page 2-25, the authors note that Poston felt that his model probably over-predicts water column concentrations of PAHs. A similar statement about the Poston model is made on page 4-3. Also on page 2-25, the authors noted that Brooks's model over-predicted environmental concentrations at all locations at the Westham Island Bridge location and both over- and under-predicted concentrations at the Belcarra Bay site. On page 2-26, the authors report that Brooks's model over-predicted water column concentrations at the Sooke Basin site and that it over-predicted sediment concentrations for all but one sampling event. Thus, it is unclear why the authors claim that these models underestimate leaching. Although there is uncertainty in both models, they appear more likely to over-predict than under-predict. In light of the number of parameters involved, the predictions made by the Brooks model are relatively close to environmental concentrations.

Another point of concern in the creosote report is the authors' derivation of what appears to be a completely new, and perhaps unrealistically low, threshold value for sediment PAH levels. In Chapter 3 (Section 3.4.2), the authors summarize various biological effects concentrations discussed in the literature. They note that the issue has been widely studied, and in Table 3.2 they summarize sediment quality guidelines and criteria that have been developed or used by various regulatory agencies as a result of this prior work. They then apparently disregard this previous work in favor of using the data of two NMFS scientists whose research is limited to PAH effects on English sole in Puget Sound. Utilizing this data, they derive a new threshold value (1.0 mg/kg) that is well below that previously utilized by any government agency. Considering the large body of scientific study and considerable expertise that were applied to establishing previous sediment criteria, such a large change based on very limited data does not appear prudent. Unfortunately, this 1.0 mg/kg is then used later in the report (see page 4-2, for example) as if it were a well-established and well-accepted PAH threshold for comparison with observed environmental concentrations.

Specific Comments

Other points in the waterborne preservative report that need clarification are discussed below in the order in which they appear in the text:

Page 2-2, 3rd paragraph—The authors state that the leaching of copper from CCA is typically higher than that of arsenic. This statement is true only for wood exposed in seawater (as cited by the author in Lebow et al. 1999). Most studies of leaching in freshwater, soil, or precipitation have reported that arsenic release is greater than copper release.

Pages 2-6 through 2-10—The authors discuss models developed by Dr. Brooks to assess leaching from CCA-, ACZA-, and CA-B-treated wood and leave the impression that Brooks feels that his models underestimate leaching. In fact, Brooks made this statement for the ACZA models only, and this statement does not apply to the CCA or CA-B models.

Chapter 2, Section 2—The authors comment that models developed to date suffer from variability and uncertainty. Although this criticism has some validity, this same comment could be made about all attempts to model natural phenomena. And the outcomes of models constructed by various authors using a range of testing conditions actually appear to be surprisingly similar. Considering the absence of any models offered for leaching from the alternative construction materials, the work presented in Chapter 2 appears rather robust. It is also unclear why or how the authors reach the conclusion that Dr. Brooks's models of CA-B release will underestimate long-term leaching rates "*by a factor of approximately 1.5 to 2 times*" (see page 2-15). The foundation for this claim is not obvious from the information provided, and as noted above, models such as this probably tend to overestimate long-term leaching because they assume that the rate of release does not decline over time.

Chapter 4, Section 2—On pages 4-2 and 4-3, the authors discuss a series of studies conducted by Weis and Weis or Weis et al. It should be noted that these studies involved use of wood that was treated with CCA to the highest marine retention (2.5 lb/ft^3). This retention is 4 to 6 times greater than that used for freshwater and terrestrial applications. This wood was also in contact with seawater, which has been shown to increase release of copper from CCA-treated wood relative to that in freshwater.

Chapter 6, Section 2—In this section the authors summarize content from a Forest Service publication titled "Guide for Minimizing the Effect of Preservative Treated Wood on Sensitive Environments." It should be noted that the last bullet point in this section misinterprets the Forest Service article in regards to the use of field-applied coatings. The Forest Service publication actually cautioned that the benefit of applying coatings or finishes over aquatic environments was probably not worth the risk of the potential impacts of the coatings themselves.

Page 7-7, final bullet point—The authors appear to suggest use of a preservative system that has not been standardized and has not been evaluated using accepted standard methods. It is important to reference only preservative systems that have demonstrated efficacy in their intended end use.

Other points in the creosote report that need clarification are discussed below in the order in which they appear in the text:

Page 1-5—The authors incorrectly state that copper naphthenate is not recommended for use in freshwater applications. It is standardized for use in freshwater, although at this time its usage is very low compared with that of other preservatives. The authors are correct that copper naphthenate is not standardized for use in seawater.

- *Page 4-10, 3rd bullet point*—It is unclear what toxicity threshold effects level the authors are referring to.

- *Pages 4-4 to 4-6*—Charlestown Navy Pier and San Diego Naval Station: The situation described in the Charlestown Navy Pier is an anomaly that occurred in 1987. The creosote re-treatment required by the National Park Service led to the high degree of leaching observed. It is misleading to state that the piles were treated to a retention that was "higher than the BMP's specified." It is not clear what BMPs the authors are referring to, because the current BMPs had not yet been developed at that time. The piles in that situation were certainly not treated to any type of modern BMP specification. The authors, conclusions based on the San Diego Naval Station study appear speculative. There are many sources of PAH in the environment, and as the authors state, the Navy had taken steps to reduce PAH contributions from multiple sources. The study does not establish what proportion, if any, of the PAH reduction in the harbor was attributable to removal of creosote-treated piles.

Page 4-17, final paragraph—This paragraph is out of place in a report whose intent is to summarize and interpret scientific literature. In the first sentence the authors appear to be expressing the opinion that policies should dictate science. The subsequent statement that "…*levels of contaminants originating from treated wood are often toxic*" conflicts with the majority of studies of creosote impacts. It also conflicts with the authors' own conclusions on page 4-14, where the authors state, "*However the degree of PAH accumulation to sediment associated with these structures appears relatively minor in many settings, particularly in well-circulated waters and over time.*" As a whole, this paragraph diminishes the credibility of the report and should be removed.

Positive Comments

Although there are problems with the Stratus Reports, they do make some recommendations that are worthwhile. For example, the recommendation that wood intended for aquatic environments be treated according to industry best management practices. Treatment of wood to these BMPs will reduce concerns about variability in treatment quality with respect to leaching. Recommendations about prefabrication, fabrication off site, and debris collections are also excellent. It should be noted that these practices are currently followed in most Forest Service construction projects, but further reinforcement of this concept is worthwhile.

Summary

There are several areas where the Stratus interpretations of the relevant science and their resulting recommendations are inconsistent and inadequate. The recommendations presented at the end of the reports conflict with data presented in the reports and with the authors' own conclusions earlier in the reports. Recommendations in both reports would require site-specific biological assessments for any construction project, regardless of volume of wood used, volume of water, or rate of circulation. This recommendation is not supported by the numerous studies and models that have indicated that projects involving moderate volumes of treated wood or rapidly moving water do not warrant further evaluation. Most Forest Service structures, for example, do not appear to warrant a site-specific assessment. The reports should be modified to include simple screening criteria (based on project size and current velocity, for example) that would exclude such projects from the site-specific assessment requirement.

The information provided for alternative construction materials is inadequate to allow comparisons with preservative-treated wood. Although the authors note that the alternatives do release potential toxicants into the environment, there is no attempt to estimate or model these releases. However, it appears that if the authors used logic similar to that used for treated wood, the lack of environmental data for these materials would lead to a broad recommendation of site-specific assessments for every project. The economic assessment of the alternative materials does not consider the additional costs of installing the alternative materials in remote locations and does not consider members other than piles.

Both reports focus almost solely on piles even though piles are absent from many treated-wood structures and constitute only a fraction of the volume of wood used in others. The reports should be expanded to include assessment of risks from above-water structures.

In both reports, the authors make statements that laboratory studies and modeling efforts are likely to underestimate in-service leaching. These statements are not supported by the data presented. In the case of the creosote models, the data appear to suggest that the models are more likely to overestimate environmental accumulations.

In essence, these reports provide very limited guidance. It is clear from these and other reports that although treated wood presents little concern in many projects, there are some situations where further evaluation is warranted. Instead of providing models or criteria that can be used to identify projects that may be of concern, the authors simply recommend that all projects be subjected to site-specific assessment.

Volume II

Section II

Stratus Creosote Report and Comments

6. Letter with comments from William B. Smith of Wood Products Engineering of SUNY Syracuse.

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May 2, 2006

Mr. Joseph J. Dillon
Water Quality Coordinator
National Marine Fisheries Service
777 Sonoma Ave., suite 325
Santa Rosa, CA 95409

via email and fax 301/427-2540

Dear Mr. Dillon:

I have recently obtained a copy and reviewed the draft report on *Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations*, prepared by Stratus Consulting. It is my understanding that this report was prepared for the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA), and is intended to assist the NMFS in developing guidance on the use of treated wood in aquatic environments. Stratus has presented an extensive review of data and other information related to creosote, aquatic environments, and components of creosote such as PAHs. Unfortunately, as currently written, the primary conclusions and recommendations put forth in this report are not properly supported nor substantiated by the data reviewed. As such it would be inappropriate at this time for the NMFS to promulgate any policy, guidelines or restrictions based upon this document.

Stratus has correctly noted that the U.S. EPA is currently undertaking a scientific technical review and risk assessment of creosote treated wood, to assist in deciding whether creosote will continue to be registered as a pesticide. They have also reported, however, that despite pending federal review, many states have implemented their own regulations. What is left unsaid is that much, if not all, of the state regulatory activity has been without scientific justification. In New York State, for example, over the past several years legislative bills to restrict use of creosote treated wood have been vetoed by Governor Pataki, who in each case noted that the reasons for his veto included lack of supporting scientific data and that most appropriate action would best be addressed from the upcoming EPA review. The implication provided to an uninformed reader is that the individual state regulations have been necessarily implemented due to the absence of federal guidelines and restrictions, Aeditorially≅ implying that those regulations were in fact necessary. The Acircular logic≅ of this argument has no place in a scientific document, and its presence suggests strongly an inappropriate prejudicial bias on behalf of the Stratus authors. Such author bias subsequently serves to cast doubt on the confidence of other data, analysis, results and conclusions.

Stratus acknowledges that in 2003 the federal EPA, upon significant study, review and analysis of data, concluded that use of creosote-treated wood products does not result in excessive translocation of creosote or its components into the environment, nor does it result in acute or chronic toxicity to fish and aquatic invertebrates. Also included in this report are data noting that while some PAHs can migrate from treated wood structures into aquatic environments, the degree of PAH accumulation associated with such structures is relatively minor, particularly shortly after new installations, when products are produced, handled and installed in accordance to published BMPs (Best Management

Practices), in well circulated waters, and over time. Data of any PAH accumulation was also shown to be quite limited spatially to areas very close to structures, and yet was still not generally found to be associated with measured, significant biological effects on fish, invertebrates or other aquatic organisms. Duration of any reported biological effects appeared to specifically attenuate within a short time of construction, after which minimal, if any, effects were measurable.

Subsequent to the reporting of various data on creosote components and their possible presence and effect in aquatic environments, and that adverse biological effects from aquatic use of creosote-treated wood have not generally been substantiated or observed, it was concluded by Stratus that nevertheless, several factors suggest that a precautionary principle might be applicable to certain treated wood uses. I am not aware of how such a Aprecautionary principle≅ can be defined, nor what data would be properly used in its development, or how it could be appropriately implemented. For example, I can only presume that through use of the precautionary principle it would be appropriate for protection of aquatic environments to ban boating, swimming, or any human activity within hundreds of yards of such water. This concept clearly has no merit in a scientific document. It was also noted as part of the conclusions and recommendations that the level of environmental protections applied to threatened and endangered (T&E) species should occur at the individual rather than the population or community level. I am not aware of this being accepted procedure or protocol for toxicological or epidemiology studies, and again, I see no scientific justification to making such a statement.

The two current Stratus reports on both creosote- and copper-treated wood in aquatic environments have reviewed a considerable amount of data and reports of performance and biological activity over many years, and as such can provide a meaningful start to the NMFS as it addresses use of treated wood. Unfortunately, the use of inappropriate analysis, editorializing without scientific justification, and suggestions without merit that alternative materials such as steel or plastic pilings and timbers (which take considerably more energy, petroleum and other non-renewable resources to manufacture, are of considerably higher cost, and have questionable performance characteristics as compared to wood) would be better than treated wood, make the conclusions in these reports unusable and much of the rest of the information provided potentially suspect.

I very much appreciate your time and willingness to consider my review and comment upon both of these reports. Please call me at 315/470-6832 or 6880, or email to [redacted] , [redacted] [redacted] [redacted] [redacted] [redacted]. [redacted] [redacted].

[redacted],

William B. Smith

[redacted] [redacted]. [redacted], [redacted].
[redacted]

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Section II

Stratus Creosote Report and Comments

7. Peer Review comments by Timothy T. Townsend, PE, PhD, prepared by the University of Miami Independent System for Peer Review.

Review of

"Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations"

and

"Treated Wood in Aquatic Environments: Technical Review and Use Recommendations"

Prepared by:
Timothy T. Townsend, PE, PhD

Prepared for
"University of Miami Independent System for Peer Review"

March 13, 2006

Executive Summary

Treated wood products by design contain toxic chemicals that are designed to prevent deterioration of the wood by organisms. Several treated wood applications involve submerged wood structures, and in these cases, preservative chemicals are known to leach from the wood products into the surrounding aquatic environment. Concerns have been raised as to the effect of leached preservative chemicals on non-target organisms. The National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) has such a concern with respect to the impact of treated wood on threatened and endangered species in NMFS trust fishery resources. As such, the NMFS is in the process of developing guidelines for the appropriate use of treated wood products in these habitats. The NMFS commissioned two technical documents for use in the development of this guidance, and this current report is a review of those documents.

The following two reports were reviewed: "Treated wood in aquatic environments: Technical review and use recommendations" and "Creosote-treated wood in aquatic environments: technical review and use recommendations." The information covered in the two documents summarizes several different topic areas pertaining to treated wood in aquatic environments: leaching and transport, toxicity of preservative chemicals, risk assessment and evaluation, and best management practices for minimizing risks. This reviewer responded to specific review questions.

The two documents provide an excellent summary of currently available information regarding preserved wood in aquatic environments, specifically information regarding pollutant leaching, available models for predicting transport and fate of preservative chemicals, toxicity of preserved wood chemicals to aquatic organisms, factors to consider in conducting a risk assessment, and existing best management practices for treated wood usage in aquatic environments. These documents represent the most complete, up-to-date compilation of this information currently available. The documents further propose a set of use recommendations for assessing whether treated wood use is appropriate for specific construction projects in a given aquatic environment. These recommendations are warranted and their application is supported by existing data. Given the many uncertainties associated with the current available science on the impact of treated wood products on the aquatic environment, these recommendations should provide conservative protection to threatened and endangered species in NMFS trust resources.

One fundamental component of the use recommendations is the performance of a site-specific ecological risk assessment for projects identified as sensitive in a screening-level project evaluation. The documents provide elements that should be included in such assessments and the factors that should be considered. The documents do not, however, provide sufficient guidance or documentation to conduct a site-specific ecological risk assessment; this does not appear to have been part of the scope of work. Thus, NMFS should focus future guidance development on the production of detailed guidelines for conducting such a risk assessment. Based on past use by the reviewer of

some of the existing leaching and transport models cited, these tools are not adequately reviewed, validated, nor documented to be of wide-spread use. NMFS guidelines should include detailed description of leaching and transport models, and should include a sensitivity analysis so that those conducting ecological risk assessments understand which factors most heavily influence the assessment. The guidelines should include very specific examples demonstrating the application of these models as part of a risk assessment; several examples should be provided, included those where results find that treated wood usage should be restricted and those where usage is not restricted. A logical component to such guidelines would be an easy-to-use software application.

1. Background

Treated wood products contain preservative chemicals specifically added for the purpose of preventing biological decay. The chemicals act as toxins (biocides) to organisms that would otherwise deteriorate the wood. The presence of these toxic chemicals raises natural concern when other non-target species may be impacted. An area of such concern is the use of treated wood structures in aquatic environments and the impact they may have on fish and aquatic invertebrates. Preservative systems are designed to remain active and retained in or on the wood structure for many years, but preservative chemicals do leach at relatively low concentrations over time when exposed to water. These chemicals have the potential to impact biota when dissolved in water and when accumulated in sediment.

The National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) are in the process of developing guidelines for the use of treated wood products in aquatic environments utilized by federal trust fishery resources. NOAA contracted with Stratus Consulting to prepare two technical reports that dealt with treated wood use in aquatic environments. One report focused on the use of creosote treated wood and the other focused on water-soluble preservatives (referred to herein as the "waterborne" report). The reports contain (1) background information on treated wood, (2) data on preservative chemical leaching in aquatic environments, (3) available toxicity information for a variety of biota and different preservative chemicals, (4) existing policies and best management practices for treated wood use in aquatic environments, and (5) recommendations for future projects that might involve the use of treated wood. The purpose of these reports is to assist NMFS and NOAA in future guidance development.

The present document provides a review of the above referenced reports by Timothy Townsend. Dr. Townsend is an associate professor in the Department of Environmental Engineering at the University of Florida in Gainesville, Florida. His area of specialization is solid and hazardous waste management. Much of his research has focused on the leaching of preservative chemicals from treated wood, particularly CCA-treated wood. Some of his research has involved evaluating the toxicity of treated wood leachates use in a variety of aquatic toxicity assays. Under agreement with the University of Florida, Dr. Townsend also provides technical consulting services to a variety of public and private organizations.

2. Review Activities

The following two reports were provided:

- "Treated wood in aquatic environments: Technical review and use recommendations" by Stratus Consulting, Inc., and Paladin Water Quality Consulting

- "Creosote-treated wood in aquatic environments: technical review and use recommendations" by Stratus Consulting, Inc., and Duke University

The reviewer read through each of these documents and prepared a review report based on specific questions that were posed.

3. Summary of Findings

This summary of findings is organized by restating the questions that were asked as part of the review (see original scope of work in Appendix A) followed by a detailed response.

Task Evaluate the synthesis and interpretation of the toxicology information, and state whether or not the conclusions regarding the potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.

Toxicity information is provided in Chapter 3 of the waterborne preservatives report and in Chapter 3 of the creosote report. The report authors provide what appears to be a very complete and up-to-date compilation of aquatic toxicity data related to the wood preservative chemicals evaluated.

<u>Surface water</u>: In the creosote report, the final section of the chapter (3.4) summarizes biological effects concentrations for surface water. In the waterborne report, US EPA water quality criteria for the preservative chemicals of interest are first summarized. Then in the detailed text that follows, the authors conclude that in most cases (cautions are noted) the water quality criteria are protective of regulated species.

<u>Sediment</u>. In the creosote report, the final section of the chapter (3.4) summarizes sediment quality guidelines from several different organizations. In the waterborne report, sediment toxicity thresholds for freshwater sediment were summarized, and it was concluded that these thresholds can serve as meaningful screening tools, but that site specific risk assessment may be needed in some cases.

The report authors did a good job of synthesizing and interpreting the toxicological data. The conclusions reached on potential effects on target species are supported. Certainly the impact of preservative of chemicals on aquatic organisms is influenced by numerous factors and will be very site specific. It is very likely that in many cases no deleterious effects will be observed. But the existing toxicological data do suggest that in some circumstances, preservative chemicals can result in a negative impact to some species.

Task Evaluate the synthesis and interpretation of fate and transport information and state whether or not the conclusions regarding potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.

Fate and transport information is provided in Chapter 2 of the waterborne preservatives report and in Chapter 2 of the creosote report. Both reports review available data preservative leaching from submerged treated wood and review available models that have been proposed to predict leaching. Both reports also describe several transport models that have been developed to assess the fate of leached chemicals in a water body (water column concentrations and sediment concentrations). Finally each report describes available data that compare model predictions to actual measured data.

The authors conclude that the available models do provide a useful tool for predicting how different conditions and parameters impact preservative concentrations in the sediment and the water column, but that the caution must be used when evaluating the absolute magnitude of the modeled concentrations. Results from field measurements and model predictions were reported in most cases to be different.

The specific conclusions that are reached with regard to various aspects of fate and transport appear to be supported by the available data. More discussion on this question is provided in response to questions below.

Task If the conclusions are not supported by the available evidence, please provide a detailed explanation and new conclusions.

See above. The conclusions provided by the authors are supported by the data.

Task Did the review adequately characterize these models by addressing model assumptions, uncertainties, and their applicability to ESA listed salmonids and the habitats of NOAA's Trust Resources? If not, provide explanation(s) and how subsequent conclusions are affected.

The reports did a good job of describing the fate and transport models, but the level of review is not sufficient for someone to then apply the models. The reports were not prepared to the level of a users guide; this is assumed not to have been part of the work scope. Assumptions and uncertainties were adequately characterized. The applicability to ESA listed salmonids and trust resource habitats was adequately characterized in general terms. The reports did not provide sufficient detail and

examples for someone to apply the models.

This reviewer has in the past tried to use some of the models referenced in the report. It is important to note that the models familiar to the reviewer were not peer reviewed, and often times the documentation was minimal and it was very difficult to understand why certain model steps were undertaken. The models (that the reviewer is familiar with) were not particularly user-friendly.

One recommendation is that additional work needs to be conducted to develop a new model (based on the same methodology already described in the existing models) or to take an existing model, peer review it, and provide better documentation, i.e., create a users guide. The authors of the two reports reviewed here did a good job of summarizing the models that exist, but a detailed critique/examination of the models was not presented (I assume this was outside their work scope).

The above recommendation does not imply that the authors made any false conclusion. The conclusions reached by the authors are appropriate.

Task The review concluded that most of the factors present in the models would lead to an increase in leaching in the field compared to that observed in the laboratory. Is this conclusion supported by the scientific evidence? Please explain in detail why the models do or do not result in an under prediction of leaching.

In my opinion, this conclusion is somewhat overstated. The authors of the waterborne report conclude that in-service conditions are "likely to produce much higher leaching rates" compared to laboratory studies. In response to the question above, this conclusion is not supported by the scientific evidence. But I do not believe that the authors were basing their conclusion on measured data as much as they were on plausible expectations.

If you look at table 2.5, the authors describe many factors that could result in more leaching to occur in the field than predicted in the lab. The primary reason provided is incomplete fixation and excess preservative material. While it is true that incomplete fixation might tend to be less of a problem in the laboratory (because of the controlled nature of the experiments), the authors imply that incomplete fixation is a common occurrence. It is not my understanding that incomplete fixation is that common of an occurrence; it certainly happens, but one could argue the other way. In some cases, wood is not treated to sufficient retention levels, and thus the concentrations in the field might be less than what is observed in controlled laboratory experiments. With regard to post-

treatment cleanup, yes, perhaps excess material might exist in a full-scale situation that might not exist in the lab, but again I am aware that this was a very common occurrence. And in the actual applications, there are also factors that could result in leaching already occurring before these products are installed. For example, after treatment, the wood is stored out doors, it is transported on open truck beds and it may be stored at the construction site. During this time period it might be exposed to rain thus washing off preservatives that would not be washed off in the lab.

So I agree that the factors in table 2.5 do suggest that in some cases the mass of preservative leaching per volume of water it comes in contact with may be greater in the field than predicted in the lab, but this concern seems to be overstated. The authors should provide more documentation that treated wood is not being properly fixed or post-treated if this is truly the case. It seems that the error introduced by this might be less than the error inherent in the other factors of the risk assessment. I do not suggest removing this discussion, but it should be thought through better and referenced, and it may need to be toned down accordingly.

Task Are these models sufficient to predict leaching concentrations for use in ecological risk assessments concerning ESA listed species and their habitat?

I believe the approach behind the models is sound and appropriate. In this respect they are sufficient. However these models are not available in a format that could be used routinely by different parties to conduct site-specific ecological risk assessments. In this respect they are insufficient. The models need to be reviewed for their scientific merit as part of a separate review, a user's guide with detailed explanations of terms and procedures needs to be developed, and detailed examples for different use scenarios need to be published. This type of modeling is something that lends itself well to producing easy-to-use software as well.

Task Are additional precautions required to add a margin of safety to the model predictions? Provide examples?

The steps described above are needed. As part of the review above, there should be a sensitivity analysis of the different parameters. This would enable one to recommend where it is appropriate to assign safety factors.

Task The risk evaluation chapters in both reports conclude with a list of factors to be considered in risk assessments concerning the use of treated wood. Are there any other factors missing from the lists?

The list appears complete. As noted elsewhere in the report, other water quality factors may impact toxicity, e.g., dissolved organic carbon

content. Perhaps these factors should be mentioned in this section as well.

The variability of the current velocity and direction may also be important. Which velocity do you choose in the model? The average? Again, it would be helpful to see a sensitivity analysis to determine how important these choices are.

Under "size of proposed structure," does this include above water treated wood? If the piles are holding up a walkway, does the preservative leaching from the walkway after a rain and after abrasion matter? It is unclear whether this is included in the "surface area of the exposed wood." So in addition to "size of proposed structured," may also want to add information for "type of structure" and "proposed structure usage."

Task The copper treated wood report contains a chapter concerning alternative materials and includes a brief examination of toxicity considerations regarding these products. Are there any other considerations that are not mentioned in this chapter?

This is good information. It would be helpful to get a better handle of the proposed lifespan of different materials. This clearly has a strong impact on the annualize costs. The only life spans that are used are 15 and 20 years. It has always been my understanding that plastic can last a lot longer than treated wood. The authors should comment on how reliable these numbers are; limitations of the assumptions and the impact the results should be noted. Otherwise some alternative materials may be unduly dismissed from consideration on a project. A recommendation of getting site specific costs for all projects may be warranted.

Task The current regulations and best management practices (BMP) chapter in the copper treated wood report discusses BMPs put forth by the industry as well as several government agencies. Do you feel that the available scientific evidence warrants the use of these BMPs? Do you think that utilization of the BMPs, given consideration of the site specific factors listed at the end of the risk evaluation chapters, will provide protection to individuals of ESA listed species and to the habitat components of EFH?

The available scientific evidence does warrant the use of BMPs. Preservative chemicals do leach and they can be toxic. The data suggest that although the risk to biota should be low in many cases, there may be times when the risk is not acceptable. The use of proper BMPs can provide protection to ESA listed species. As described above, some components of the "tools" to be used as part of the BMPs need to be refined. A big component of the BMPs is conducting a site specific ecological risk assessment for sensitive sites. The guidance for

conducting this risk assessment needs to be strengthened.

Task Do any of the BMPs or restrictions seem unwarranted or are there additional BMPs or restrictions which should be utilized? Please provide explanations to answers including any site specific factors that should be considered in making decisions regarding the use of treated wood products in aquatic environments.

The recommended BMPs provided in chapter 7 are appropriate. The institution of manufacturing/processing/production BMPs could make a very big difference. The conditions in the screening-level project evaluation review are appropriate and supported by existing information. Additional guidance needs to be provided on how to conduct site-specific ecological risk assessments.

4. Conclusions and Recommendations

The information summarized and presented in the two documents appears to be complete and thorough with respect to the topic of treated wood and its use in aquatic environments. The best management practices recommended are sound and would, if properly used, provide protection of ESA biota. The reports review existing models for determining fate and transport of preservative chemicals from treated wood used in aquatic environments that are conceptually correct and can be used as a tool in an overall risk assessment. Based on the reviewer's understanding of some of these models and the state of their documentation, validation and support, additional work needs to be performed to create a guide that can be used to conduct a site-specific ecological risk assessment of a proposed treated wood project on a potentially sensitive site. This guide should include detailed definitions and derivations of the equations used (with appropriate references), recommended tables for water and sediment toxicity thresholds (these are outlined in the existing report, but they need to be summarized in one spot), a sensitivity analysis, and several examples for different projects (outlined in a step by step fashion). Such a guide could also easily be accompanied by a spreadsheet or simple software package.

Appendix A: Statement of Work

Consulting Agreement Between the University of Miami and Dr. Timothy Townsend

February 20, 2006

Background

The purpose of the technical review documents requiring independent review is to present an analysis of the potential effects and mitigations for the use of treated wood products in aquatic environments. The documents focus on copper treated wood, primarily ammoniacal copper zinc arsenate (ACZA), as this is the most prominent material used on the west coast of the United States and in Alaska, and creosote treated products.

These products are being examined by NOAA's National Marine Fisheries Service (NOAA Fisheries) to determine the risks generated by their usage to the living marine resources which NOAA is responsible for managing, referred to as NOAA's Trust Resources. These include anadromous salmonids managed under the Endangered Species Act (ESA) and Essential Fish Habitat (EFH) as designated by the Magnuson-Stevens Fishery Management and Conservation Act. The use of treated wood in or near aquatic environments commonly requires a permit issued by the U.S. Army Corps of Engineers under section 404 of the Clean Water Act. Under the ESA, federal agencies are to consult with NOAA Fisheries to insure that any action authorized, funded or carried out by the federal agency does not jeopardize the continued existence of any threatened or endangered anadromous salmonids or result in the destruction or adverse modification of designated critical habitat. The issuance of this permit by the U.S. Army Corps of Engineers requires consultation under the ESA to determine whether its approval action would jeopardize Federally-listed species or adversely modify designated critical habitat, and requires an EFH assessment to determine whether its approval action would adversely affect EFH. Since the use of treated wood materials in situations that may expose aquatic ecosystems is widespread along the west coast of the United States and in Alaska, development of these guidelines should help to streamline the review of permitting processes as well as the permitting processes themselves. In some instances, these guidelines may be used to update existing policies regarding treated wood.

The purpose of the ESA is to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved, to provide a program for the conservation of threatened and endangered species and to take steps that may be appropriate to achieve this conservation. Conservation is defined in the ESA to mean using, and the use of all methods and procedures necessary to bring any endangered or threatened species to the point at which the protections provided by the ESA are no longer necessary. It is the policy of Congress, as declared in the ESA, that all Federal departments and agencies shall seek to conserve endangered and threatened species and

shall utilize their authorities in furtherance of the purposes of the ESA. ESA regulates an activity with an eye toward its impact to as little as a single listed individual. These guidelines are meant to clarify the extent to which these authorities need to be applied for the use of treated wood.

The Magnuson-Stevens Fishery Conservation and Management Act established procedures designed to identify, conserve, and enhance EFH for those species regulated under a Federal fisheries management plan. EFH regulates an activity with an eye toward its impact on habitat characteristics. EFH is defined as those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity. Waters include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; substrate includes sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle. Essential Fish Habitat for salmonids includes their saltwater and fresh water ranges.

Effects of treated wood that need to be examined under the ESA and EFH regulations include direct, indirect, and cumulative effects. An example of direct effects includes the acute and sublethal impacts of copper and polycyclic aromatic hydrocarbons to salmonids and EFH regulated species. An example of an indirect effect includes the adverse impacts to the prey base upon which ESA listed and EFH regulated species depend. An example of a cumulative effect includes the impacts of multiple structures and contaminants in an area with or without additional loading from urban sources, historic mining, smelters, ships’ hulls or any other source. The synthesis of these effects to habitat and to individuals, coupled with local environmental conditions and specific species of concern, defines the risk of a project proposing the use of treated wood.

The objective of the technical review and use recommendations development was to establish a solid scientific basis from which guidance development and implementation could proceed, particularly concerning potential direct and indirect effects.

Objectives of the CIE Review

The information presented for review has been developed by a consulting firm under contract to NOAA Fisheries. The use of an independent firm was determined to be the best way to initiate and complete a thorough review of the best available science concerning effects of treated wood, effects of the most likely contaminants coming from treated wood, and policies and guidelines already developed and in use throughout the United States, Canada and/or other jurisdictions involving the use of treated wood products. A brief review of the economic aspects of treated wood and its leading competitors as well as engineering aspects of all these materials was also commissioned as part of the process.

The review panelist is required to review the following reports (*Treated Wood in Aquatic Environments: Technical Review and Use Recommendations* and *Creosote – Treated Wood in Aquatic Environments: Technical Review and Use Recommendations*), in particular, the aquatic toxicology, the fate and transport aspects of the suite of contaminants that may result from its use, and the modeling that is used in conducting risk assessments concerning treated wood. These sections make up the bulk of the submitted documents and have been an area of considerable debate for many years.

Specific terms of reference for the review include:

- Evaluate the synthesis and interpretation of the toxicology information, and state whether or not the conclusions regarding the potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.
- Evaluate the synthesis and interpretation of fate and transport information and state whether or not the conclusions regarding potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.
- If the conclusions are not supported by the available evidence, please provide a detailed explanation and new conclusions.
- Evaluate the review of the leaching and environmental concentration models presented in both of the reports.
  - A) Did the review adequately characterize these models by addressing model assumptions, uncertainties, and their applicability to ESA listed salmonids and the habitats of NOAA's Trust Resources? If not, provide explanation(s) and how subsequent conclusions are affected.
  - B) The review concluded that most of the factors present in the models would lead to an increase in leaching in the field compared to that observed in the laboratory. Is this conclusion supported by the scientific evidence? Please explain in detail why the models do or do not result in an under prediction of leaching.
  - C) Are these models sufficient to predict leaching concentrations for use in ecological risk assessments concerning ESA listed species and their habitat?
  - D) Are additional precautions required to add a margin of safety to the model predictions? Provide examples?
- The risk evaluation chapters in both reports conclude with a list of factors to be considered in risk assessments concerning the use of treated wood. Are there any other factors missing from the lists?
- The copper treated wood report contains a chapter concerning alternative materials and includes a brief examination of toxicity considerations regarding these products. Are there any other considerations that are not mentioned in this chapter?
- The current regulations and best management practices (BMP) chapter in the copper treated wood report discusses BMPs put forth by the industry as well as several government agencies. Do you feel that the available scientific evidence warrants the use of these BMPs? Do you think that utilization of the BMPs, given consideration of the site specific factors listed at the end of the

risk evaluation chapters, will provide protection to individuals of ESA listed species and to the habitat components of EFH?

- Do any of the BMPs or restrictions seem unwarranted or are there additional BMPs or restrictions which should be utilized? Please provide explanations to answers including any site specific factors that should be considered in making decisions regarding the use of treated wood products in aquatic environments.

Specific Activities and Responsibilities

The review panelist's duties shall occupy a maximum of 5 workdays (i.e., a few days for document review and a few days to prepare a Review Report). The review panelist will review the treated wood technical review and use recommendations documents and develop a review report in the context of responsiveness to the terms of reference. See Annex 1 for further details on report contents.

No later than March 13, 2006, the review panelist shall submit the Review Report to the CIE for review[1]. The CIE reports shall be addressed to "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via e-mail to ddie@rsmas.miami.edu and to Mr. Manoj Shivlani via e-mail to mshivlani@rsmas.miami.edu.

[1] All reports will undergo an internal CIE review before they are considered final.

ANNEX 1: Contents of Panelist Report

1. The report shall be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report shall consist of a background, description of review activities, summary of findings, conclusions/recommendations, and references.

3. The report shall also include as separate appendices the bibliography of all materials provided and any papers cited in the Panelist's Report, along with a copy of the statement of work.

Appendix B: Background material

Stratus Consulting, 2005. Treated Wood in Aquatic Environments: Technical Review and Use Recommendations. 160 pp.

Stratus Consulting, 2005. Creosote-treated Wood in Aquatic Environments: Technical Review and Use Recommendations. 104 pp.

Volume II

Section II

Stratus Creosote Report and Comments

8.Peer Review comments by Jason M. Weeks of Cefas

Reviewers Report on;
Treated Wood in Aquatic Environments: Technical Review and Use Recommendations
&
Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations

By

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Other general comments
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Objectives of the CIE Review

This review considers the information presented by a consulting firm working under contract to NOAA Fisheries. The consultants report was intended to be a complete and thorough review of the best available science concerning effects of treated wood in aquatic environments, providing both a technical review and use recommendations for wood treated with products other than creosote (see second review). The key focus of this work is to assess the likelihood of negative effects of the most likely contaminants coming from such treated wood on protected habitats and species. The documents focus on copper treated wood, primarily ammoniacal copper zinc arsenate (ACZA), as this is the most prominent material used on the west coast of the United States and in Alaska.

These products are being examined by NOAA's National Marine Fisheries Service (NOAA Fisheries) to determine the risks generated by their usage to the living marine resources, which NOAA is responsible for managing, referred to as NOAA's Trust Resources. These include anadromous salmonids managed under the Endangered Species Act (ESA) and Essential Fish Habitat (EFH) as designated by the Magnuson-Stevens Fishery Management and Conservation Act. The use of treated wood in or near aquatic environments commonly requires a permit issued by the U.S. Army Corps of Engineers under section 404 of the Clean Water Act. Under the ESA, federal agencies are to consult with NOAA Fisheries to ensure that any action authorized, funded or carried out by the federal agency does not jeopardize the continued existence of any threatened or endangered anadromous salmonids or result in the destruction or adverse modification of designated critical habitat.

This review also considers the information presented by a consulting firm working under contract to NOAA Fisheries. The consultants report was intended to be a complete and thorough review of the best available science concerning effects of creosote treated wood and the effects of the most likely contaminants coming from such treated wood.

Executive Summary

This document comprises a critical review of the reports "Treated Wood in Aquatic Environments: Technical Review and Use Recommendations" and "Creosote-Treated Wood in Aquatic environments: Technical Review and Use Recommendations". It reports on key areas addressed by the Terms of Reference and attempts to provide a holistic overview of the value of the report in terms of meeting its intentions. Several areas are highlighted where the reviewer believes the report fails to provide adequate guidance or make clear its judgements. The reviewer believes there are changes to the reporting style that would accelerate learning by the reader and provide greater assistance in providing use recommendations.

Key Recommendations

The following key recommendations are made; other suggestions are presented in the full text below.

- The structure of the report requires modification to include additional sections and commentaries on a series of issues not currently addressed by the consultants report.

- More recommendations are required, and key statements addressing the issues should be given, i.e. much evidence is presented, but few firm conclusions are extracted and made.

- The modelling sections do not fully highlight their associated uncertainty – the message requires more purpose in its reporting; what are the key recommendations from this report and where is the evidence for these decisions?

- The risk assessment section is weak and requires context and specific recommendations to be given.

- The report suffers from inadequate linking to the final protection goal, i.e. the species and habitats of concern.

- It further suffers from excluding international literature which could often strengthen ones point of view. Although the brief was clearly to use local examples for direct relevance much of the background information could be provided from other sources. This is also highlighted by the lack of consideration of global issues pertaining by way of example, say CCA and how policy makers are dealing with similar issues.

Creosote

- The structure of the report requires modification to include additional sections and commentaries on a series of issues not currently addressed by the consultants report.

- More recommendations are required and statements addressing the issues should be given, i.e. much evidence is presented but no firm conclusions are extracted and made

- The modelling sections are consistently ambivalent – the message is confused and requires more purpose in its reporting, what are the key recommendations from this report and where is the evidence for these decisions?

- The risk assessment section is weak and requires context and specific recommendations to be given.

- The report suffers from inadequate linking to the final protection goal, i.e. the species and habitats of concern

- It further suffers from excluding international literature which could often strengthen ones point of view. Although the brief was clearly to use local examples for direct relevance much of the background information could be provided from other sources.

Introduction

Wood preservation products based on a mixture of copper sulphate, sodium dichromate and arsenic pentoxide have been used for decades for the industrial pre-treatment of timber using pressure impregnation. The chemicals bind with constituents in the wood and are essentially 'fixed' to the wood in a form that is resistant to leaching out by water. The treated timber is used in areas where long term protection is needed and this resistance to leaching is particularly important in e.g. telegraph poles, motorway fencing and timber in cooling towers. Some treated timber is used in outdoor playground equipment.

It is well established that both inorganic arsenic compounds (such as arsenic pentoxide) and sodium dichromate can produce serious adverse health effects, in particular cancer, and both are regarded as human carcinogens. The concerns with arsenic specifically relate to skin and lung cancer, and in the case of dichromate, lung cancer when exposure is via inhalation.

There is no doubt that the components of CCA are hazardous. They are only used at industrial sites under strictly controlled conditions. The treatment process is in enclosed systems and any exposure to operators is minimal.

With regard to the treated wood, again normal handling and use does not result in any significant exposure because of the fixation of the compounds in a form which does not result in any exposure to the compounds of concern.

However, the application of such timbers in situations such as marine pilings may give rise to concern. This report undertaken by the consultants sets out to address this issue and report a series of recommendations and best use practise.

The objective of the technical review and use recommendations development was to establish a solid scientific basis from which guidance development and implementation could proceed, particularly concerning potential direct and indirect effects of treated timbers.

Creosote is a wood preservative used for commercial purposes only; it has no registered residential uses. Creosote is obtained from high temperature distillation of coal tar (itself a mixture of hundreds of organic substances), and over 100 components in creosote have been identified. It is used as a fungicide, insecticide, miticide, and sporicide to protect wood and is applied by pressure methods to wood products, primarily utility poles and railroad ties. The US EPA is currently reassessing creosote as part of its ongoing re-registration program for older pesticides. Federal law directs EPA to periodically re-evaluate older pesticides to ensure that they continue to meet current safety standards. Due to the smell (diesel-like) and feel (often sticky) creosote-treated timber is not generally used for residential or contact uses, but because of creosote's efficacy in protecting wood, creosote-treated timber is used in industrial applications in Australia and North America.

Creosote as a ``heavy duty wood preservative," was first registered in the United States in 1948 as a coal tar creosote active ingredient. Presently, 16 products are registered for use as industrial wood preservatives for above and below ground wood protection treatments, as well as treating wood in marine environments. Creosote wood preservatives are used primarily in the pressure treatment of railroad ties/crossties (about 70% of all creosote use) and utility poles/cross-arms (about 15-20% of all creosote use). Assorted creosote-treated lumber products (e.g., timbers, poles, posts and ground-line support structures) account for the remaining uses of this wood preservative in the US. The consultants report addressed the use of such creosote treated wood in aquatic environments through a report detailing technical and use recommendations.

Structure of the Report

The report provided for review follows a logical framework and is similar in structure to the report on Creosote Treated Wood in Aquatic Environments: Technical Review and Use Recommendations.

The report is based on a series of naturally linked chapters, with Chapter 1 providing a general introduction to the issue and a background to the types of wood treatment. Chapter 2 moves immediately to an examination of metal leaching potential from treated wood and the potential for environmental exposure, and is based around a series of 5 subsections examining metal leaching rates; Models of leaching rates; application of laboratory derived leaching results to field conditions, field trials; and attempts at Predicting Environmental Concentrations (PEC) of metals from leaching models. This is followed by a series of conclusions. Chapter 3 goes on to look at the toxicity of wood treatment chemicals to aquatic organisms and consists of 3 subsections: 1) examining water column exposure, 2) looking at sediment concentrations, and 3) dietary exposure. Chapter 4 undertakes a risk evaluation containing three subsections: 1) looking at predictive risk assessments, 2) laboratory and field studies, and 3) factors to be considered in aquatic risk assessments. Chapter 5, with 5 subsections examines the use of alternative materials or treatments to that of using wood and covers in section 1) material

types; 2) toxicity considerations; 3) economic considerations of these alternatives and 4) a summary of costs for alternative piling treatments with section 5) presenting annualized costs for a hypothetical fender piling project. Chapter 6 examines in 4 sections current regulations and Best Management Practices (BMP) and looks at 1) the production and treatment of treated wood, 2) construction specifications, 3) when to use treated wood and 4) a set of conclusions of their use. Chapter 7 provides a section covering general conclusions and recommendations, followed by a set of references and appendices detailing information referred to in the preceding chapters.

Generic Comments on the overall report

The report is fairly well written and follows a useful framework. However, I would like to see the following additions;

1) An executive summary

2) A bulleted list of recommendations

3) Greater numeration of sections for ease of reference

4) A critical re-evaluation and set of conclusion(s) at the end of each section/ chapter or statement clearly identifiable from the remainder of the report and showing how chapter 7 was complied from such recommendations within the report – better road mapping

5) It would be useful to have a chapter providing an overview of the current legislative status of treated wood in an international context (see section below on other comments), comparing policy and guidance from e.g. US EPA with other sources such as Canada and Europe. This could be included possibly as part of chapter 6.

6) A summary at the end of each chapter addressing the key aspects.

7) A section detailing site specific risk assessment and the processes involved would be useful

Overall the report is written in a style that does not reflect the degree of uncertainty or evidence base for which some of the primary assertions are made. Greater relevance must be paid to the protection endpoints.

Chapter 1

Sets the objectives of the report and defines its protection goal as working towards setting recommendations that are protective of the habitats and species outlined in the section above. The report authors then go on to describe the different types of wood treatment.

Chapter 2

This section looks at models of leaching rates from metals. These models are largely empirical and based on the results of laboratory studies. The models reviewed demonstrate a high degree of variance suggesting that the models are inadequate for dealing with natural systems. The Brooks (2005) model, however, appears to provide fairly robust short-term predictions, but is unable to address chronic leaching which may be underestimated by as much as twice. This section leads on to more obvious statements and conclusions regarding the ability of models to predict environmental metal concentrations from leaching (2.4.3). The underlying assertion is that the available models are inadequate in predicting actual field metal concentrations because of the highly complex nature of individual site scenarios (this message is not as clear for the creosote report where the data and models are equally deficient). I concur with the authors. A list of conclusions is presented on page 2-27 and I would agree with each. I would further add that the prediction of a chemical in the environment is a measure of its potential to cause harm, but not necessarily one that says harm will occur. The uptake of metals is via metal-ion interactions and the result of available metal species in the aqueous and other phases. The underlying uptake of heavy metals is not considered in this report.

Chapter 3

This section deals with the toxicity of wood treatment chemicals to aquatic organisms through different exposure routes: Water, sediment, food and the implication of both direct and indirect toxicity. The section is fairly detailed using the consultants brief to pre-select examples only relevant for the US situation. However, what is missing from this entire chapter is a series of highlights, summaries recommendations and bullet points underlying the key interpretations of the data presented. Much more could be made of this section.

Chapter 4

This chapter addresses the risk(s) from metal impregnated timbers posed to the sensitive habitats and species required to be protected as described above. My comments on this chapter are repeated later for the creosote report. I regard this chapter to be the weakest of all within the review and to my mind (and I am a practicing risk assessor) does not address a formulative approach to risk assessment. The risk assessment process is not described; the chapter represents a series of case studies and scenarios with no clear outputs. The factors to be considered (section 4.3) are important but reflective issues to be considered during a risk assessment rather than dictating or driving the process itself – if you like - these factors all represent degrees of uncertainty that would be required to be addressed during a risk assessment process, and where it is not possible to do so they

weigh heavily in the process as uncertainties. This section does not address a risk assessment methodology or process. Moreover the authors do not address the requirements to be protective of the species or habitats of concern; e.g. salmonids and their habitats. The list of factors to be considered in the Aquatic risk assessment (RA) is useful but not unexpected given the foregoing. I would like to see greater perception and understanding of the risk assessment process and the utility of site specific risk assessment prior to the use of metal treated timber products in each case – a clear requirement not addressed.

Chapter 5

This section considers alternative material in place of treated timbers. The comments below are repeated in my review of the creosote report also. Overall the report fails to consider alternative or more novel methods in place of treated timbers for the protection of the marine environment, including the use of naturally durable woods (e.g. those with high silica content species such as *Dalium*, *Parinari*, etc.) or wood species with natural resistance attributed to natural plant exudates e.g. *Euclyptus marginata*. Other considerations might be the use of other chemical preservation techniques: protection using physical barriers, e.g. plastic sheathing, plastic coatings for example, pile guard etc., fish oils or creosote floating collars etc. The use of dual treatments of creosote plus CCA/ACA is not mentioned. Novel treatments using the incorporation of other organic pesticides (fungicides, mollusicide and insecticides) are not covered and perhaps such warrant a brief mention as an alternative approach.

Chapter 6

This section looks at the different legislative and other guidance documents in existence for the protection of the environment from treated timbers during both the prior consideration of their use in different applications, through to guidance on construction techniques etc. Again, these BMPs and legislative guidance do not necessarily link to the described risk assessment process, a clearly designed tiered hierarchical risk assessment framework would be able to adopt or interchange relevant legislation and guidance for a given situation with a degree of confidence. Currently it is difficult to find a roadmap through this chapter with an underlying certainty of adopting the correct procedure. It is useful to note that the European Commission has prepared a draft proposal (Directive (76/769/EEC) to prohibit the use of copper chrome arsenic (CCA) as a wood preservative. This proposal is based on a potential risk to children's health from wood treated with preservatives containing CCA in playground equipment and risks to human health from the use of treated wood. The risks related to domestic household burning of CCA treated wood will also be addressed. The Commission's scientific committee (CSTEE) also reached a number of conclusions, in particular that the substance is both genotoxic and a well-known carcinogen, and that it may be appropriate to assume that no safe level exists. Based on this advice, the European Commission brought forward proposals to restrict the marketing and use of CCA.

It is this type of context that is missing from the current report, i.e. what is happening elsewhere and advances in other regions.

Chapter 7

I actually quite like this section and I concur with the statements, recommendations and conclusions drawn. One has to ask, however, where the authors were able to draw these conclusions from given the lack of summary evidence in the preceding chapters. If these conclusions are an accumulation of suggestions, recommendation and observations collated from the bulk of the document, then it is not transparent how or necessarily why several of these conclusions were reached. Again, a call for better road mapping through the document is made.

Other general comments

GLOBAL TRENDS IN THE WOOD PRESERVATION INDUSTRY

The following global trends in the Wood Preservation Industry have been identified which may have an impact upon the consultants report.

<u>The CCA issue</u>

CCA preservatives will not be used for treating timber destined for residential (domestic and contact) uses in the US and Canada after December 2003, and in the EU after June 2004. In addition to domestic uses, CCA preservatives will also not be used for timber destined for marine and most agricultural uses in the EU after June 2004. The Wood Preservation Industry estimates that the reduction in CCA applications may reduce the volume of CCA-treated timber produced in the US by about 80%, meaning that 52% of all treated timber will be treated with a different preservative. Due to the varying concentrations of preservatives in working solutions, the impact on the total volume of high risk chemicals being used (identified in the US as CCA, pentachlorophenol and creosote) may only be reduced by about 5%.

This trend away from CCA-treated timber has been driven by four factors.

1. The most recently completed risk assessment of arsenic, carried out by the Commission of the European Communities CSTEE (Scientific Committee for Toxicity, Ecotoxicity and the Environment) concluded that it is appropriate to consider that no threshold exists for the carcinogenic effect of arsenic. The US EPA and the Canadian Pest Management Regulatory Authority (PMRA) have not assessed that CCA-treated wood poses unreasonable risks to the public or the environment when used in accordance with normal handling procedures. The US EPA and the US Consumer Products Safety Commission are currently conducting a probabilistic assessment of potential cancer risks to children from exposure to CCA in residential settings.

2. Following from the CSTEE's risk assessment, the CSTEE concluded that it would be appropriate to apply the precautionary principle, and move to reduce the production of CCA-treated timber.

3. The US wood preservation industry perceived a consumer demand shift away from CCA-treated timber, driven by increased public awareness of arsenic risks, and media coverage of recent studies into the risk of preservatives leaching from treated timber playground equipment.

4. Viable alternative preservatives are now available on the market to replace CCA, and maintain the same level of hazard protection for the timber product. Alternatively treated timber costs between 8–15% more than CCA-treated timber, but this premium is expected to be diluted through economies of scale once production expands to fill the current CCA market.

INTERNATIONAL REGULATORY STATUS OF PRODUCTS CONTAINING CCA

There has been a significant level of action taken internationally in relation to the continued availability and use of CCA timber treatment products.

US Environmental Protection Agency (US EPA)

On 12 February 2002, US EPA announced a voluntary decision by industry to move away from timber treatments containing arsenic by December 31 2003, in favour of new alternatives. This transition affects virtually all residential uses of wood treated with CCA, including wood used in play-structures, decks, picnic tables, landscaping timbers, residential fencing, patios and walkways/boardwalks. US EPA will not allow CCA products to be used to treat wood intended for any of these residential uses from 1 January 2004.

The US EPA has not concluded that there is unreasonable risk to the public from these products, but is of the view that any reduction in exposure to arsenic is desirable. This action comes ahead of the US EPA completing its regulatory and scientific assessment of CCA.

United States Consumer Products Safety Commission (CPSC)

More recently (February 2003), a report by the United States CPSC raised further concerns about the potential health risks associated with CCA-treated timber in playgrounds.

PMRA Canada

Canadian regulatory authorities are working in collaboration with the US EPA to effect similar actions in Canada.

Commission of the European Communities

A risk assessment conducted by the EC Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE) noted that the main risks associated with CCA were those to human health from the disposal of timber treated with CCA and in particular risks to children's health from the use of CCA–treated timber in playground equipment. The CSTEE raised further concerns regarding the potential for children to be exposed to CCA through ingestion and/or inhalation of sand particles in playground equipment. They concluded that arsenic is both carcinogenic and genotoxic. The CSTEE also identified a risk to the aquatic environment in certain marine waters.

Structure of the report (Creosote)

The report provided for review follows a logical framework and is similar in structure to the previous report on Treated Wood in Aquatic Environments: Technical Review and Use Recommendations.

The report follows a general introduction, addressing the nature and use of creosotes their composition and current regulations, policies and Best Management Practises (BMPs). Chapter 2 moves to looking at the available models of PAH leaching from treated wood and consequences for environmental exposure. This chapter is broken into 4 sections examining: 1) Factors affecting PAH leaching from treated wood, 2) Models of PAH leaching, 3) Predicted environmental concentrations (PECs) of PAH resulting from treated wood, and 4) conclusions section. Chapter 3 goes on to examine the toxicity of creosote to estuarine organisms, and again is split into four sections, examining: 1) the toxic components of creosote, 2) routes of exposure, 3) toxicities, and 4) conclusions, including a discussion on biological effects. Chapter 4 provides a framework for a risk evaluation and again four sections describe: 1) previous risk assessments, 2) risk assessments based on PAH leaching models, 3) laboratory and field studies, and 4) factors to be considered in a risk assessment. There is then a section containing references.

In terms of overall layout, structure and readability, I feel the report could focus the reader by providing;

1) An executive summary

2) A list of recommendations

3) Greater numeration of sections for ease of reference

4) A critical re-evaluation and set of conclusion(s) at the end of each section/ chapter or statement clearly identifiable from the remainder of the report

5) It would be useful to have a chapter providing an overview of the current legislative status of creosote treated wood, comparing policy and guidance from e.g. US EPA with other sources such as Canada and Europe

6) A summary at the end of each chapter addressing the key aspects.

7) A "Recommended Use" section appears to be missing despite being part of the report title

8) A section detailing site specific risk assessment and the processes involved

9) A final conclusion, ways forward, recommendations section (as a separate Chapter 5)

Overall the report is written in a style that does not reflect the complexity of the subject matter nor the degree of uncertainty or evidence base for which some of the primary assertions are made. The focus is almost entirely on PAHs and not on creosote. There is also limited consideration of the endpoints dictated by the study objectives; i.e.

"The purpose of the ESA is to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved, to provide a program for the conservation of threatened and endangered species and to take steps that may be appropriate to achieve this conservation. Conservation is defined in the ESA to mean using, and the use of all methods and procedures necessary to bring any endangered or threatened species to the point at which the protections provided by the ESA are no longer necessary."

Furthermore, … "The Magnuson-Stevens Fishery Conservation and Management Act established procedures designed to identify, conserve, and enhance EFH for those species regulated under a Federal fisheries management plan. EFH regulates an activity with an eye toward its impact on habitat characteristics. EFH is defined as those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity. Waters include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; substrate includes sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle. Essential Fish Habitat for Salmonids includes their saltwater and fresh water ranges".

The report suffers from the brief to use only literature examples from the US, there are many instances where work has been described elsewhere that could certainly fit the brief given. To this end may I suggest that the book by Peter Douben (Douben, 2003) be

consulted? Furthermore, there is a complete lack of linkage of the chapter tasks to the need to link to the protection of particular species or habitats types (as detailed above).

Generic comments on the overall report

Chapter 2

Based on the overall simplicity and generic assumptions made in the development and application of models to predict leaching rates, the conclusions derived by the reviewers are relevant. However, the models presented are limited in the quality of their predicted outputs and thus appear at best to be poor substitutes for real data collected from water or sediments, or through the use of SPMEs. In my opinion, the utility of the models is over played by the paucity of the data presented. They appear to either grossly under/ or over estimate water and sediment PAH concentrations as a consequence of variable leaching rates. Mostly this is a consequence of the highly variable (noisy) environments that the applications are attempting to model. More effort invested in defining better model parameters would be time usefully spent. Again the focus of all the models is on predicting the fate and behaviour of only the PAH fraction of creosotes, as we recall creosote is a chemical mixture of up to 300 different compounds, including polycyclic aromatic hydrocarbons (PAHs) some of which are known carcinogens.

Chapter 3

Begins to examine the toxicity of creosote to estuarine organisms and again focuses largely on the impact of PAHs on biota. The chapter is largely effects based, rather than estimating the significance of any measured effects in terms of consequences for ecosystem harm. The chapter covers in fair depth a series of experimental studies in both lab and field and collates evidence form these. This evidence is not necessarily interrogated or criticised, for example, links between measured biomarkers and health of animal populations are not made – partly, I would imagine, because the evidence is absent. I wonder how the conclusion drawn on page 3-14 "…the response measures described in the preceding sections of this chapter appear to be appropriate and <u>reasonably</u> protective of aquatic receptors in evaluating wood-treating <u>projects</u>"(?), I presume that products should be substituted for projects. I see little evidence to justify this statement. Indeed there is not a chapter summary, detailed conclusion, or firm set of recommendations forthcoming from the literature review of this section.

Chapter 4

This chapter addresses the risk posed to the sensitive habitats and species required to be protected as described above. This chapter is the weakest of all within the review and to my mind (and I am a practicing risk assessor) does not address a formulative approach to risk assessment in any form. The risk assessment process is not described; the chapter represents a series of case studies and scenarios. The conclusions drawn (section 4.3.5) do not address a risk assessment methodology or process. Moreover they do not address the requirements to be protective of the species or habitats of concern; e.g. salmonids and their habitats. The list of factors to be considered in ARA is useful but not novel. I would like to see greater perception and understanding of the risk assessment process and the utility of site specific risk assessment prior to the use of creosote treated timber products in each case – a clear requirement is not addressed.

Other general comments

Overall the report fails to consider alternative or more novel methods for the protection of the marine environment including the use of naturally durable woods (e.g. high silica content species such as *Dalium, Parinari*, etc.) or wood species with natural resistance attributed to natural plant exudates, e.g. *Euclyptus marginata*. Other considerations might be the use of other chemical preservation techniques; protection using physical barriers, e.g. plastic sheathing, plastic coatings for example, pile guard etc., fish oils or creosote floating collars etc. The use of dual treatments of creosote plus CCA/ACA is not mentioned. Novel treatments using the incorporation of other organic pesticides (fungicides, mollusicide and insecticides) are not covered and perhaps such warrant a brief mention as an alternative approach. It is worthy of note that in December 2002, the largest creosote producer in the US, Kerr-McGee LLP, announced that it was leaving the forest products industry following several law suits involving harm caused by wood preservation plants using creosote. A factor in this trend is the availability of viable alternative materials, such as steel, composites and concrete, for the applications of creosote-treated timber. This was not considered in the consultants report.

Specific Comments addressing the points highlighted by the specific terms of reference (ToR)

Evaluate the synthesis and interpretation of the toxicology information, and state whether or not the conclusions regarding the potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.

What is missing from this entire section is a series of highlights, summaries recommendations and bullet points underlying the key interpretations of the data presented. Much more could be made of this section. The issue of CCA is not explicit, many countries including the US are working towards banning such a timber treatment for marine and other applications.

Creosote

Serious ecological damage from PAHs has been recorded locally as a consequence of severe oil spills. Less dramatically leakages from offshore oil operations have also caused local pollution issues. Most reported harmful effects are from the physical action of the oil rather than the toxicity of PAHs. So although it has been relatively easy to demonstrate local short term effects of "oil" pollution establishing longer term effects on marine organisms or ecosystems has proved more difficult to demonstrate for PAHs, notwithstanding the persistence of PAH residues in sediments. In various studies outside of those cited (i.e. non-US situation), indicator organisms have been shown to demonstrate negative effects along a pollution gradient in the neighbourhood of an oil terminal. The impacts of PAHs were assessed using a suite of biomarkers. The study by Moore et al. (1987) and Livingstone et al. (1988) showed a strong correlation between tissue concentrations of 2 and 3 ring PAHs and health of marine mussels. Although this work may be criticised on the grounds that other contaminants could have followed the same pollution gradient, there was some supporting evidence from a controlled mesocosms study which showed a similar dose/response relationship. Thus strong evidence exists that harmful effects are possible in individuals, but what is not clear is whether these affects can lead to population declines. The authors of the report also link the presence of high PAH levels in the marine environment with a high incidence of tumours in fish. Again these may not be linked to population declines but certainly influence the value of fish as a consumer commodity, and may be symptomatic of a cascade of health implications. The ecological implication of much of the evidence presented by the authors, however, is not known.

In the marine environment, there can be significant levels of PAH locally as a result of many sources, including creosote treated pilings. PAHs can be biomagnified by some aquatic invertebrates, but not in organisms higher in the food chain that undergo rapid metabolism. To fish, however, they can show considerable toxicity in the presence of UV light as a consequence of their photooxidation. In humans, the main concern of PAHs has been about their mutagenic and carcinogenic properties. However, the ecological concerns of PAHs remain uncertain.

It is an extremely low level of PAH that is required to produce a behavioural effect in aquatic organisms. Considering the contamination of water or sediments, contamination of sediments with relatively high levels of PAHs is probably of most importance with respect to any potential effects on fish behaviour. It is not known whether the large quantities of PAHs in water after immersion of pilings might affect important behavioural responses in fish, such as alteration of homing behaviour to natural rivers by salmon, but compounds with greater solubility and aromaticity possibly within the complex creosote mixture are also likely to be of great importance.

Therefore although PAHs are ubiquitous in the environment, demonstrating a causative linkage between their occurrence and ecosystem harm is very difficult.

Evaluate the synthesis and interpretation of fate and transport information and state whether or not the conclusions regarding potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence

Generally, the information is insufficiently presented to be able to demonstrate linkages to the protected species or habitats – partly because such linkages would be hard to demonstrate for any toxin and partly because of the limited use of international examples.

Creosote
Given my comments above on the inadequate nature of the modelling and the interpretation of the data, in particular the focus on PAHs alone, I doubt that the approach or the conclusions reached are sufficient to guarantee the protection from potential from deleterious effects to the ESA and EFH regulated species and habitats; given the high degree of uncertainty surrounding the model data. There is uncertainty of predicted sediment concentrations and the unknown implication of exposure to acute low concentrations of PAHs and the other compound used in creosote on natural populations. It is unlikely that the conclusions and recommendations from the report (where made) would safeguard the species of concern in every situation.

If the conclusions are not supported by the available evidence, please provide a detailed explanation and new conclusions.

The conclusions presented reflect the evidence provided.

The models as described (some incompletely) reflect a high degree of variability and uncertainty. I do not believe that as described the evidence is sufficiently compelling to warrant their use in ERA, and although the authors of the report hint at this in their section 2 conclusions it is not sufficiently explicit to the reader. I would rather use empirical measurements or real data collected from a site.

Creosote
If one summarizes the data and information available for the past 15 years concerning the impacts of PAHs, and complex mixtures containing PAHs then a consensus can be built using a weight of evidence approach that may be used for assessing the ecotoxicological potential of PAHs for fish. This approach is useful because of the improbability of establishing either a strict scientific or legal standard of causal evidence for regulatory bodies to use in assessing environmental effects associated with mixed contamination.

Combining field and laboratory data and using a weight of evidence approach, it is suggested that levels of PAHs commonly found near pilings in many marine and freshwater environments are causing or contributing to health effects in fish. Effects have recently been reported (See comprehensive overview in Douben (2003)) with very low concentrations of PAHs in water. This points to a potential for effects on fish and especially larvae.

Evaluate the review of the leaching and environmental concentration models presented in the report.

Creosote

Furthermore, the complex and jointly ubiquitous nature of PAHs, halogenated hydrocarbons and metal contaminants often found in creosote or creosote combinations or creosote versus other marine contaminants makes it difficult to identify biological responses caused by PAHs. Separation of PAH effects from the effects of whole creosote is also difficult. The PAN Pesticides database (www.pesticideinfo.org) has very little information actually listed for creosote including a complete absence of acute toxicity test data. I am concerned that the focus of the review was almost entirely devoted to demonstrating the effects of PAHs in isolation of the parent complex mixture that is creosote.

Did the review adequately characterize these models by addressing model assumptions, uncertainties, and their applicability to ESA listed salmonids and the habitats of NOAA's Trust Resources? If not, provide explanation(s) and how subsequent conclusions are affected.

Creosote

The conclusion derived at by the reviewers should be more pointed and clearly highlight the uncertainties associated with using the models presented. I do not believe they are appropriate to be used to protect Salmonids or their habitats.

The review concluded that most of the factors present in the models would lead to an increase in leaching in the field compared to that observed in the laboratory. Is this conclusion supported by the scientific evidence? Please explain in detail why the models do or do not result in an under prediction of leaching.

Creosote

The justification presented in the text is sufficiently robust to indicate the degree of variability associated with the extrapolation of laboratory based measurements used to calibrate the models with real field data where variability is greater and control lost. The models are insufficiently robust to be able to accurately reflect what is happening to the 300 or so compounds contained in creosote, not least the inadequacies associated with simply predicating PAH concentrations.

Are additional precautions required to add a margin of safety to the model predictions? Provide examples?

The current models are insufficiently robust to be used as anything other than a qualitative estimate.

All these points are covered in detail above – the models are demonstrated by the authors of the report to be insufficient for risk assessment purposes.

The risk evaluation chapters in both reports conclude with a list of factors to be considered in risk assessments concerning the use of treated wood. Are there any other factors missing from the lists?

The factors are comprehensive, what is missing as described above is a detailed risk assessment protocol, although the final chapter alludes to this.

Creosote

In the EU there are New Regulations to prohibit the use of Creosote in certain circumstances. Most European countries have met the obligation to implement the provisions (in part) of European Directive 94/60/EC (the 14th Amendment to the Marketing and Use 76/769/EEC). This Regulation prohibits the placing on the market of wood treated with creosote and prohibits, subject to an exception for old treated wood, the use of treated wood in certain circumstances. Given the hazards of creosote and treated wood the regulation seeks to minimise the overall risk to man and the environment. A similar review is taking place in the US led by the EPA. Worthy of considerable note and relevant in the context of this report is that the decision to ban the use of creosote was based not on sound scientific evidence but on the principle of uncertainty and the precautionary principal.

The Directive was negotiated in 1993/94 by DTI (Department for Trade and Industry) and HSE (Health and Safety Executive) and was as stated above not based on a detailed risk assessment. However, the risks posed by creosote are well documented. Creosote placed on the market can have widely different compositions and thus exhibit different properties. Potentially they may cause skin irritation and cause harm when swallowed. Furthermore, all creosote contains aromatic type substances, some of which are known carcinogens. All contain phenols, which may pose a threat to the water compartment of the environment. It was this information in itself with the associated degree of uncertainty regarding the nature of the products in terms of their environmental safety that led to the ban.

It is this lack of accounting within the current report that causes me some unease. Correct, it is very difficult to show categorically that PAHs are deleterious to the environment, equally due to lack of documented information. It is virtually impossible to

demonstrate this for creosote itself. So, you are left with the requirement to make decisions surrounded by a huge degree of uncertainty and lacking evidence. It is in this environment where the risk based approach (RBA) (detailing and highlighting the site specific risk assessment is crucial) and it is this aspect of the work that is lacking. The models portrayed are insufficient, in my opinion, to accurately predict harm to ecosystems (partly because that was never their intention) but partly because the model parameters are not constants.

One approach would be to use a risk based management approach, based around identifying and reducing risks associated with contamination to a level protective of the environment. In the context of RBM, risk is the measure of the likelihood and magnitude of an adverse effect including injury disease, ecological loss or economic loss arising from the realisation of a hazard. Within this approach the contamination is only identified as representing a risk if all three elements of a contamination linkage are present;

- A source;
- A sensitive receptor, and;
- A pathway linking the source to the receptor.

If one of these pathways is absent there can be no significant risk to the receptor. This is the basis of the site specific risk assessments necessary to be undertaken and such an approach requires elaboration within this report structure.

The copper treated wood report contains a chapter concerning alternative materials and includes a brief examination of toxicity considerations regarding these products. Are there any other considerations that are not mentioned in this chapter?

See text and comment above.

The current regulations and best management practices (BMP) chapter in this report discusses BMPs put forth by the industry as well as several government agencies. Do you feel that the available scientific evidence warrants the use of these BMPs? Do you think that utilization of the BMPs, given consideration of the site specific factors listed at the end of the risk evaluation chapters will provide protection to individuals of ESA listed species and to the habitat components of EFH?

See specific comments above.

Do any of the BMPs or restrictions seem unwarranted or are there additional BMPs or restrictions which should be utilized? Please provide explanations to answers including any site specific factors that should be considered in making decisions regarding the use of treated wood products in aquatic environments.

See specific comments above and further details given below covering aspects of the use of creosote treated wood.

The consultants report does not review the BMPs that exist but alludes to their location and literature source. In the absence of such detailed information it is difficult to make further judgements. However, one would envisage a Best Working/ Management Practice that considers a site specific risk assessment and details the process that should ensure as a consequence of such a requirement being triggered.

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Appendix A: Statement of Work

Consulting Agreement Between the University of Miami and Dr. Timothy Townsend

February 20, 2006

Background

The purpose of the technical review documents requiring independent review is to present an analysis of the potential effects and mitigations for the use of treated wood products in aquatic environments. The documents focus on copper treated wood, primarily ammoniacal copper zinc arsenate (ACZA), as this is the most prominent material used on the west coast of the United States and in Alaska, and creosote treated products.

These products are being examined by NOAA's National Marine Fisheries Service (NOAA Fisheries) to determine the risks generated by their usage to the living marine resources which NOAA is responsible for managing, referred to as NOAA's Trust Resources. These include anadromous salmonids managed under the Endangered Species Act (ESA) and Essential Fish Habitat (EFH) as designated by the Magnuson-Stevens Fishery Management and Conservation Act. The use of treated wood in or near aquatic environments commonly requires a permit issued by the U.S. Army Corps of Engineers under section 404 of the Clean Water Act. Under the ESA, federal agencies are to consult with NOAA Fisheries to insure that any action authorized, funded or carried out by the federal agency does not jeopardize the continued existence of any threatened or endangered anadromous salmonids or result in the destruction or adverse modification of designated critical habitat. The issuance of this permit by the U.S. Army Corps of Engineers requires consultation under the ESA to determine whether its approval action would jeopardize Federally-listed species or adversely modify designated critical habitat, and requires an EFH assessment to determine whether its approval action would adversely affect EFH. Since the use of treated wood materials in situations that may expose aquatic ecosystems is widespread along the west coast of the United States and in Alaska, development of these guidelines should help to streamline the review of permitting processes as well as the permitting processes themselves. In some instances, these guidelines may be used to update existing policies regarding treated wood.

The purpose of the ESA is to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved, to provide a program for the conservation of threatened and endangered species and to take steps that may be appropriate to achieve this conservation. Conservation is defined in the ESA to mean using, and the use of all methods and procedures necessary to bring any endangered or threatened species to the point at which the protections provided by the ESA are no longer necessary. It is the policy of Congress, as declared in the ESA, that all Federal departments and agencies shall seek to conserve endangered and threatened species and

shall utilize their authorities in furtherance of the purposes of the ESA. ESA regulates an activity with an eye toward its impact to as little as a single listed individual. These guidelines are meant to clarify the extent to which these authorities need to be applied for the use of treated wood.

The Magnuson-Stevens Fishery Conservation and Management Act established procedures designed to identify, conserve, and enhance EFH for those species regulated under a Federal fisheries management plan. EFH regulates an activity with an eye toward its impact on habitat characteristics. EFH is defined as those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity. Waters include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; substrate includes sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle. Essential Fish Habitat for salmonids includes their saltwater and fresh water ranges.

Effects of treated wood that need to be examined under the ESA and EFH regulations include direct, indirect, and cumulative effects. An example of direct effects includes the acute and sublethal impacts of copper and polycyclic aromatic hydrocarbons to salmonids and EFH regulated species. An example of an indirect effect includes the adverse impacts to the prey base upon which ESA listed and EFH regulated species depend. An example of a cumulative effect includes the impacts of multiple structures and contaminants in an area with or without additional loading from urban sources, historic mining, smelters, ships’ hulls or any other source. The synthesis of these effects to habitat and to individuals, coupled with local environmental conditions and specific species of concern, defines the risk of a project proposing the use of treated wood.

The objective of the technical review and use recommendations development was to establish a solid scientific basis from which guidance development and implementation could proceed, particularly concerning potential direct and indirect effects.

Objectives of the CIE Review

The information presented for review has been developed by a consulting firm under contract to NOAA Fisheries. The use of an independent firm was determined to be the best way to initiate and complete a thorough review of the best available science concerning effects of treated wood, effects of the most likely contaminants coming from treated wood, and policies and guidelines already developed and in use throughout the United States, Canada and/or other jurisdictions involving the use of treated wood products. A brief review of the economic aspects of treated wood and its leading competitors as well as engineering aspects of all these materials was also commissioned as part of the process.

The review panelist is required to review the following reports (*Treated Wood in Aquatic Environments: Technical Review and Use Recommendations* and *Creosote – Treated Wood in Aquatic Environments: Technical Review and Use Recommendations*), in particular, the aquatic toxicology, the fate and transport aspects of the suite of contaminants that may result from its use, and the modeling that is used in conducting risk assessments concerning treated wood. These sections make up the bulk of the submitted documents and have been an area of considerable debate for many years.

Specific terms of reference for the review include:

- Evaluate the synthesis and interpretation of the toxicology information, and state whether or not the conclusions regarding the potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.
- Evaluate the synthesis and interpretation of fate and transport information and state whether or not the conclusions regarding potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.
- If the conclusions are not supported by the available evidence, please provide a detailed explanation and new conclusions.
- Evaluate the review of the leaching and environmental concentration models presented in both of the reports.
  - B) Did the review adequately characterize these models by addressing model assumptions, uncertainties, and their applicability to ESA listed salmonids and the habitats of NOAA's Trust Resources? If not, provide explanation(s) and how subsequent conclusions are affected.
  - C) The review concluded that most of the factors present in the models would lead to an increase in leaching in the field compared to that observed in the laboratory. Is this conclusion supported by the scientific evidence? Please explain in detail why the models do or do not result in an under prediction of leaching.
  - D) Are these models sufficient to predict leaching concentrations for use in ecological risk assessments concerning ESA listed species and their habitat?
  - E) Are additional precautions required to add a margin of safety to the model predictions? Provide examples?
- The risk evaluation chapters in both reports conclude with a list of factors to be considered in risk assessments concerning the use of treated wood. Are there any other factors missing from the lists?
- The copper treated wood report contains a chapter concerning alternative materials and includes a brief examination of toxicity considerations regarding these products. Are there any other considerations that are not mentioned in this chapter?
- The current regulations and best management practices (BMP) chapter in the copper treated wood report discusses BMPs put forth by the industry as well as several government agencies. Do you feel that the available scientific evidence warrants the use of these BMPs? Do you think that utilization of the BMPs, given consideration of the site specific factors listed at the end of the

risk evaluation chapters, will provide protection to individuals of ESA listed species and to the habitat components of EFH?

- Do any of the BMPs or restrictions seem unwarranted or are there additional BMPs or restrictions which should be utilized? Please provide explanations to answers including any site specific factors that should be considered in making decisions regarding the use of treated wood products in aquatic environments.

Specific Activities and Responsibilities

The review panelist's duties shall occupy a maximum of 5 workdays (i.e., a few days for document review and a few days to prepare a Review Report). The review panelist will review the treated wood technical review and use recommendations documents and develop a review report in the context of responsiveness to the terms of reference. See Annex 1 for further details on report contents.

No later than March 13, 2006, the review panelist shall submit the Review Report to the CIE for review[1]. The CIE reports shall be addressed to "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via e-mail to ddie@rsmas.miami.edu and to Mr. Manoj Shivlani via e-mail to mshivlani@rsmas.miami.edu.

[1] All reports will undergo an internal CIE review before they are considered final.

Appendix B: Background material

Stratus Consulting, 2005. Treated Wood in Aquatic Environments: Technical Review and Use Recommendations. 160 pp.

Stratus Consulting, 2005. Creosote-treated Wood in Aquatic Environments: Technical Review and Use Recommendations. 104 pp.

Volume II

Section II

Stratus Creosote Report and Comments

9.Peer Review comments by Judith S. Weis of Rutgers for University of Miami Independent System for Peer Review

University of Miami Independent System for Peer Review

Review of Treated Wood Documents by Stratus Corp.

Judith S. Weis
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Review of *Treated Wood in Aquatic Environments: Technical Review and Use Recommendations* from Stratus Corp. Prepared for Joe Dillon, NOAA Fisheries. 2005

Executive Summary

This report has a very brief inadequate section that covers environmental fate and effects of the metals released from treated wood. By omitting a number of important peer-reviewed papers and taking at face value a large number of unrefereed reports from the wood treatment industry that tend to minimize and gloss over the risks, this report overall probably underestimates the risks posed by treated wood in the aquatic environment. However, it does include important information about best management practices and alternative materials that could be used, and does take a generally precautionary approach to protecting salmonids.

Background

I have read this report, and my findings and evaluation follow.

Findings

The Stratus reviewer has included a lot of papers, but has also omitted a number of important references – why this has been done is unclear. The report seems to have left out many peer-reviewed journal publications and included a large amount of "gray literature" reports. For example, a number of papers from the Weis group are omitted, and the many excellent papers of the Solo-Gabriele and Townsend group (some journal articles, some reports) dealing with leaching, and others are not included. I have included many of these references at the end of this evaluation. The report has 45 pages of appendices, including acute toxicity values of Cu, Cr, and As to all sorts of aquatic animals. It must have been time consuming to compile all this information that is probably not germane to the topic, since treated wood is not likely to cause mortality. They would have seen greater benefit from focusing on a better, more thorough, literature review.

I do not understand what kind of a literature search would come up with all this gray literature and leave out so many peer-reviewed journal articles. The consulting agreement says "The use of an independent firm was determined to be the best way to initiate and complete a <u>thorough review</u> of the <u>best available science</u>" (emphasis mine). This review does not meet that standard. Peer reviewed papers are the "gold standard" of scientific publishing, and good research should be submitted to scientific journals. Furthermore, with the exception of the chapter on models, the Stratus reviewer seems to have taken all the papers at face value, and has not read them all critically. The review does not distinguish between the value of peer-reviewed publications and "gray literature" reports from consultants to the wood preserving industry.

The report does include 11 citations by K. Brooks, who works for the wood preservers, of which only one was in a refereed journal. There are also several "personal communications" from Brooks. There do not seem to have been any personal communications with the investigators whose peer-reviewed publications have been omitted. I have not read all of Brooks' reports in detail, but one that I have read in detail was Brooks (2000) in the document from the Forest Products Laboratory studying the impact of preservative-treated wood in a wetland boardwalk. He concluded that leachates from wooden walkways increase the metal levels in sediments nearby, but do not affect the benthic community. Since Weis & Weis (1994, 1998) found clear effects on estuarine benthic communities near CCA-treated bulkheads, this finding of no effect of a "worst case scenario" on the benthic community was of considerable interest. When one reads the methods section of this report, one finds that the samples taken for infaunal community analysis were not replicated. Replication is essential for any good scientific study. In Brooks' study, replicates were taken for the invertebrates that settled on artificial substrates, but not for the Petite Ponar grab samples for infauna (although replicates were taken during the baseline survey prior to construction of the boardwalk). Although he found differences in abundance and diversity of organisms near and far from the treated wood, differences were not statistically significant. For example, at the AZCA site, taxa richness and diversity indices all drop immediately downstream of the site, but are not significant. For the CCA site, 16 species were found 1 m from the wood, while 46 species (3 times as many) were found 3 m away, but the difference was not considered significant. Similarly, for the sampling of invertebrates associated with vegetation, there were no replicates taken. Organisms in the vegetation at 0.5 m from the ACZA site are heavily dominated by one opportunistic species, *Limnodrilus* (a sign of stress), while at 2.0 m there is much greater evenness, reflecting a healthier environment. These differences are not considered significant. Biological samples tend to vary, and properly done benthic infaunal community studies generally take a minimum of 3-5 replicate samples. The fewer samples one takes, the less work one has to do and the less the chances of finding statistically significant differences. If there are no replicates taken, "statistically significant" differences are not likely to be found. If someone had the goal of finding "no significant differences" a good way to do it would be to not take replicate samples! This type of science would probably never have gotten through the peer review system of scientific journals. It is also interesting that there appears to be bias even in the formulation of a hypothesis for this study of a "worst case" scenario. Despite the fact that there was new wood and a poorly flushed system, Brooks hypothesized that "there would be no statistically significant changes in the benthic and epibenthic invertebrate community associated with the construction of wetland boardwalks…" This would be expected to be the <u>null</u> hypothesis for an unbiased researcher. The author of the Stratus review does not seem to have read this report critically and seen its major flaws, but takes its conclusions at face value, saying "no significant changes in invertebrate communities were reported." It is possible that careful critical review of other papers from this author would reveal other flaws.

In contrast, peer-reviewed studies of benthic communities at a number of different estuaries on the Atlantic coast found major (statistically significant) reductions in

diversity in communities adjacent to and out for a few meters from treated wood bulkheads of various ages in both well-flushed and poorly flushed environments (Weis and Weis 1998).

The review devotes three pages and includes a table from the Forest Products Laboratory 2000 (Lebow et al. 2000) report on the chemical accumulation under a wetland boardwalk. However, it does not mention a comparable peer-reviewed publication (Weis and Weis 2002) dealing with contamination of salt marsh sediments and biota from CCA boardwalks. In that study, sediments and marsh plants from directly underneath and out from walkways that were new (three years old) and older (15 years old) were analyzed for the three metals. Dispersal was greater in the low marsh than the high marsh (due to tidal effects) and accumulation of the metals was also greater in the low marsh. While levels right below the boardwalk were greater under the new walkway, contaminants had spread out over a greater area from the older walkway. On the Pacific Coast, marsh plants provide juvenile salmon places to forage and hide, and the detritus-based food web provides them with abundant prey. They could be considered essential fish habitat for the juveniles. Meyer et al. (1981) and Weitkamp and Campbell (1980) found that juvenile salmon showed preferences for marsh-associated copepods, chironomids, and amphipods in a number of Puget Sound estuaries. Therefore salt marshes and their potential contamination with metals from treated wood should have been of interest in this review. Since juvenile salmon associate with salt marshes and would be expected to associate more with the low marsh than the high marsh, it is surprising that this relevant paper is omitted from the report.

I am unable to evaluate the leaching models, but assume that since Brooks' model passed peer review for the journal "Estuaries" it is reasonable and sound. The Stratus reviewers analyze the strengths and weaknesses of the model. Models need to incorporate estuarine conditions as well as riverine conditions into them; flow rates and directions change and reverse during the tidal cycle in an estuary. I agree that it is likely that the environmental conditions in the field will probably in most cases produce greater leaching than observed in laboratory studies.

In discussing laboratory and field studies, the report repeatedly uses the word "potential" with regard to impacts or adverse effects, when many of these have been clearly demonstrated. On page 4-11 the report says that biological effects appear to become attenuated within several months of construction. This is repeated in first paragraph of the conclusions on page 7-1. While this is the case for leaching and water levels of the metals, this is not the case for bioaccumulation as seen in a number of papers (e.g. Weis and Weis, 1992; Weis et al 1993). The report doesn't appear to appreciate the fact that, although leaching decreases with time and the water concentrations of the metals will decrease with time, this does not apply to metal levels in the sediments or bioaccumulation in the benthic and epifaunal animals, and the potential effects on the benthos. Clear, statistically significant, effects were seen in decreased diversity and abundance of estuarine benthos in many sites near treated wood bulkheads that had been in place for many years (Weis & Weis 1994, 1998). In the discussion of the 1998 paper, he says "effects were negligible by >1 m from the structures." While this was true for

some of the sites, other sites showed effects out to 3 or even 10 m. Effects were seen both at sites with low water movement and sites with much faster water movement.

The section on toxicity of the chemicals is quite cursory and brief, and omits many important papers on sublethal effects of low levels of the three metals to aquatic biota. Effects generally are seen at the low *u*g/l level. It does do a good job on the avoidance response of salmonids to Cu, however, this is the only sublethal effect that is considered in any detail. The section does not consider Cu toxicity to algae and gastropods, both of which are particularly sensitive taxa (Cu can be used as an algicide and molluscicide) and important members of aquatic communities. The report has omitted a number of papers demonstrating additional aspects of leaching and the toxicity of CCA wood leachates. In fresh water subject to simulated acid rain, Warner and Solomon (1990) found that the leaching rate was accelerated. The copper leached was far in excess of the lethal level for *Daphnia magna*. Buchanan and Solomon (1990) reported that the LC_{50} for this species is about 36 µg Cu l^{-1}, which is only about 2% of the concentration in the leachate. Leachates from treated wood from different tree species all failed LC_{50} tests using fish. The acute toxicity of the three metals together to *Daphnia* was greater than that for Cu alone indicating that the metals act jointly. There was evidence that Cu and Cr interact synergistically. Sublethal effects were seen in oysters living on CCA bulkheads, which had elevated levels of micronuclei, an indication of genotoxicity (Weis et al. 1995). Laboratory bioassays of leachate were performed on larval oysters (*Crassostrea gigas*) to investigate behavioral responses (Prael et al. 2001). Early veliger stage larvae were observed to avoid concentrated leachate, and three- and seven-day old larvae swam faster in leachate than in clean seawater and moved up and down more in the leachate. This altered behavior may retard settlement of the larvae to metamorphose into adults.

Bacteria that normally degrade pentachlorophenol (PCP) play an important role in degrading and waste removal of this other chemical used as a wood preservative. When exposed to CCA, their ability to degrade the PCP was inhibited. Inhibitory effects were seen at concentrations thousands of times less than those used commercially (Wall and Stratton 1994). Other ecosystem level effects on microbial activities have been seen in terrestrial environments. Microbes in CCA-contaminated soils in the field have been shown to be negatively affected (Bardgett et al, 1994). Microbial biomass, carbon, and nitrogen were lower in contaminated soils. Bacterial respiration, biomass P, and denitrification all declined with increasing CCA contamination. In another study, biological activities, including respiration, nitrification and sulphatase, were reduced in soils contaminated by CCA (Yeates et al. 1994). It is likely that similar effects would be seen in bacteria in aquatic environments.

There is only one small paragraph devoted to dietary exposure to chemicals from leachate (P. 3-11). This is the probable route of exposure for salmon, which are the main reason for this report. This section should be much longer. He concludes that there is little likelihood of dietary toxicity because of limited potential for substantial metal accumulation in invertebrates. There have been at least two journal articles showing trophic transfer of CCA wood-derived contaminants. Algae taken from CCA bulkheads were fed to mud snails (*Ilyanassa obsoleta*), which caused snails to retract into the shells,

cease activity, and eventually die (Weis and Weis 1992). Oysters taken from CCA bulkheads were fed to carnivorous snails (*Thais haemastoma*) and caused them to reduce their feeding rate, and thus reduce their growth (Weis and Weis 1993). After two months of consuming these contaminated oysters, the snails acquired body burdens of Cu equal to that of snails collected from treated wood bulkheads. These studies indicate that there is indeed a "potential for dietary toxicity." Trophic transfer is related to the way in which the prey organism stores the metal. The marine isopods *Limnoria* spp. (gribbles) bore through wood, including CCA-treated wood. (This is ironic, since one of the reasons for the use of preservative-treated wood in the marine environment is to prevent damage by marine borers.) They can tolerate the high concentrations of metals by storing copper in granules. An increased number of copper-containing granules were found in isopods from CCA-treated wood compared to those taken from untreated wood. The ability to store copper in inert granular form may explain why these organisms can consume CCA wood without suffering toxicity (Tupper et al. 2000). Furthermore, metals stored in granules are not available to consumers (Wallace et al 2003). This is another aspect of trophic transfer that is not covered in the report.

In any risk assessment, there is a need to distinguish between bulkheads or walkways, which have a lot of surface area for leaching, and pilings, which have much less surface area. From an overview of the literature, it appears that leachates from pilings in reasonably well-flushed areas do not produce obvious negative effects in the immediate vicinity. It would be expected that when flow rate is higher, the leaching rate might be higher, but the metals would be swept away downstream rather than accumulate near the treated wood. It should be noted, however, that estuaries have areas in which there are high rates of sediment deposition ("turbidity maximum") and the leachates that are swept away from the immediate site of the treated wood are probably being deposited somewhere else downstream. Metals do not degrade, but will accumulate at these depositional sites. The question is whether the risk assessment will be only for the immediate vicinity of a treated wood structure, or if it will consider potential effects at the depositional sites further downstream. Another factor that needs to be incorporated is the initial concentration of metals in the wood – for marine and estuarine uses it is 2.5 lb/ft^2 but in freshwater the wood used may be lower than this.

The best management practices (BMPs) as listed and described will reduce the potential for toxicity somewhat, but since there will still be leaching from treated wood, and the leaching is greatest when the wood is new, I would recommend another, more effective, BMP. If the wood were to be soaked out on site at the treatment facility for a few months before being put into service, the greatest amount of leaching into the environment, and thus the greatest amount of risk, would be eliminated. The water into which the wood leached could later be recycled by pressure-treating it into new pieces of wood. This would eliminate the large amount of leaching from newly installed wood, which is responsible for the greatest amount of the problems.

The discussion of alternative materials is good and appears to be thorough.

Specific comments

P. 2-18 discusses factors that could affect the leaching rates. The presence of knotholes in the wood is not discussed and could affect leaching rate. Knotholes are common in Southern yellow pine, which is the wood used most frequently in the Atlantic coast.

Chapter 3 , 3.1 discusses water exposures and briefly considers the toxicity of each of the three metals, but does not discuss the possibility of interactions (additivity, synergism, antagonism) when all three are present in the water.

I was surprised that there was no discussion of the importance of speciation and bioavailability of any of the metals. These are very important issues relevant to the effects of leachates from metal-treated wood in the aquatic environment and should be included in a report like this.

P 3-10 has bulleted different approaches to sediment toxicity, but does not include the Effect Range-Low and Effects Range Median approach of Long and Morgan, that is discussed later. The acid-volatile-sulfide (AVS) (Long et al.1998) approach and other sulfide-related approaches (Rozan et al. 2000) might also be included among the approaches to sediment toxicity.

P 7-4, recommendation #4, last bullet suggests that minimum current velocities should be greater than 2 cm/sec for treated wood to be acceptable. If taken strictly, this could rule out its use in estuaries, where during parts of the tidal cycle current velocities are less than this, or zero.

Summary and Conclusions

Overall, by having a very cursory review of sublethal toxicity studies, omitting many relevant peer-reviewed publications, and not critically reviewing the "gray literature" cited in the report. The report generally seems to underestimate the risks associated with copper-based treated wood, and says that any effects would attenuate after several months. This is clearly not the case in terms of bioaccumulation and effects on the benthic community, or in terms of trophic transfer. However, it does take a precautionary approach to salmon, especially juvenile life stages.

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Review of "*Creosote-treated Wood in Aquatic Environments: Technical Review and Use Recommendations*." from Stratus Corp. Prepared for Joe Dillon, NOAA Fisheries. 2005

Executive Summary

This report includes a much more adequate and comprehensive review of the literature than the previous report on metal-treated wood. It documents extensive toxicity of creosote and its components to aquatic life at low concentrations, includes regulations from many areas banning its use, and demonstrates that creosote components can accumulate in sediments many meters away from the structure. Therefore, the conclusions and recommendations that tend to say that this is not something to be concerned about do not seem to be in keeping with the documented effects. The report does not have a section discussing the breakdown of the PAHs in water and sediments, which should be important considerations in evaluating the risks posed by creosote treated wood. They do take a precautionary approach to salmonids, however.

Background

I have read this report and my evaluation follows.

Findings

The report documents faster leaching from newly treated wood, and shows that leaching occurs faster when flow rate is faster. It also shows that temperature can affect the leaching rate, and that different PAHs have different leaching rates, with low molecular weight compounds dissolving more readily than the heavier PAHs.

It considers the Brooks (1997) model, and notes that it has not been published in the peer-reviewed literature. The report critically examines the various models of Brooks and Poston and points out their strengths and weaknesses. One criticism of the Brooks model they do not mention is the assumption that low molecular weight PAHs do not volatilize. One criticism of the Poston model is using acute levels (LC_{50}) for the toxic threshold. A point where 50% of the animals die is certainly an extremely high level to be considered a threshold!

The authors of the report spend considerable time discussing Goyette and Brooks (1998, 2001) study of a "worst case scenario" of leaching, and note that "no positive controls were reported and percent recovery was not reported." They also point out that higher than expected amounts of creosote were found in the offshore direction – suggesting greater transport than the model expected. They also point out that the model does not consider the number or density of pilings, which would appear to be important issues, and that the model ignores the effect of water flow on leaching rate. This indicates that the Stratus reviewers were reading this part of the report critically – a good thing.

The chapter on toxicity is much more thorough and comprehensive than the comparable chapter of the other report dealing with CCA and related chemical treatments. They review routes of exposure, cover many peer-reviewed papers dealing with both water and sediment exposures, and indicate that effects in fish can be seen at water concentrations down to 16 *u*g/L. They have a brief section on phototoxicity, which can increase the toxicity of PAH compounds. They cover carcinogenesis, which has been studied extensively by the NOAA Seattle group, as well as researchers studying the Atlantic Wood Superfund site in the Elizabeth River. They have a good section on developmental effects, both laboratory studies and the field observations of herring eggs deposited near treated wood (Vines et al.2000). Eggs deposited on a very old creosote piling (40 years old!) failed to develop. This is a very important finding, in that the leaching and toxicity would have been expected to be minimal from such an old piling. That work indicated that 0.003 mg/L significantly reduced hatching success, and increased abnormalities in herring eggs. Wassenberg and diGiulio (2004) found effects of low concentrations on developing *Fundulus heteroclitus*, a species that is quite tough and insensitive to environmental toxicants. They cover effects on immunotoxicity, reporting that sediment levels of 25 mg/kg produced effects on winter flounder, and that Karrow et al (1999) found effects in rainbow trout at 17 *u*l/L. There is a table on pg 3-15 indicating that effects generally become apparent around 3 *u*g/L in the water.

The report does not have a section discussing the breakdown of the PAHs in water and sediments. The rate of degradation under various environmental conditions, pathways, persistence and toxicity of the degradation products should be important considerations in evaluating the risks posed by creosote treated wood. There is an extensive body of literature on this topic. Rates of degradation would be expected to be rather slow (given the creosote-loaded Superfund sites at former wood treatment facilities), and faster in aerobic vs anaerobic environments, both of which would be relevant to the issues involved in this report.

In examining community-level effects, they note that microcosm studies have found community level effects on zooplankton at levels as low as about 3 ug/L (Sibley et al. 2001). In contrast, Goyette and Brooks (1998, 2001) found significant sediment accumulation as far as 7.5 meters away from creosote-treated pilings, but no effects on the benthic community ("No significant changes in benthic community structure were observed.") Another study by Brooks (2000) is reported as finding that "Despite the toxicity threshold exceedences, the biological data that was collected did not reveal adverse effects on biota from PAHs at either the newer bridge site or the older bridge site" (p. 4-10). These reports are not in the open literature and were provided to me. I note that sampling procedures used by Goyette and Brooks (1998) involved three replicates, although, interestingly enough, they state that they were originally going to do only one sample per site. Perhaps this is the influence of Goyette on Brooks and it is a much better design than that used by Brooks subsequently (2000) in the study of walkways treated with copper preservatives in which no replicate samples were taken for infauna. In the creosote report, they note that baseline (before putting in the pilings) benthic community was extremely variable from place to place around Sooke Bay. It is likely that this natural variability masked any potential effects of the creosote. Given such

a variable baseline, it might have been better to take benthic samples at the very same sites before and after putting in the pilings. In their graphs of abundance and taxa richness at different distances from the wood, despite taking three replicates, they do not indicate the variance around the means. Since they found that after over one year, the sediments 0.5 m from the piling exceeded various standards for PAHs, that mussel larval development was impaired, and that amphipod survival was reduced by these sediments, it is likely that a before/after design would have indicated a reduced benthic community as well. It should also be noted that this site, in British Columbia, has rather cold temperatures, and leaching and effects would be more severe at warmer temperatures.

There is only one paper discussed dealing with trophic effects (Rice et al. 2000), in which contaminated worms were fed to English sole, producing growth impairment. I am confident that there must be other papers dealing with trophic transfer. This issue, as with metals, is quite important if salmonids are of particular interest.

Risk Evaluation

Having established that effects can be seen at quite low levels, and that significant amounts of PAHs leach from treated wood and persist in the sediments, I was surprised by their risk evaluation. The evaluation seems to discount much of this work, although as they say on page 4-3 these results indicate that "PAHs that leach from treated wood are present at concentrations that are predicted to be toxic to aquatic biota under realistic environmental scenarios."

The report describes the large studies at Charlestown Navy Pier and Naval Station San Diego where new pilings severely contaminated the water and produced sediments with PAH concentrations 250 times greater than at a control site (Costa and Wade, 1989). The risk evaluation section then relies on the Goyette and Brooks (1998). Their Addendum Report (Goyette and Brooks, 2001) indicated that even after four years, evidence of sediment toxicity could still be detected as far as 2 m away from the wood.

It was a big surprise, after all the documentation, to read their conclusions on 4-14 that sediment accumulation "appears to be relatively minor." They further write "the duration of any biological effects appears to be attenuated within several months of construction (the time period when leaching rates are likely to be the highest)." This is not true for the creosote in the sediments that can cause tumors in bottom-dwelling fish, nor for the unfortunate herring eggs deposited on a 40-year old piling. The only possible justification for such a conclusion would be if the creosote degraded rapidly in sediments, which does not appear to be the case. There ought to be a section in the report covering rates of degradation of creosote PAHs, degradation pathways, toxicity of degradation products, and the length of time that various degradation products persist.

In any risk assessment, there is a need to distinguish between bulkheads or walkways, which have a lot of surface area for leaching, and pilings, which have much less surface area. It is expected that when flow rate is higher, the leaching rate will be higher, but the

PAHs would be swept away downstream rather than accumulate near the treated wood. It should be noted, however, that estuaries have areas in which there are high rates of sediment deposition ("turbidity maximum") and the leachates that are swept away from the immediate site of the treated wood are probably being deposited somewhere else downstream. The question is whether the risk assessment will be only for the immediate vicinity of a treated wood structure, or if it will consider potential effects at the depositional sites further downstream. After their conclusion they then advocate a precautionary approach with regard to salmonids.

The best management practices (BMPs) as listed and described will reduce the potential for toxicity somewhat, but there will still be leaching from treated wood, and the leaching is greatest when the wood is new. The Goyette and Brooks (1998, 2001) studies used wood treated to BMP standards, and nevertheless found persistent accumulation and toxicity in the sediments near the wood. And this was just a piling! I would recommend another, more effective, BMP. If the wood were to be soaked out on site at the treatment facility for some time before being put into service, the greatest amount of leaching into the environment, and thus the greatest amount of risk, would be eliminated. The water into which the wood leached could then be recycled into new pieces of wood for treatment.

Summary and Conclusions

The report documents numerous studies demonstrating toxic effects of creosote at very low environmental concentrations and the leaching of creosote from treated wood and accumulation in sediments going out over 7 meters. However, the conclusions then imply that effects are relatively minor, of short duration and not of great concern. The conclusions do not seem to follow from all the research documented in the report. Since many states and municipalities have banned the use of creosote treated wood in aquatic environments, they must have concluded that effects are of great concern. Nevertheless, the Stratus reviewers do recommend a precautionary approach to dealing with salmonids' exposure to creosote leached from treated wood.

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Appendix 1

Materials Provided:

Stratus Consulting, 2005. Treated Wood in Aquatic Environments: Technical Review and Use Recommendations. 160 pp.

Stratus Consulting, 2005. Creosote-treated Wood in Aquatic Environments: Technical Review and Use Recommendations. 104 pp.

Appendix 2 – Statement of Work

Consulting Agreement Between the University of Miami and Reviewer

February 20, 2006

Background

The purpose of the technical review documents requiring independent review is to present an analysis of the potential effects and mitigations for the use of treated wood products in aquatic environments. The documents focus on copper treated wood, primarily ammoniacal copper zinc arsenate (ACZA), as this is the most prominent material used on the west coast of the United States and in Alaska, and creosote treated products.

These products are being examined by NOAA's National Marine Fisheries Service (NOAA Fisheries) to determine the risks generated by their usage to the living marine resources which NOAA is responsible for managing, referred to as NOAA's Trust Resources. These include anadromous salmonids managed under the Endangered Species Act (ESA) and Essential Fish Habitat (EFH) as designated by the Magnuson-Stevens Fishery Management and Conservation Act. The use of treated wood in or near aquatic environments commonly requires a permit issued by the U.S. Army Corps of Engineers under section 404 of the Clean Water Act. Under the ESA, federal agencies are to consult with NOAA Fisheries to insure that any action authorized, funded or carried out by the federal agency does not jeopardize the continued existence of any threatened or endangered anadromous salmonids or result in the destruction or adverse modification of designated critical habitat. The issuance of this permit by the U.S. Army Corps of Engineers requires consultation under the ESA to determine whether its approval action would jeopardize Federally-listed species or adversely modify designated critical habitat, and requires an EFH assessment to determine whether its approval action would adversely affect EFH. Since the use of treated wood materials in situations that may expose aquatic ecosystems is widespread along the west coast of the United States and in Alaska, development of these guidelines should help to streamline the review of permitting processes as well as the permitting processes themselves. In some instances, these guidelines may be used to update existing policies regarding treated wood.

The purpose of the ESA is to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved, to provide a program for the conservation of threatened and endangered species and to take steps that may be appropriate to achieve this conservation. Conservation is defined in the ESA to mean using, and the use of all methods and procedures necessary to bring any endangered or threatened species to the point at which the protections provided by the ESA are no longer necessary. It is the policy of Congress, as declared in the ESA, that all Federal departments and agencies shall seek to conserve endangered and threatened species and shall utilize their authorities in furtherance of the purposes of the ESA. ESA regulates an

activity with an eye toward its impact to as little as a single listed individual. These guidelines are meant to clarify the extent to which these authorities need to be applied for the use of treated wood.

The Magnuson-Stevens Fishery Conservation and Management Act established procedures designed to identify, conserve, and enhance EFH for those species regulated under a Federal fisheries management plan. EFH regulates an activity with an eye toward its impact on habitat characteristics. EFH is defined as those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity. Waters include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; substrate includes sediment, hard bottom, structures underlying the waters, and associated biological communities; necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and "spawning, breeding, feeding, or growth to maturity" covers a species' full life cycle. Essential Fish Habitat for salmonids includes their saltwater and fresh water ranges.

Effects of treated wood that need to be examined under the ESA and EFH regulations include direct, indirect, and cumulative effects. An example of direct effects includes the acute and sublethal impacts of copper and polycyclic aromatic hydrocarbons to salmonids and EFH regulated species. An example of an indirect effect includes the adverse impacts to the prey base upon which ESA listed and EFH regulated species depend. An example of a cumulative effect includes the impacts of multiple structures and contaminants in an area with or without additional loading from urban sources, historic mining, smelters, ships' hulls or any other source. The synthesis of these effects to habitat and to individuals, coupled with local environmental conditions and specific species of concern, defines the risk of a project proposing the use of treated wood.

The objective of the technical review and use recommendations development was to establish a solid scientific basis from which guidance development and implementation could proceed, particularly concerning potential direct and indirect effects.

Objectives of the CIE Review

The information presented for review has been developed by a consulting firm under contract to NOAA Fisheries. The use of an independent firm was determined to be the best way to initiate and complete a thorough review of the best available science concerning effects of treated wood, effects of the most likely contaminants coming from treated wood, and policies and guidelines already developed and in use throughout the United States, Canada and/or other jurisdictions involving the use of treated wood products. A brief review of the economic aspects of treated wood and its leading competitors as well as engineering aspects of all these materials was also commissioned as part of the process.

The review panelist is required to review the following reports (*Treated Wood in Aquatic Environments: Technical Review and Use Recommendations* and *Creosote – Treated Wood in Aquatic Environments: Technical Review and Use Recommendations*), in particular, the aquatic toxicology, the fate and transport aspects of the suite of contaminants that may result from its use, and the modeling that is used in conducting risk assessments concerning treated wood. These sections make up the bulk of the submitted documents and have been an area of considerable debate for many years.

Specific terms of reference for the review include:

- Evaluate the synthesis and interpretation of the toxicology information, and state whether or not the conclusions regarding the potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.
- Evaluate the synthesis and interpretation of fate and transport information and state whether or not the conclusions regarding potential effects to ESA and EFH regulated species and habitats are supported by the scientific evidence.
- If the conclusions are not supported by the available evidence, please provide a detailed explanation and new conclusions.
- Evaluate the review of the leaching and environmental concentration models presented in both of the reports.
  A) Did the review adequately characterize these models by addressing model assumptions, uncertainties, and their applicability to ESA listed salmonids and the habitats of NOAA's Trust Resources? If not, provide explanation(s) and how subsequent conclusions are affected.
  B) The review concluded that most of the factors present in the models would lead to an increase in leaching in the field compared to that observed in the laboratory. Is this conclusion supported by the scientific evidence? Please explain in detail why the models do or do not result in an under prediction of leaching.
  C) Are these models sufficient to predict leaching concentrations for use in ecological risk assessments concerning ESA listed species and their habitat?
  D) Are additional precautions required to add a margin of safety to the model predictions? Provide examples?
- The risk evaluation chapters in both reports conclude with a list of factors to be considered in risk assessments concerning the use of treated wood. Are there any other factors missing from the lists?
- The copper treated wood report contains a chapter concerning alternative materials and includes a brief examination of toxicity considerations regarding these products. Are there any other considerations that are not mentioned in this chapter?
- The current regulations and best management practices (BMP) chapter in the copper treated wood report discusses BMPs put forth by the industry as well as several government agencies. Do you feel that the available scientific evidence warrants the use of these BMPs? Do you think that utilization of the BMPs, given consideration of the site specific factors listed at the end of the

risk evaluation chapters, will provide protection to individuals of ESA listed species and to the habitat components of EFH?

- Do any of the BMPs or restrictions seem unwarranted or are there additional BMPs or restrictions which should be utilized? Please provide explanations to answers including any site specific factors that should be considered in making decisions regarding the use of treated wood products in aquatic environments.

Specific Activities and Responsibilities

The review panelist's duties shall occupy a maximum of 5 workdays (i.e., a few days for document review and a few days to prepare a Review Report). The review panelist will review the treated wood technical review and use recommendations documents and develop a review report in the context of responsiveness to the terms of reference. See Annex 1 for further details on report contents.

No later than March 13, 2006, the review panelist shall submit the Review Report to the CIE for review[1]. The CIE reports shall be addressed to "University of Miami Independent System for Peer Review," and sent to Dr. David Die, via e-mail to ddie@rsmas.miami.edu and to Mr. Manoj Shivlani via e-mail to mshivlani@rsmas.miami.edu.

[1] All reports will undergo an internal CIE review before they are considered final.

ANNEX 1: Contents of Panelist Report

1. The report shall be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report shall consist of a background, description of review activities, summary of findings, conclusions/recommendations, and references.

3. The report shall also include as separate appendices the bibliography of all materials provided and any papers cited in the Panelist's Report, along with a copy of the statement of work.

Volume II
Section II
Stratus Creosote Report and Comments
10. Stratus Creosote Report

STRATUS CONSULTING

Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations

Prepared for:

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In the fall of 2004, the National Marine Fisheries Service (NMFS) contracted with Stratus Consulting to conduct an independent, third party review of treated wood utilization in aquatic environments. This review is meant to support developing or updating NMFS guidelines for the use of treated wood along the Pacific Coast of the United States. The contract was awarded for copper-treated wood products and later amended to include a review of creosote-treated products as well. Substantive work on the project was completed in the fall of 2005. These reports are the findings of Stratus Consulting regarding the use of treated wood. They have been subject to peer review and public comment. NMFS may utilize these reports and other available information, as appropriate, to develop or update guidelines on the use of treated wood in aquatic environments. Accordingly, these documents are not NMFS guidelines themselves.

Creosote-Treated Wood in Aquatic Environments: Technical Review and Use Recommendations

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December 31, 2006
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Acronyms and Abbreviations

AAC	alkyl ammonium compound
AET	Apparent Effects Threshold
AHR	aryl hydrocarbon receptor
amu	atomic mass unit
AWPA	American Wood-Preservers' Association
BaP	benzo[*a*]pyrene
BCFs	bioconcentration factors
BMPs	best management practices
BPDE	benzopyrene diol epoxide
CCC	California Coastal Commission
CPF	chlorpyrifos
CRMP	Coastal Resources Management Program
CTL	chlorothalonil
Cu8	oxine copper
CuN, CuNapth	copper naphthanate
CYP	cytochrome P450
DCOI	4,5-dichloro-2-n-octyl-4-isothiozolin-3-one
DDT	dichloro-diphenyl-trichloroethane
DMBA	7,12-dimethylbenzanthrace
EECs	estimated environmental concentrations
EFH	Essential Fish Habitat
ER-L	Effects Range-Low
ER-M	Effects Range-Median
EROD	ethoxyresorufin O-deeethylase
ESA	Endangered Species Act
ESUs	Evolutionarily Significant Units
FCA	foci of cellular alteration
FID	flame ionization detector
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act

GC	gas chromatography
GENEEC	Generic Expected Environmental Concentrations
HAPC	habitat areas of particular concern
HPAH	heavy PAH
IPBC	3-iodo-2-propynyl butyl carbamate
ISQG	Interim Sediment Quality Guideline
ISW	interstitial water
LOEC	lowest observable effects concentration
LPAH	light PAH
MSA	Magnuson-Stevens Act
MW	molecular weight
NAVSTA	Naval Station San Diego
NMFS	National Marine Fisheries Service
NEC	no effects concentrations
NOAA	National Oceanic and Atmospheric Administration
NOEC	no observable effects concentration
NOEL	no observable effects level
NPS	National Park Service
OC	organic carbon
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
pcf	pounds per cubic foot
PCP, Penta	pentachlorophenol
PEC	pigment-emulsified creosote
PEL	Probable Effect Level
Penta	pentachlorophenol
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
PPZ	propiconazole
PVC	polyvinyl chloride
QSAR	quantitative structure-activity relationship

RPD	redox potential discontinuity
RQs	risk quotients
SPMDs	semipermeable membrane sampling devices
SPME	solid-phase microextraction
SQGs	sediment quality guidelines
SQuiRTs	Screening Quick Reference Tables
T&E	threatened and endangered
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
TEB	tebuconazole
TEL	Toxicity Effect Level
TOC	total organic carbon
TPAH	total PAH
TU	toxic unit
U.S. EPA	U.S. Environmental Protection Agency
USFS	USDA Forest Service
USFWS	U.S. Fish and Wildlife Service
UV	ultraviolet
WHO	World Health Organization
WSF	water-soluble fraction
WWPI	Western Wood Preservers Institute

1. Introduction

1.1 Background and Report Organization

Wood is a common construction material used for bridges, docks, piers, and other submerged and overwater structures. Wood is subject to fungal decay and to attack by wood-boring organisms, especially in saltwater and estuarine environments. To reduce the incidence of decay and attack, chemicals are impregnated into wood used for submerged and near-water construction. Wood-treating chemicals, which include a wide array of organic and inorganic chemicals, can leach from the wood into the immediate aquatic environment, potentially harming aquatic biota.

The National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) is developing guidance on the use of treated wood in aquatic environments inhabited by NMFS trust resources. NMFS trust resources include commercially important marine species and their habitats, as well as threatened and endangered (T&E) marine species and their habitats. The NMFS provides review and consultation on marine, estuarine, and freshwater construction projects that potentially could impact trust resources. Federal and state agencies and industry have requested guidelines from the NMFS on the use of construction materials, including treated lumber, in aquatic environments in the Pacific coastal region.

The purpose of this report is to assist the NMFS with the development of these guidelines. Data and information are reviewed to evaluate potential hazards to aquatic organisms from treated wood in aquatic environments. The data and information review focused specifically on the Pacific Coast states of California, Oregon, Washington, and Alaska. This report is a companion to "Treated Wood in Aquatic Environments: Technical Review and Use Recommendations" (Stratus Consulting and Paladin Water Quality Consulting, 2005). That report describes water-soluble wood treatments; this report describes creosote treatments. The two reports share a similar introduction and overall structure; however, the other report includes separate chapters about alternative materials and current regulations and best management practices (BMPs) that are covered more briefly in the introduction of this report.

In the following sections, we describe NMFS trust resources, types of oil-borne wood preservatives, the chemical composition of creosote, and creosote policies, regulations, and BMPs.

The remainder of this report is organized as follows. In Chapter 2, we discuss data and information regarding leaching of creosote from treated wood into aquatic environments, and the potential for exposure of aquatic organisms to leached creosote. In Chapter 3, we discuss the

toxicity of the leached creosote compounds to aquatic biota. In Chapter 4, we discuss potential risks to NMFS trust resources, including recommendations to minimize the environmental risks of toxic chemicals in aquatic environments. Literature cited follows Chapter 4.

1.2 Trust Resources

Under the Magnuson-Stevens Act (MSA), sections 303(a)(7) and 305(b)(2), the NMFS is responsible for managing commercially harvested aquatic species (including several salmonid species) by, among other things, implementing fishery management plans and designating protective Essential Fish Habitat (EFH) areas. The fishery management plans for commercially important species are managed by regional fisheries management councils. The Pacific Fisheries Management Council manages commercially important species for the States of California, Oregon, and Washington. The Northern Pacific Fisheries Management Council manages commercially important species for the State of Alaska.

The fishery management plans must designate both the habitat essential to the commercial species of concern and the threats to their habitats from fishing and non-fishing activities. EFH areas include, as defined by Congress, ". . . those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." EFH guidelines at 50 CFR 600.10 also specifically define substrate as including, ". . . associated biological communities." This is interpreted to mean all organisms (and particularly prey organisms) belonging to the same food web as any of the trust species. Salmonid EFH areas designated in accordance with the MSA include all streams, lakes, and other water bodies currently or historically accessible to salmon in Alaska, Washington, Oregon, and California, and include most Pacific Coast rivers, streams, and estuaries. In addition to EFH areas, which are geographically broad, NMFS may designate habitat areas of particular concern (HAPC) for the protection of the commercially important species it manages.

Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*) are the three main commercially significant salmon species managed under the MSA by the North Pacific and Pacific Fishery Management Councils. EFH for these species in marine and estuarine areas of the Pacific Coast region extends seaward from the shoreline out to the 200-mile limit of the U.S. Exclusive Economic Zone. Shoreward, salmonid EFH comprises all bodies of water extending inland that were historically accessible to salmon, with the exception of certain barriers and dams that fish cannot pass (PFMC, 2004). Chinook salmon habitat spans from the U.S.-Mexico border to Kotzebue Sound in northwestern Alaska. Coho salmon spawn in tributaries from the San Lorenzo River in Monterey Bay, California, to Point Hope, Alaska, and throughout the Aleutian Islands (PFMC, 2003).

Under the Endangered Species Act (ESA), NMFS' trust resources include T&E aquatic species. In addition to the MSA-mandated habitat protections, sections 3(5)(A) and 7 of the ESA require NMFS to conserve the ecosystems on which T&E species depend, to provide a program for the conservation of T&E species, and to ensure that they (and all federal agencies) do not fund, authorize, or carry out any actions that will harm the habitat or jeopardize the continued existence of listed species. To this end, NMFS is authorized to designate "critical habitat" for those species. Under ESA section 7(a)(2), NMFS is responsible for developing guidelines and policies to protect federally listed T&E aquatic organisms and their habitats from pollutants.

There are 1,290 species, subspecies, Distinct Population Segments, and Evolutionarily Significant Units (ESUs) listed under the ESA. Of the aquatic species, the NMFS Office of Protected Resources manages mostly marine and anadromous species. The U.S. Fish and Wildlife Service (USFWS) manages the remainder of the listed species, which are primarily terrestrial and freshwater species. The NMFS Office of Protected Resources manages 61 ESA-listed aquatic species, 43 aquatic species of concern, and approximately 175 marine mammal stocks listed under the Marine Mammal Protection Act. Of the 51 salmonid ESUs, 30 are either listed as T&E, or are candidates for listing (Table 1.1).

Table 1.1. Status of West Coast salmonid species and ESUs

Species	ESU	Listing status[a]	T/E status[b]
Pink salmon	Even year ESU[c]	NW	
	Odd year ESU[c]	NW	
Coho salmon	Central CA ESU	L	E
	Southern OR/northern CA coasts ESU	L	T
	OR coast ESU	L	T
	Puget Sound/Strait of Georgia ESU	C	
	Lower Columbia River ESU	C	
	Olympic Peninsula ESU	NW	
	Southwest Washington	NW	
Chinook salmon	Sacramento River winter-run ESU	L	E
	Snake River fall-run ESU	L	T
	Snake River spring/summer-run ESU	L	T
	Puget Sound ESU	L	T
	Lower Columbia River ESU	L	T

Table 1.1. Status of West Coast salmonid species and ESUs (cont.)

Species	ESU	Listing status[a]	T/E status[b]
Chinook salmon (cont.)	Upper Willamette River ESU	L	T
	Upper Columbia River spring-run ESU	L	E
	Central Valley spring-run ESU	L	T
	CA coastal ESU	L	T
	Central Valley fall and late fall-run ESU	C	
	Upper Klamath-Trinity rivers ESU	NW	
	OR coast ESU	NW	
	WA coast ESU	NW	
	Mid-Columbia River spring-run ESU	NW	
	Upper Columbia River summer/fall-run ESU	NW	
	Southern OR/northern CA coasts ESU	NW	
	Deschutes River summer/fall-run ESU	NW	
Chum salmon	Hood Canal summer-run ESU	L	T
	Columbia River ESU	L	T
	Puget Sound/Strait of Georgia ESU	NW	
	Pacific Coast ESU	NW	
Sockeye salmon	Snake River ESU	L	E
	Ozette Lake ESU	L	T
	Baker River ESU	NW	
	Okanogan River ESU	NW	
	Lake Wenatchee ESU	NW	
	Quinault Lake ESU	NW	
	Lake Pleasant ESU	NW	
Steelhead	Southern CA ESU	L	E
	South-Central CA coast ESU	L	T
	Central CA coast ESU	L	T
	Upper Columbia River ESU	L	E
	Snake River Basin ESU	L	T
	Lower Columbia River ESU	L	T
	CA Central Valley ESU	L	T
	Upper Willamette ESU	L	T

Table 1.1. Status of West Coast salmonid species and ESUs (cont.)

Species	ESU	Listing status[a]	T/E status[b]
Steelhead (cont.)	Middle Columbia River ESU	L	T
	Northern CA ESU	L	T
	OR coast ESU	C	
	Southwest WA ESU	NW	
	Olympic Peninsula ESU	NW	
	Puget Sound ESU	NW	
	Klamath Mountains Province ESU	NW	

a. L = listed, C = candidate, NW = not warranted.
b. E = endangered, T = threatened.
c. Managed by NMFS every other year (jointly with Canada).
Source: NOAA, 2005.

1.3 Types of Oil-borne Wood Preservatives

Treated wood pilings, timbers, and other wooden lumber have been used in marine construction in the United States for more than a hundred years (Lebow and Tippie, 2001). Although some woods are more naturally resistant to deterioration, wood construction materials exposed to water must be preserved with chemicals to prevent deterioration and eventual destruction by marine borers such as crustaceans (gribbles, *Limnaria* spp.), mollusks (boring clams, *Teredo* or *Bankia* spp.), and other wood-degrading organisms, including fungi. To protect wood from these organisms, preservative formulations must be toxic to the wood-degrading organisms.

Oil-borne wood treatments include creosote, creosote mixed with coal tar or petroleum, and other preservatives such as pentachlorophenol (PCP) and copper naphthanate (CuN) (Table 1.2) (Hutton and Samis, 2000; AWPA, 2003). Creosote is the most commonly used wood preservative worldwide, and comprises nearly 15% of the total volume of wood treatment preservatives used in the United States (Crawford et al., 2000). PCP is not resistant to marine borers, and therefore is only recommended for pilings in freshwater or in saltwater splash zones. CuN currently is not recommended for use in either freshwater or saltwater. The remainder of the P8 preservatives listed in Table 1.2 are used so infrequently that they are not listed in the BMPs for oil-borne preservatives (Hutton and Samis, 2000; Lebow and Tippie, 2001; WWPI, 2002b). Therefore, in this report we confine our analysis of oil-borne preservatives to creosote.

Table 1.2. Coal-derived and oil-borne wood preservatives in the United States

Type of preservative	AWPA standard	Components
Creosote	P1/P13	Coal tar distillate
Creosote solution	P2	Mixture of creosote and coal tar
Creosote-petroleum solution	P3	Mixture of creosote and petroleum, comprising at least 50% creosote
Other oil-borne preservatives	P8	Pentachlorophenol (PCP or Penta) Copper naphthenate (CuN or CuNapth) Oxine copper (copper-8-quinolinolate or Cu8) Alkyl ammonium compound (AAC) 4,5-dichloro-2-n-octyl-4-isothiozolin-3-one (DCOI) 3-iodo-2-propynyl butyl carbamate (IPBC) Chlorothalonil (CTL) Tebuconazole (TEB) Propiconazole (PPZ) Chlorpyrifos (CPF)

Sources: AWPA, 2003; Dickey, 2003.

The American Wood-Preservers' Association (AWPA) currently approves only the P1/P13 creosote standard (AWPA, 2003). The term creosote in this report refers specifically to the AWPA-recognized P1/P13 creosote standard. Australia has a standard for pigment-emulsified creosote (PEC), which it claims does not leach from treated wood (Crawford et al., 2000). Because this compound is not available in the United States, we have excluded it from our analysis.

1.4 Creosote Composition

Creosote is a distillate of coal tar, and its chemical composition varies depending on the source of the coal tar and the distillation conditions and fraction removed. The World Health Organization (WHO, 2004) concluded that there might be 1,000 compounds present in a typical coal tar creosote mixture, though most of them are present in minute quantities. Creosote compounds can be distributed among several chemical classes, including polycyclic aromatic hydrocarbons (PAHs), alkyl-PAHs, tar acids/phenolics, tar bases/N-heterocyclics (quinolines and carbazoles), S-heterocyclics (thiophenes), O-heterocyclics/furans (dibenzofuran), and aromatic amines (such as aniline). A detailed discussion of the physical properties and chemical structures of these compounds is beyond the scope of this document. See WHO (2004) and Eisler (2000) for more details.

Several studies have included summaries of creosote compositions, including Ingram et al. (1982), Cooper (1991), U.S. EPA (2003b), and WHO (2004). WHO (2004) includes creosote compositional analyses from eight separate studies, including creosotes from the United States, Britain, Germany, and the former Soviet Union.

Table 1.3 contains summary statistics for the more prominent chemical compounds in creosote from each of the above sources. On average, the compounds shown in Table 1.3 comprise roughly two-thirds of creosote. The remaining one-third includes hundreds of other compounds, each comprising less than 1% of the total mixture.

Table 1.3. Summary statistics for major compounds in creosote (by percent)

Class	Compound	n	Max	Min	Mean
PAHs	Phenanthrene	9	21.0	6.7	13.3
	Naphthalene	10	15.5	1.3	9.1
	Acenaphthene	10	14.7	3.1	8.4
	Fluorene	10	10.0	3.1	6.3
	2-methylnaphthalene	9	12.0	1.2	5.6
	Fluoranthene	9	10.0	2.3	5.3
	1-methylnaphthalene	8	14.5	0.9	4.4
	Pyrene	10	8.5	1.1	4.3
	Anthracene	8	8.2	0.8	3.3
	Chrysene	9	6.1	0.1	1.9
Phenolics	Phenol	3	0.6	0.2	0.3
	Cresols	3	2.3	0.3	1.2
O-heterocyclics/furans	Dibenzofuran	9	7.5	1.1	4.7
N-heterocyclics	Quinoline	6	2.0	0.6	1.0
	Carbazole	6	3.9	0.2	1.6
S-heterocyclics	Benzothiophene	4	0.5	0.3	0.4

Sources: Ingram et al., 1982; Cooper, 1991; U.S. EPA, 2003b; WHO, 2004.

The data in Table 1.3 show a wide range in composition for many compounds, depending on the source of the creosote. Xiao et al. (2002) and the U.S. Environmental Protection Agency (U.S. EPA, 2003b) cite separate studies that list creosote composition as typically 85% PAHs, 10% phenolic compounds, and 5% heterocyclics. However, of the 10 creosote compositions that are included in Table 1.3, the greatest total of phenolic compounds (sum of phenol, 2,4-dimethylphenol, and cresols) is 3.5% (WHO, 2004).

PAHs are by far the most common compounds in creosote (Table 1.3). In addition to the PAHs listed in Table 1.3, high molecular weight PAHs such as benzo[*a*]pyrene (BaP), benz[a]anthracene, and benzo[b]fluoranthene are some of the more common compounds in creosote not listed in Table 1.3 (U.S. EPA, 2003b; WHO, 2004).

Based on creosote industry data, U.S. EPA (2003b) lists the top 17 aromatic hydrocarbons typically in creosote. These include the 10 PAHs in Table 1.3 [which comprise 80% of creosote in the U.S. EPA (2003b) example], plus biphenyl, 2,3-dimethyl naphthalene, 2,6-dimethyl naphthalene, 2-methyl anthracene, anthraquinone, 2,3-benzo(b)fluorene, and BaP. The U.S. EPA notes that 16 of the 17 compounds are on the U.S. EPA's List of Priority Pollutants, pursuant to the Clean Water Act.

The U.S. EPA has classified seven PAHs as Group B2 probable human carcinogens: BaP, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene. Most of these have been identified in creosote, including BaP, the most studied PAH in terms of carcinogenicity (WHO, 2004). In addition, of U.S. EPA's 31 priority chemicals, eight are PAHs: acenaphthene, acenaphthylene, anthracene, benzo[g,h,i]perylene, fluorene, naphthalene, phenanthrene, and pyrene (U.S. EPA, 2005).

Many studies of PAHs and creosote compounds in aquatic and marine environments distinguish between light PAHs (LPAHs) and heavy PAHs (HPAHs). Generally, PAHs with two or three aromatic rings are denoted LPAH, while PAHs containing greater than or equal to four rings are termed HPAH. All U.S. EPA Group B2 probable human carcinogens are HPAH, while all but two (benzo[g,h,i)perylene and pyrene) of the eight U.S. EPA priority chemical PAHs are LPAH. This distinction becomes important in later discussions of creosote-related environmental fates and toxicities. When considering the environmental impacts and toxicity of leached creosote in this report, we often refer to the contaminants in leachate as "PAHs" for simplicity, though we in fact mean "PAHs, phenolics, heterocyclics, and other contaminants."

1.5 Creosote Regulations and Policies

Both the European Union and the United Kingdom have banned all nonprofessional use of creosote (HSE, 2005). The U.S. EPA published a risk assessment, described below, that will be used by the Agency to decide whether creosote will be re-registered as a pesticide. Meanwhile, in the absence of federal guidelines, many states and local agencies have implemented their own regulations. A thorough review of creosote regulations and policies is beyond the scope of this document. However, Table 1.4 provides some examples of creosote regulations and policies that have been enacted in the past few years and demonstrates the consistency of approaches toward creosote use in aquatic environments.

Table 1.4. Examples of creosote regulations and policies as of summer 2005

Management entity	Regulation/action	Source
Washington State Ferries	Washington State Ferries concluded that creosote-treated timbers were significantly degrading water quality in Puget Sound, and they commenced a large-scale project to replace all creosote timbers in the ferry system. This project has been ongoing since 2000. By 2012, Washington State Ferries will have replaced over 15 million board-feet of creosote timbers in Puget Sound.	1
Port of Port Angeles, Washington	In 2004, Port Angeles instituted prohibitions on the installation of creosote-treated timbers in waters under their jurisdiction.	2
Oregon Dept. of Environmental Quality, State Marine Board	BMPs for recreational boating facilities state that creosote-treated wood should be avoided, and existing creosote-treated wood pilings should be removed.	3
California Coastal Commission (CCC)	The CCC originally recommended that creosote-treated pilings be wrapped in plastic to prevent leaching of creosote into water. After discovering that the plastic wrap tears readily, they recommended that plastic pilings should be used.	4
U.S. Army Corps of Engineers, Los Angeles District	Standard permit conditions restricting the use of creosote-treated wood, and requiring maintained isolation of creosote via plastic wrappings.	5
Delaware Dept. of Natural Resources and Environmental Control	Delaware banned creosote-treated timbers for boat docks in the early 1990s.	6
New York State legislature	In 2004, the legislature passed S04975 to phase out the manufacture, sale, and use of creosote in the state. Gov. Pataki vetoed the bill.	7, 8
Rhode Island Coastal Resources Management Program (CRMP)	CRMP "Red Book" of regulations specifies that no residential docks, piers, or floats may be constructed of creosote-treated timbers, and creosote may not be used as a wood preservative on wetland boardwalks.	9

1. WSDOT, 2005.
2. PPF, 2004.
3. Oregon DEQ, 2002.
4. CCC, 2003.
5. Personal communication, D.J. Castanon, U.S. Army Corps of Engineers, Los Angeles District, November 30, 2004.
6. Delaware Department of Natural Resources and Environmental Control, 1992.
7. Pesticide.Net, 2004.
8. Online Lawyer Source, 2004.
9. RI CRMC, 2005.

In 2003, the U.S. EPA performed a data review and risk assessment on creosote as part of the creosote re-registration process (U.S. EPA, 2003a). The studies they reviewed did not meet the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) guidelines, did not describe specific creosote compositions, and many of the studies examined the fate of specific PAHs rather than creosote as a whole. Based on these limited data, the U.S. EPA calculated risk quotients (RQs) for acute and chronic effects on fish using their Generic Expected Environmental Concentrations (GENEEC) computer model to create estimated environmental concentrations (EECs) of creosote compounds. The U.S. EPA's (2003a) conclusions follow:

> The Agency has concluded that risk to birds and terrestrial mammals is probably minimal, due to lack of exposure and the ability of these organisms to avoid creosote. Risk to terrestrial plants would also be considered minimal due to lack of exposure. However, risk to freshwater and marine/estuarine aquatic organisms is harder to quantitate using these data. Certainly there will be some exposure due to leaching from the treated wood into the aquatic environment; however, determining the amount of exposure and the amount of toxicity due to this exposure is difficult using the data at hand. The RQ values calculated with the available data do not demonstrate a concern for acute effects on aquatic organisms or chronic effects on freshwater fish. However, the EECs were calculated for the component PAHs, while the aquatic toxicity data were generated using whole creosote. The available data found in the open literature were not adequate to supply the information needed to assess chronic effects to freshwater invertebrates or to marine/estuarine aquatic organisms. It is not possible, therefore, to determine the chronic risk creosote may present to freshwater invertebrates and marine/estuarine aquatic organisms, including endangered species. However, the data indicate that creosote does not exceed the level of concern for acute toxicity to fish and aquatic invertebrates or for chronic toxicity to freshwater fish.

According to the U.S. EPA re-registration schedule, the U.S. EPA is expected to make a decision on the re-registration of creosote soon. As detailed in Chapters 2-4 of this report, the conditions under which toxic constituents of creosote can reach marine resources are common enough that U.S. EPA's conclusions may benefit from greater emphasis on the known transport and toxicity of toxic constituents, rather than on the uncertainties. U.S. EPA's description of some of the uncertainties is valid, but might better fit in a standard characterization of uncertainties in a more definitive finding regarding the risks that creosote constituents pose to elements of the marine environment.

1.6 Creosote BMPs

The AWPA and the Western Wood Preservers Institute (WWPI) maintain BMPs for creosote-treated wood (WWPI and Canadian Institute of Treated Wood, 1996; WWPI, 2002b; AWPA, 2003). Most other sources of creosote treatment BMPs (e.g., Hutton and Samis, 2000; Lebow and Tippie, 2001; WDNR, 2002) reference the AWPA and/or the WWPI. The BMPs are quite detailed, with different BMPs for different tree species and different creosote mixtures. These BMPs are readily available from AWPA and WWPI and therefore will not be described here. For the purposes of this report, we attempt to call attention to laboratory and field leaching studies where BMPs are not followed. Most researches specify when they are not following BMPs in their leaching tests, particularly as they pertain to creosote retention in the timber. However, verifying that every leaching study that we reviewed followed BMPs was not possible.

2. Models of PAH Leaching from Treated Wood and Environmental Exposure

In this chapter we review and evaluate models that have been developed to predict the leaching of creosote constituents, primarily PAHs, from creosote-treated wood and the resultant concentrations in the environment. The rate and amount of PAHs that leach from treated wood is a key component in the evaluation of the potential effects of creosote-treated wood on aquatic biota, and much study has been conducted in this area. Nearly all studies of leaching from creosote-treated wood have been conducted in the laboratory under controlled conditions. The leaching models that have been developed predict PAH leaching under such controlled conditions. Estimating the environmental concentrations that result from the leaching is a second component in evaluating potential effects on aquatic biota. Few field and laboratory studies address this component, but two transport models have been developed to predict concentrations of PAHs in surface water and sediments around creosote-treated piling, based on modeled leaching rates.

Our review focuses primarily on PAHs, but where their leaching characteristics have been studied, N-heterocycles are also discussed. In Section 2.1, we discuss factors that affect PAH leaching rates from creosote-treated wood. In Section 2.2, we review leaching models that have been developed and applied; in Section 2.3, we discuss predictions of environmental concentrations of PAHs resulting from the use of creosote-treated wood; and in Section 2.4, we present conclusions.

2.1 Factors that Affect PAH Leaching from Treated Wood

The rate at which PAHs leach from treated wood is a complex function of many factors, including the nature of the wood, the treatment solution and method, and various environmental variables. In this section, information on factors that affect PAH leaching rates from treated wood is presented and summarized as a prelude to the description of the PAH leaching models contained in Section 2.2. In Section 2.1.1, specific laboratory and field studies on PAH leaching rates and the variables that can affect them are presented. In Section 2.1.2, review articles and other more general information on factors that affect PAH leaching from treated wood are summarized.

2.1.1 Laboratory observations of PAH leaching from creosote-treated wood immersed in water

Ingram et al. (1982)

Study description

Ingram et al. (1982) measured leaching of creosote from dual-treated southern pine pilings immersed in freshwater and seawater. The authors quantified the effects of water temperature, piling age, and exposure time on leaching rates.

The test pilings were treated to a preservative retention of 354 to 378 kg/m^3, and then aged for six months in open air. Leaching from the recently treated pilings was compared to leaching from dual-treated pilings that had been in seawater for approximately 12 years off Key West, Florida. Preservative retention in the aged sections ranged from 442 to 596 kg/m^3. Before testing, the freshly cut ends of all piling sections were coated with epoxy resin.

Water concentrations of 16 PAHs and dibenzofuran were measured. The tests were conducted in large (300-gallon steel tanks) and small (4-liter glass beakers) vessels. In both tests, the water in test vessels was stirred continuously. The focus of the small vessel studies was to compare leaching from recently treated wood in freshwater (distilled water), aged wood in freshwater, and aged wood in seawater. Water temperatures were held at 20ºC, 30ºC, or 40ºC. Test duration was 30 days. For the large vessel studies, pilings were placed in 200 to 250 gallons of seawater for 12-21 days. Water temperature was controlled to between 18ºC and 21ºC. Two-liter samples were removed daily, and analyzed by gas chromatography.

Temperature effects on leaching

Leaching rates in freshwater and saltwater increased with increasing water temperature (Table 2.1), with slopes of 1.5 and 1.7, respectively (Figure 2.1). The rates presented in Table 2.1 are an average of leaching over the first three days following immersion. Vertical bars in Figure 2.1 show the range of the leaching rates measured. At each temperature tested, total PAH leaching (the sum of all compounds measured) was higher in freshwater than in saltwater. Ranges of water concentrations are reported in the paper for each of the 16 PAHs plus dibenzofuran, and leaching was generally more rapid for the more water soluble compounds.

Table 2.1. Temperature and salinity effects on PAH leaching rates

Temperature (ºC)	Salinity (ppt)	Minimum (µg/cm^2 per d)	Maximum (µg/cm^2 per d)
20	0	26.6	35.9
30	0	39.4	56.9
40	0	52.5	70.2
20	30	7.94	7.94
30	30	14.7	27.7
40	30	36.6	47.9

Source: Ingram et al., 1982.

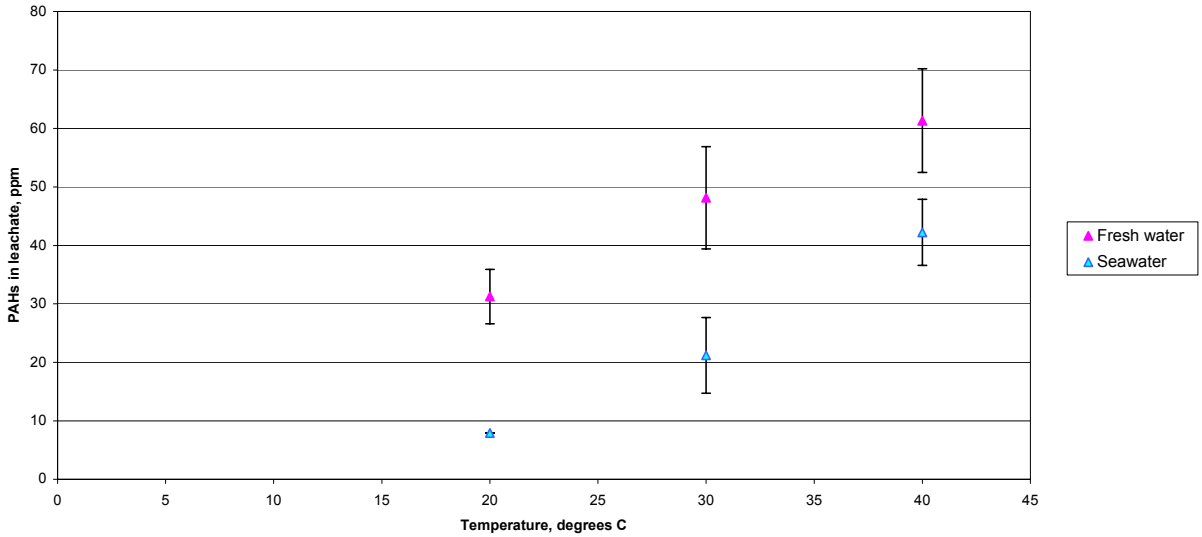

Figure 2.1. Effects of temperature and salinity on leaching.

Source: Ingram et al., 1982.

Aging effects on leaching

Leaching of PAHs into seawater over 30 days was greater from recently treated pilings than from aged pilings. Final concentrations of PAHs in seawater were approximately 750 µg/L for the aged wood and 1,000 µg/L for the recently treated wood (as estimated from graphs presented in Ingram et al., 1982). The 12 years of field installation in seawater appeared to have reduced leaching rates by only about 25%. This reduction is smaller than most model predictions suggest (see Section 2.3). Since the sample ends were sealed, leaching from the freshly cut portions should not have been a factor in the leaching rates. However, the aged and recently treated samples probably differed in other respects, including creosote formulation, initial retention, treatment method, post-treatment processing and storage, wood density, and possibly, wood species. The results may also be influenced by the test method: the water was stirred but not replaced, so increasing concentrations in the water over time might have limited leaching and diminished differences between the sample types.

PAH concentrations over time

Ingram et al. (1982) observed a decline in the concentration of PAHs in the large test tank over the 288-hour run of their "long-term" leaching experiment. In this study, concentrations leached from recently treated wood peaked at 432 parts per billion (ppb) after 72 hours, and declined to 156 ppb after 288 hours. PAH concentrations in the tank containing aged wood declined even more. The aged samples might have contained microbes that degrade PAHs. Therefore, the reported PAH leaching rates might underestimate either the total amount of leaching or the leaching rate. Furthermore, the tanks and beakers were not sealed, and the loss of volatile PAHs such as naphthalenes cannot be ruled out.

Kang et al. (2003)

Study description

Kang et al. (2003) determined leaching rates of individual PAHs at two flow rates: 1.2 cm/sec, and 3.3 cm/sec. Samples of Douglas fir lumber were treated with P1/P13 creosote to a retention of 12 pounds per cubic foot (pcf), in compliance with the WWPI's BMPs. Freshly cut ends were sealed with epoxy. The samples were completely immersed in carbon-filtered tap water held at approximately 12°C. Water samples for PAH analysis were collected periodically throughout the 14-day test.

Effect of flow rate on leaching

Initial loss rates at 3.3 cm/sec were at least double, and, often, substantially more than double, the loss rates for the same compounds at 1.2 cm/sec.

Variations between individual PAHs

Leaching rates at the two flow rates over the 14-day test were reported for naphthalene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, and pyrene. As observed in several other studies, phenanthrene appeared to leach at a higher rate than predicted by its water solubility, but the remaining compounds tended to leach in a more predictable manner based on water solubilities.

Non-detected compounds

HPAH compounds were not detected in the leachate at any time during the test. Either these compounds did not leach from the wood, they were not detected because of some deficiency of the analytical method, or they were lost through volatilization, biodegradation, sorption to organic matter, or other route. HPAH compounds are routinely detected in similar tests, so it is unlikely that they did not leach from the samples in this test. Because of their low vapor pressures, it is also unlikely that they were lost though volatilization.

Naphthalene was lost at a high rate initially, but concentrations declined to below detection after four days. No PAHs were detected after seven days. The decline and lack of detection may reflect biodegradation, as suggested in Ingram et al. (1982), or methodological problems, as suggested above.

Becker et al. (2001)

Study description

Becker et al. (2001) compared leaching of creosote compounds in three water preparations. Samples comprised 5-mm diameter borings of *Pina nigra*, cut to 10-mm lengths. Samples (10 g each) were immersed in 100 mL of deionized filtered water, deionized water buffered to pH 4.7, or a solution containing humic substances. The water was stirred continuously during the 120-hour test. Water changes were performed at 24 and 48 hours.

Effect of water chemistry on leaching

The leaching rates of most of the creosote compounds measured were highest in deionized water. Leaching rates of N-heterocyclic compounds were greater than leaching rates of PAHs. The loss rates of N-heterocycles declined rapidly with time, but still exceeded the loss rates of the PAHs by approximately an order of magnitude at the end of the study. N-heterocycles are susceptible to protonation, unlike homocyclic PAHs. Even partial protonation tends to increase the water solubility of a compound, making it more available for leaching (Schwarzenbach, 1993; as cited in Becker et al., 2001), particularly in low pH water.

Although this study showed high leaching of N-heterocycles (in apparent contrast to other study results), most of the other researchers did not analyze for these compounds. In addition, because this study used small wood samples with a higher surface area to volume ratio, which increases the amount of leaching per volume, the results are not directly comparable to studies performed with larger samples of wood.

Xiao et al. (2000)

Study description

Xiao et al. (2000) treated Douglas fir samples with P1/P13 creosote in accordance with WWPI's BMPs. Freshly cut ends were sealed with epoxy, and the samples were wrapped in plastic to reduce volatilization losses between treatment and leaching in deionized water. An antimicrobial compound was added to the test water to prevent loss of creosote constituents through biodegradation. The tests were run at 35ºC. The water was replaced after each 72-hour test run. Wood samples were subjected to three consecutive test runs, and water concentrations were averaged among the runs at each time point. Water samples were collected regularly for analysis of four PAHs plus dibenzofuran (acenaphthene, fluorene, phenanthrene, and fluoranthene) using solid-phase microextraction (SPME) fibers analyzed by gas chromatography with a flame ionization detector (GC/FID).

PAH leaching rates over time

All components except phenanthrene leached at linearly declining (though different, based on their relative water solubilities) rates over the first eight hours. Phenanthrene leached at a higher rate than predicted by its solubility. With this exception, its leaching behavior was similar to that of the other PAHs.

Chemical concentrations appeared to approach a steady state at about 24 hours. The time between sample collection and analysis increased during the course of the study, and recovery rates were reduced by 8 to 14% per day of delay in analysis. Therefore, the apparent steady state might have been a function of increasingly poor compound recovery in samples collected at later intervals. Also, averaging water concentrations across three consecutive runs might have reduced the reported average concentrations since concentrations decreased with each subsequent round of leaching.

Xiao et al. (2002)

Study description

In a subsequent experiment, Xiao et al. (2002) treated Douglas fir samples with P1/P13 creosote to a retention of 12 pcf in accordance with WWPI's BMPs. Freshly cut ends were sealed with

epoxy, and the samples were wrapped in plastic to reduce volatilization losses between treatment and leaching in deionized water. An antimicrobial compound was added to the water to prevent loss of creosote constituents through biodegradation. Test conditions included three temperatures (5ºC, 20ºC, and 35ºC) and three water flow rates (0 cm/sec, 4 cm/sec, and 8 cm/sec). Tanks were sealed and airspaces minimized to reduce volatilization of PAHs. The water was replaced after each 72-hour test run. Water samples were collected regularly for analysis of PAHs.

Variations between individual PAHs

During the test, there was variable detection of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene, including non-detects. Those chemicals were excluded from further analysis. Concentrations of the same four remaining PAHs, plus dibenzofuran, in water were determined as in the previous study, by sampling with SPME (fibers), followed by GC/FID analysis. This method avoided delays in sample analysis. A high initial leaching rate was followed by an apparent decrease in leaching rate. Leaching of the remaining individual components was comparable to leaching reported by Ingram et al. (1982).

Effect of temperature and flow rate on leaching

Leaching rates of the sum of the PAHs measured increased with temperature and flow rate (Figure 2.2). The effect of temperature depended on flow rate; temperature had a smaller effect in still water, but an increasing effect with increasing flow rate. Leaching was greatest in warm, turbulent water.

Bestari et al. (1998a)

Study description

Bestari et al. (1998a) designed an outdoor freshwater mesocosm study to mimic field leaching conditions as closely as practical. Treated Douglas fir pilings (retention rate not specified) were suspended in 12,000 L mesocosms containing sediment, rooted and floating macrophytes, fish, phytoplankton, zooplankton, and benthic invertebrates. The pilings did not contact the sediment. Water column and sediment PAH concentrations were analyzed for 15 priority-pollutant PAHs over 16 weeks.

Leaching rates of individual PAHs

The authors estimated a leaching rate of 50 $\mu g/cm^2$ per day, leached primarily from the outer 1 mm of the piling surface. They found no differences in the relative amounts of individual PAH compounds remaining in the piling. Bestari et al. interpreted this to mean that all PAH components either leached at an equal rate, or that some type of degradation process was removing the remaining compounds in proportion to the compounds that leached.

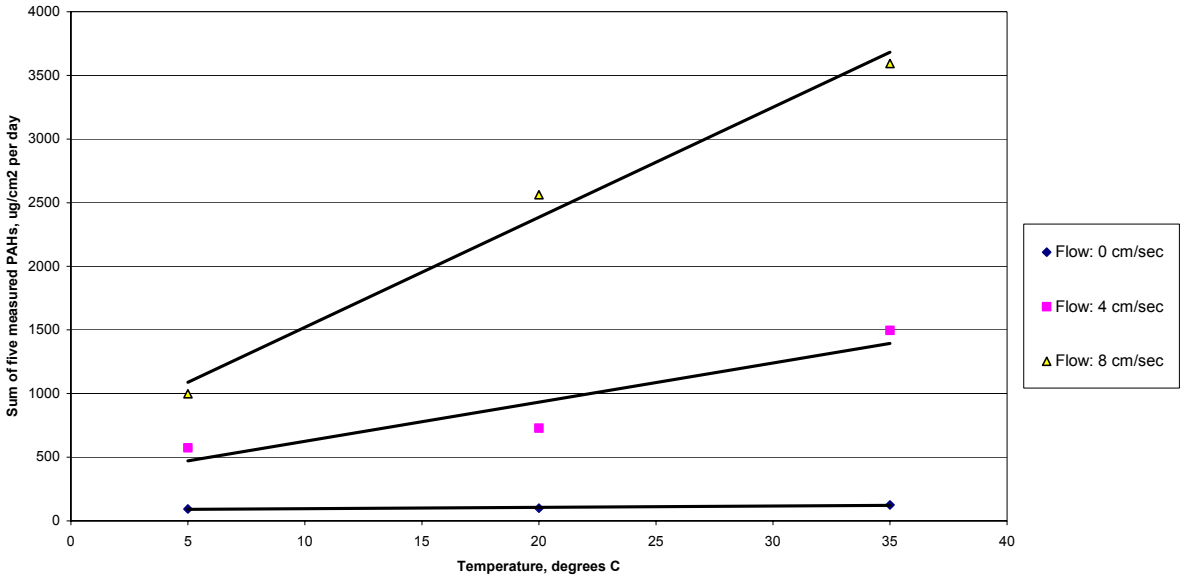

Figure 2.2. Effect of flow rate and temperature on total PAH leaching.

Source: Xiao et al., 2002.

Rao and Kuppusamy (1992)

Rao and Kuppusamy (1992) conducted field leaching tests of tropical wood species treated with a creosote formulation and method that differ from those currently recommended for use in the United States. Two relevant findings of this study are that leaching from samples treated to the same retention varied strongly both by species and within species tested.

2.1.2 Field observations of PAH leaching from creosote-treated wood subjected to natural or simulated rainfall

Whiticar et al. (1994)

Study description

Whiticar et al. (1994) subjected untreated and creosote-treated poles and timbers to natural and simulated rainfall. The treated wood was treated to retentions of 166 kg/m^3 or 198 kg/m^3. The leachate was collected and analyzed for 18 PAHs, phenols, and total organic carbon (TOC). The document reports the sum of the measured PAH concentrations, and concentrations of phenanthrene, naphthalene, benzo[a]pyrene, phenols, and TOC.

Concentrations of individual PAHs

The results of this study cannot be used to quantify leaching rates because of the design, but the relative concentrations of the individual PAHs leached from the treated wood are of interest (Table 2.2). More phenanthrene was present in the leachate than any other PAH, even though more naphthalene was present in the creosote, and the water solubility of phenanthrene is lower than that of naphthalene. This suggests that either there was less naphthalene than phenanthrene in the whole creosote before treatment, as reported by Lorenz and Gjovik (1972; as cited in Ingram et al., 1982), or that the naphthalene in the sample was lost by volatilization before analysis. Naphthalene has a relatively high vapor pressure compared to the other 17 PAHs measured.

Table 2.2. Relative concentrations in leachate

Substance	Minimum (mg/L)	Maximum (mg/L)	Solubility (mg/L)
Sum of 18 PAHs	0.6	3.2	N/A
Naphthalene	0.03	0.3	34.4
Phenanthrene	0.2	1.1	1.0
Benzo[a]pyrene	0.00066	0.026	Highly insoluble
Phenols	0.7	6.0	Highly soluble

Source: Whiticar et al., 1994.

The TOC released from untreated (control) timbers was as high or higher than the TOC released from treated timbers. TOC ranged from 11 to 261 mg/L from untreated timbers and from 11 to 194 mg/L from creosote-treated timbers. Much of the TOC released from the untreated timbers was thought to be resin acids.

2.1.3 General review papers of PAH leaching

Two papers review creosote leaching research. Cooper (1991) summarized losses of creosote from treated wood in laboratory and environmental exposures, and Sinnott (2000) described the timing of loss of creosote components based on reviews of a number of studies. Other references, including some of the specific studies cited above, draw general conclusions concerning factors that affect PAH leaching from treated wood. In this section, we list and briefly summarize the factors generally recognized as being the most important in determining PAH leach rates from treated wood.

(i) Wood species, density, and surface area

Leaching varies markedly between woods of different species, probably for many complex reasons that are not well understood (Cooper, 1991; Rao and Kuppusamy, 1992). In southern pine and Douglas fir, leaching decreases as wood density increases (Leach, 1960; Miller, 1972; both as cited in Cooper, 1991). There have been no systematic analyses of leaching rates by species or wood density.

Leaching also predictably increases as the surface area to volume ratio of the wood increases (Leach, 1960; Colley and Burch, 1961; Stasse and Rogers, 1965; Gjovik, 1977; Miller, 1977; all as cited in Cooper, 1991), so the shape and configuration of structures built from treated wood can be a factor in predicting or limiting overall leaching rates.

(ii) Preservative formulation and loading rate

Different preservatives are known to leach at different rates (Cooper, 1991), but the magnitude of the variability is not well quantified. In the United States, currently only the P1/P13 formulation of creosote is approved by AWPA for use in aquatic systems, and BMPs specify a preferred loading rate.[1] In recent studies, use of this single formulation and loading rate has allowed for investigation of leaching related to non-formulation variables. In the past, however, a number of creosote formulations and application methods and rates were used, complicating the comparison of leaching studies from different eras. Therefore, few quantifiable conclusions can be drawn about how different preservative formulations and application methods have influenced leaching rates over time.

In addition, as the preservative loading rate increases, the leaching rate may increase (Cooper, 1991). The effect of loading rate is small and inconsistent relative to environmental factors such as temperature and water flow rate.

(iii) Individual PAH compounds

The water solubilities of creosote components influence their relative leaching rates in predictable ways (Ingram et al., 1982; Cooper, 1991; Whiticar et al., 1994). Lower boiling point, low molecular weight compounds [compounds with an atomic mass less than 200 atomic mass units (amu)], and 1 to 3 benzene rings, comprise approximately 61% of the PAH compounds in creosote. These compounds dissolve more readily in the water column than the heavier PAHs. The higher molecular weight PAHs, which are compounds with an atomic mass greater than 200 amu, and 3 or more rings, are lost from wood more slowly. These heavier PAHs are more likely

1. Dual treatment of pilings with chromated copper arsenate and P1/P13 creosote is also approved by AWPA, but the leaching characteristics of dual-treated wood versus wood treated with only P1/P13 creosote have not been studied.

to accumulate in sediments than remain dissolved in the water column. Brooks (1994) presents a compilation of percent composition for 13 PAHs in creosote-treated wood.

(iv) Environmental factors

The factors that affect leaching rates most significantly are temperature, water chemistry, water flow, and disturbance or abrasion. Figure 2.1 illustrates higher leaching rates in freshwater than saltwater, and the effect of temperature on leaching rate (Ingram et al., 1982). Figure 2.2 shows that the combined effects of temperature and flow are greater than the effects of either alone (Xiao et al., 2002). Becker et al. (2001) found that leaching of PAHs and N-containing heterocyclic compounds was greatest in deionized water; less in a slightly acidic, buffered solution; and least in a solution containing humic substances.

Disturbance and abrasion, which expose more surface area and sections of wood farther from the surface, can maintain higher leaching rates over time. For example, Bestari et al. (1998a) estimated that most of the leaching they observed in their outdoor freshwater mesocosm derived from the outer 1 mm of the piling surface. Removal of the outer 1 mm of the piling surface would expose less weathered wood, and could increase leaching long after the initial immersion. Indeed, most of the investigators in the studies reviewed in this section applied epoxy to cut ends of samples to minimize the effect of disturbance and abrasion as confounding factors.

(v) Time since treatment

In general, in the absence of disturbance and abrasion, leaching decreases with time since treatment whether the wood is kept in storage or placed in the water. Numerous investigators report substantial losses by volatilization of certain creosote components during dry storage (Stasse and Rogers, 1965; Stasse, 1966; Arsenault, 1973; Ingram et al., 1984; all as cited in Cooper, 1991). Whiticar et al. (1994) document both volatilization losses and rainwater leaching losses of creosote components during outdoor storage. Similarly, numerous investigators have documented a decline in leaching rates over time following installation in water (Leach, 1960; Colley and Burch, 1961; Stasse and Rogers, 1965; Gjovik, 1977; Miller, 1977; all as cited in Cooper, 1991). Furthermore, the WWPI BMPs and other post-treatment processing can reduce the rate of leaching (WWPI and Canadian Institute of Treated Wood, 1996; WWPI, 2002a).

2.2 Models of PAH Leaching Rates

Three investigators have used mechanistic understanding of leaching rates and relevant factors to develop models of PAH leaching rates. Dr. K. Brooks, Dr. T. Poston, and Dr. Y. Xiao each lead the development of models to describe the leaching of PAHs from treated wood. In the sections below, we describe and evaluate these models. Because of the influence of multiple factors on

PAH leaching rates and the relative paucity of empirical data on PAH leaching that can be used directly in an environmental risk assessment, the available PAH leaching rate models should be viewed as incompletely calibrated to realistic environmental settings, but still useful approximations of known first-order mechanistic processes that affect leaching and transport of PAHs, including in environmental settings.

2.2.1 Model descriptions

Brooks CREOSS model

Dr. K. Brooks developed a model to predict water column and sediment concentrations of PAHs near creosote-treated wood installations. He has written two descriptive papers (Brooks, 1994, 1997) and produced several versions of a spreadsheet model, the most recent of which is called "CREOSS" (copy in Appendix to this report; Brooks, 2004a). Versions of the model have been reviewed by industry and government representatives. These reviews have included comparisons between model predictions and environmental PAH concentrations. The model has not been published in the peer-reviewed literature.

Below, we describe the equations CREOSS uses to calculate a water concentration of PAHs and a leaching rate of PAHs. The model is not set up to calculate a leaching rate, but by rearranging some of the equations, a leaching rate can be derived.

Migration factor

The first step in deriving a leaching rate is the calculation of a unitless "migration factor" (Equation 1). Calculation of the migration factor requires the user to input water temperature and salinity. The migration factor increases with water temperature and decreases with salinity. Default input values are 30 parts per thousands (ppt) salinity and 15ºC.

$$\text{Migration factor} = \left[24.4 + \left(0.78 \times \text{WaterTemp}\right) - \left(0.58 \times \text{Salinity}\right)\right] \qquad \text{Eq. 1}$$

Water concentration

The migration factor is used to calculate a water concentration (Equation 2). The equation also requires inputs of piling radius, an "age factor," a "retention factor," and a water flow rate term ("model velocity").

$$\text{Water concentration} = \frac{\left[\left(1{,}000{,}000 \times \text{MigrationFactor}\right) \times \left(3.14 \times 2 \times \text{PilingRadius}\right) \times \text{AgeFactor} \times \text{RetentionFactor} \times \text{WaterPartitioningCoefficient}\right]}{\left(2 \times 86{,}400 \times \text{PilingRadius} \times \text{ModelVelocity}\right)} \qquad \text{Eq. 2}$$

The term "water partitioning coefficient" describes the partitioning of PAHs between the dissolved and particulate compartments in the water column, and for the purpose of this equation, a default of 1.0 (indicating that all of the PAHs are assumed to be in the dissolved state) is used.

The piling age factor is calculated as an exponential decay function (Equation 3),

$$\text{Piling age factor} = \exp\left(\frac{-\text{piling age in years}}{10}\right) \qquad \text{Eq. 3}$$

The default value for piling age in the CREOSS model, 0 years, yields the highest possible piling age factor. Over the short term (less than one year), the decline in value of the piling age factor is nearly linear. After 10 years, the piling age factor decays to 0.37, or a leaching rate that is 37% of the rate at installation (Figure 2.3). After 20 years, it decays to 0.14.

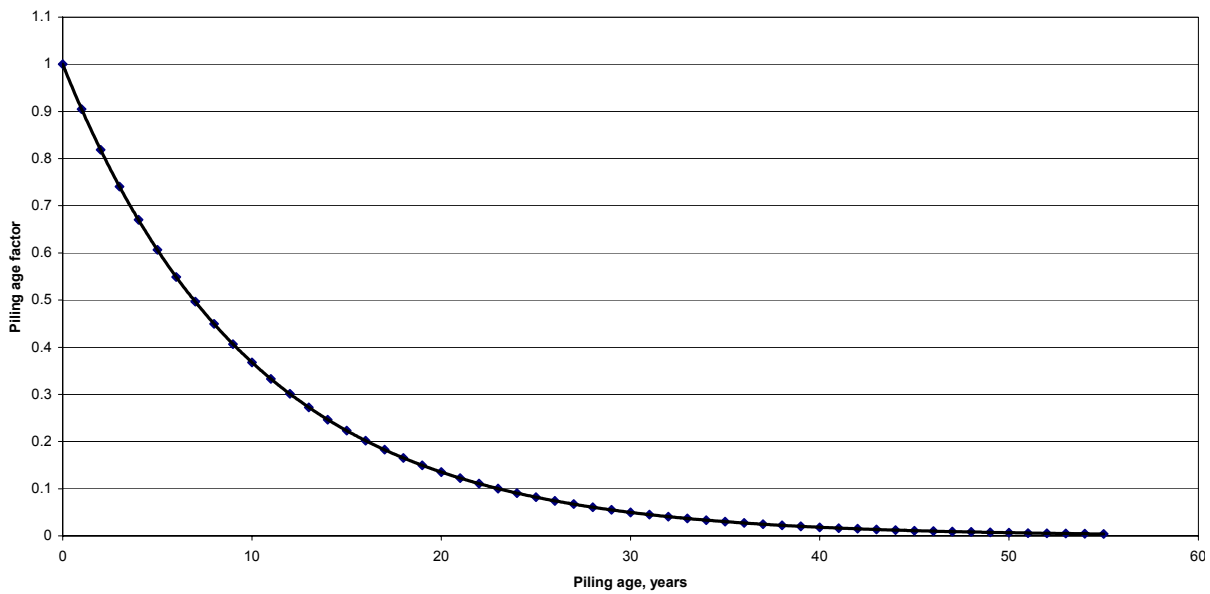

Figure 2.3. Piling age factor value over time, CREOSS model.

Source: Brooks, 2004a.

The retention factor is calculated as (Equation 4):

$$\text{Retention factor} = \exp\left\{0.5\left[\left(\frac{\text{piling retention in pcf}}{22.4}\right) - 1\right]\right\} \qquad \text{Eq. 4}$$

Although the retention factor is calculated as an exponential function, the formula yields a linear output over the range of realistic input values for piling retention, and the potential range of values is small. Using the default value for piling retention in CREOSS, 27 pcf, the retention factor is 1.108.

Leaching rate

The predicted leaching rates (μg/cm^2 per day) in fresh and seawater, calculated using the default values, are (Equation 5):

$$\text{Leaching rate} = \left[24.4 + (0.78 \times \text{WaterTemp}) - (0.58 \times \text{Salinity})\right] \times \exp\left(\frac{-\text{Piling age}}{10}\right) \times \exp\left\{0.5\left[\left(\frac{\text{Piling retention in pcf}}{22.4}\right) - 1\right]\right\} \qquad \text{Eq. 5}$$

40.0 μg/cm^2 per day in freshwater, and 20.7 μg/cm^2 per day in seawater (at 30 ppt salinity).

Poston et al. (1996) model

The Poston et al. (1996) water concentration model depends on assumptions about the leaching rate of PAHs from wood. The model uses a freshwater leaching rate of 40 μg/cm^2 per day of total creosote, from Brooks (1994), that is assumed to be constant over the first four days following piling installation. The model assumes that the components of creosote migrate from the treated wood in proportion to their concentration in the wood. The proportions are taken from a Brooks (1994) compilation of percent composition for 13 PAHs in creosote-treated wood. This assumption is not supported by laboratory leaching experiments.

Xiao et al. (2002) model

This report presents insufficient details to permit an analysis of the leaching model presented.

2.2.2 Applicability and limitations of leaching rate models

Brooks (2004a) CREOSS model

The CREOSS model is complex, and documentation is essential to understand the model design. Currently, model documentation (Brooks, 1997) is older than the most recent model version, and certain contradictions are apparent. For example, the model documentation (Brooks, 1997) states that different leaching rates are used for LPAH and HPAH. The spreadsheet, however, uses the same migration rates for all components of creosote. The model documentation itself states that this assumption is not supported by laboratory studies. In addition, the documentation of the model is insufficient to address issues such as unit consistency and the treatment of time, and it is difficult to determine which portions of the current model are mechanistic, which are empirical, what data the empirical portions are based on, and how calibration was accomplished.

In CREOSS, leaching rate is unaffected by water velocity. Water velocity only modifies a final water concentration. This conflicts with empirical data from Xiao et al. (2002), who found large increases in leaching rates as water velocity increased (Figure 2.2).

Empirical results from Ingram et al. (1982) and modeled results from CREOSS under the conditions tested in Ingram et al. (1982) are shown in Figure 2.4. Over the range of water temperatures tested by Ingram et al., leaching rates increased with temperature. The lowest temperature in the Ingram et al. test was 20°C, and if the slope of the temperature-leaching relationship above 20°C holds below 20°C, then CREOSS might over-predict leaching rates in both fresh and seawater at temperatures below 20°C.

Figure 2.4 also includes three data points from Miller (1977) and one from Graham (1991; as cited in Brooks, 1997). The Miller data points are for three pilings that were immersed in seawater for two years at a mean temperature of 10.4°C. The loss rate from one of the pilings, 89.9 $\mu g/cm^2$, is nine times greater than the maximum loss rate measured by Ingram et al. (1982) at the lowest temperature they tested in seawater (20°C). The loss rate from the other two similarly exposed pilings was zero (the two data points overlie one another in Figure 2.4). Brooks (1997) averaged the three Miller (1977) loss rates. Graham's single reported average leaching rate, 27.93 $\mu g/cm^2$ per day at 19ºC in seawater (Figure 2.4), is nearly triple that reported by Ingram et al. (1982). Discrepancies between migration rates reported by Ingram et al. (1982), Miller (1977), and Graham (1991) may be at least partially explained by the fact that Ingram et al. used WWPI BMPs, which specify treatment practices intended to minimize post-treatment loss of preservative. Regardless, it is unclear whether data from these studies were used to develop or calibrate the CREOSS model, or if the studies were cited for comparison.

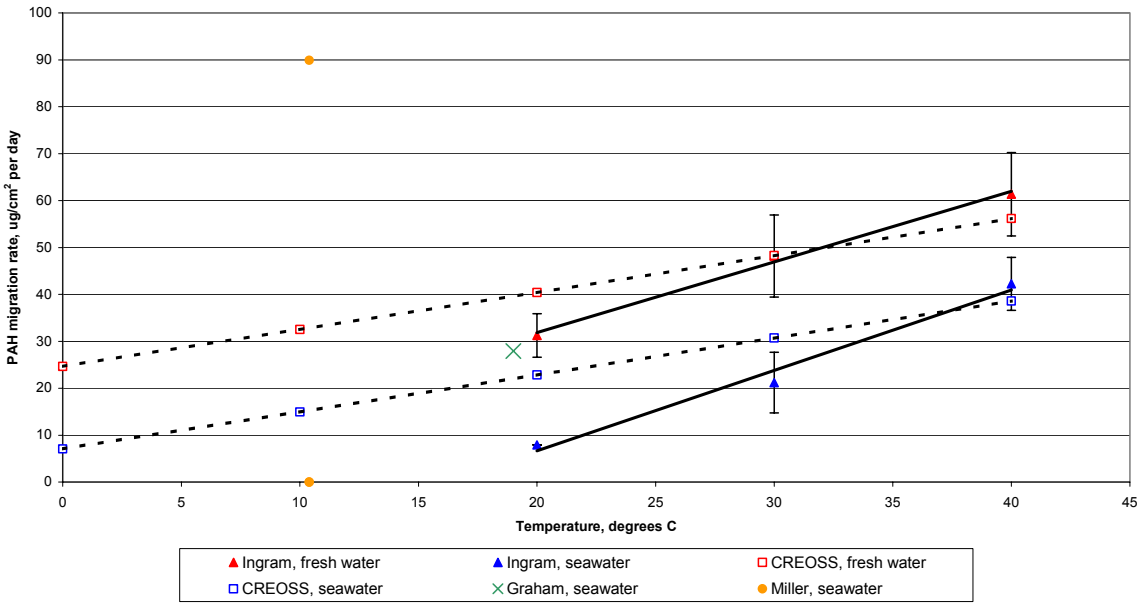

Figure 2.4. Temperature and salinity effects on leaching.

Sources: Ingram et al., 1982; CREOSS model output, Brooks, 2004a.

In CREOSS, all components of creosote leach equally as migration rates change due to changes in temperature, salinity, or other factors. Therefore, if the model over-predicts the overall migration rate, as suggested by comparison to empirical data in Figure 2.4 for temperatures below 20°C, the migration rate and amount of the less water soluble fractions leached is likely to be more over-predicted than the migration rate and amount leached of the remaining, more water-soluble fractions of creosote.

Poston et al. (1996)

The Poston et al. (1996) model uses Dr. Brooks' leaching assumptions. The applicability and limitations of those assumptions, as described above, also apply to the Poston et al. model.

2.2.3 Conclusions

Although the existing models do not account for all of the relevant data and do not contain complete documentation in some cases, they appear to adequately represent many first-order mechanisms of PAHs transport from creosote-treated wood into aquatic environments. The

models account for differential transport related to salinity, temperature, water flow rate, time since application, and chemical constituents. In Section 2.3, we evaluate how well environmental concentrations are predicted by the models.

2.3 Predicting Environmental Concentrations of PAH Resulting from the Use of Treated Wood

PAH leaching rates can be used to predict concentrations in the environment. Predicted environmental concentrations can then be compared to toxic effects thresholds (Chapters 3 and 4). PAHs in the aquatic environment are present in both dissolved form and adsorbed to particulate materials. The fate and transport of PAHs in the environment depends on concentrations in both the water column and sediments. Lower boiling point, low molecular weight compounds dissolve more readily in the water column than the heavier PAHs. The higher molecular weight PAH compounds in creosote tend to accumulate in sediment rather than remain dissolved in the water column.

Transport models estimate concentrations of PAH compounds in the surrounding water column and sediments. Below, we describe a transport model that predicts water column and sediment concentrations in tidal and non-tidal flows, and a transport model that estimates mean water column concentrations based on the ratio of the mass of contaminant leached to the volume of receiving water. The underlying objective of the models, to predict the PAH concentrations that occur under realistic environmental conditions, is the same, although their approaches differ.

2.3.1 Description of the available models

Brooks (1997)

Model description

Brooks (1997) developed a spreadsheet transport model that predicts water column and sediment concentrations of creosote-borne PAHs that leach from treated wood. The model estimates average concentrations in the water column in a cylindrical volume of water surrounding a piling, and PAH deposition in sediments with distance from the piling.

Fifteen input parameters (Table 2.3) that can be measured or estimated by the user are required to run the model. A set of recommended default input parameters for freshwater, marine, and estuarine environments is provided for cases where field data are unavailable and cannot be estimated (Brooks, 1997).

Table 2.3. Required input parameters

Parameter	Units
Piling retention of creosote	pcf
Average piling radius	Cm
Piling age	Years
Average annual water temperature	°C
Salinity	ppt
Sediment particle settling velocity	0.05 cm/s for silt; 0.0005 cm/s for clay
Sediment density	g/cm^3
Steady state current speed	cm/sec, measured at slack tide
Average maximum tidal speed	cm/sec
Redox potential discontinuity (RPD)	cm
Sediment TOC	%
Sediment total PAH standard	parts per million (ppm) TOC
Maximum allowable sediment PAH	ppm TOC
PAH water partition coefficient	unitless
PAH sediment partition coefficient	unitless

The model calculates a series of intermediate outputs including migration, age factor, retention factor, degradation coefficient, model velocity, and geometry factor as follows:

$$\text{Migration rate } (\mu g/cm^2 \text{ per d}) = 24.4 + 0.78\ T - 0.58\ S \qquad \text{Eq. 6}$$

$$\text{Age factor} = \exp\left(\frac{-A}{10}\right) \qquad \text{Eq. 7}$$

$$\text{Retention factor} = \exp\left[\frac{\left(\frac{Ret}{22.4} - 1\right)}{2}\right] \qquad \text{Eq. 8}$$

$$\text{Degradation coefficient} = \frac{\exp\left[\left(\frac{4 - RPD}{3}\right)^3\right]}{0.047\ T} \qquad \text{Eq. 9}$$

$$\text{Model velocity (cm/s)} = V_{ss} + 0.64\ V_{max} \qquad \text{Eq. 10}$$

$$\text{Geometry factor} = 1 + \frac{V_{model}}{10} \qquad \text{Eq. 11}$$

where:

T	=	temperature (°C)
S	=	salinity (ppt)
A	=	age of piling (years)
Ret	=	initial creosote retention of piling (pcf)
RPD	=	redox potential discontinuity (cm)
V_{ss}	=	steady state velocity (cm/s)
V_{max}	=	maximum tidal velocity (cm/s)
V_{model}	=	model velocity.

These intermediate outputs are then used to calculate concentrations of leached PAH in the water column and sediments. Equation 12 is used in the model to estimate water column concentrations of PAHs leached from creosote-treated pilings:

$$PAH_{water}\ (\text{pptr}) = \frac{83333.3 \times WPC \times M_r \times A_f \times Ret_f \times R_p \times G_f}{\left[\left(1800 \times V_{model} + R_p\right)^2 - R_p^{\ 2}\right]} \qquad \text{Eq. 12}$$

where:

WPC	=	water partition coefficient (defines the proportion of PAH assumed to be dissolved in the water column)
M_r	=	migration rate
A_f	=	age factor
Ret_f	=	retention factor
R_p	=	piling radius
G_f	=	geometry factor.

The tidal current equation (an input to model velocity) is based on an equation for harmonic motion, assuming a frequency of 12 hours. Transport appears to be based on advection only (molecular and turbulent diffusion are not considered), but it is not clear how advective transport is modeled.

The predicted water column concentration appears to be an average concentration, for some unspecified length of time, calculated over a volume that is dependent on the model velocity (V_{model}). However, we were unable to confirm this from the available documentation, and replication of the model was beyond the scope of this report. Therefore, we recommend further documentation and peer review of the model before reaching any definitive conclusions from these modeling results.

In addition, dimensional analysis of the equation shows inconsistent units.

The equation used in the model to estimate sediment PAH concentrations is:

$$\text{PAH sediment accumulation } (\mu g/cm^2 \text{ per day}) = \text{Deposition} \times \text{Degradation} \times \text{SPC} \times G_f \qquad \text{Eq. 13}$$

where:

$$\text{Deposition } (\mu g/cm^2 \text{ per day}) = \frac{M \times A_f \times Ret_f \times R_p}{\left[\left(\frac{V_{model}}{V_{vert}}\right) \times \left(r + R_p\right)\right]}$$

SPC	=	sediment partition coefficient (defines the proportion of PAH assumed to be adsorbed to sediment)
V_{vert}	=	particle settling velocity (cm/s)
r	=	distance from the piling perimeter where the concentration is predicted (cm).

The equation for sediment deposition appears to be mechanistically based. Average deposition is calculated by dividing the loss per unit area of the piling that partitions to the sediment by the incremental area over which that sediment is deposited. Sediment concentrations (in units of µg/g dry weight or ppm) are obtained by dividing the sediment accumulation by the sediment density. The recommended input for the particle settling velocity value (necessary to calculate the incremental area over which deposition occurs) is also mechanistically based; it is derived using Stokes' law for the settling velocities of small particles. The sediment deposition equation does not consider post-deposition disturbance such as bioturbation, sediment mixing from current, propeller wash, or other disturbances.

Model assumptions include:

- Marine-grade creosote contains 80.14% total PAH (TPAH; Environment Canada, 1993), of which 19.57% is HPAH and 60.57% is LPAH.

- HPAH and LPAH migrate from the piling in proportion to their content in whole creosote.
- Once released into the environment, all HPAHs are adsorbed to the silt-clay fraction and settle to the bottom sediment.
- Once released into the environment, 4.83% of the LPAHs are adsorbed to the silt-clay fraction and settle to the bottom sediment and 95.17% of the LPAHs are dissolved in the water column where they degrade with determinable half-lives. Brooks (1997) indicates that these values were determined by assuming minimal mineralization of HPAH in the water column and combining the relative proportions of LPAH and HPAH in whole creosote with the relative proportions reported for contaminated sediments. Explanation for the numbers used is not provided.
- No volatilization of LPAH occurs.
- Ambient water pH does not affect the migration of PAH from creosote-treated wood.
- Tidal flows are harmonic with a frequency of 12 hours.
- The receiving water volume is large in comparison with the total amount of PAH lost from the structure.

Model predictions

As an example, for a 13-in diameter piling submerged in 20 feet of seawater that leaches 1.24 grams of PAH per day, the model predicts a water column concentration of 0.003 ppb TPAH. The volume of water containing this concentration and the length of time that this concentration persists are not specified, but it appears that the concentration is an average that might not be representative of instantaneous concentrations at a particular location. The predicted sediment PAH concentration is 5.89 ppm within 25 cm of the piling and 2.00 ppm 1 m from the piling. These results are based on inputs of a maximum tidal current of 2.5 cm/s and an RPD of 3 cm.

Estimated sediment concentrations appear to be influenced by current velocity and oxygen availability in the sediments. As expected, environments with poor circulation (low velocity) and low sediment oxygen availability (low RPD) are predicted to pose the greatest risk for elevated sediment concentrations of PAHs.

Volatilization and turbulence (which would increase dilution), and abrasion of pilings (which would increase PAH loading in sediment as abraded wood particles become water logged and sink) are not considered in the model. In addition, since the model assumes that the receiving

water volume is large in comparison with the total amount of PAH lost from the structure, it is less applicable to small systems and systems lacking circulation.

Poston et al. (1996)

Model description

Poston et al. (1996) developed a "box" plume model to estimate PAH concentrations around creosote-treated wood pilings. The model estimates spatially averaged water column concentrations of PAH compounds for one-day units in a hypothetical rectangular plume. The model does not predict sediment PAH concentrations.

The source of PAHs in the model is a vertical "footprint" (in square meters) perpendicular to the current representing an assumed number of pilings (50, 100, or 350) compressed into a plane of a given area. Several footprint areas can be modeled to simulate different configurations of the pilings (200, 400, 800, and 1,524 m^2). Smaller footprint areas model higher density configurations. The volume of the box plume is determined by the surface area of the vertical plane of the source and the distance that water flows in one day (determined by the current velocity).

Initial runs were conducted at a maximum velocity of 40.6 cm/s. Four additional current velocities were also simulated: 0.3, 0.5, 1.0, and 10 cm/s. A conceptual model of the plume dimensions is shown in Figure 2.5.

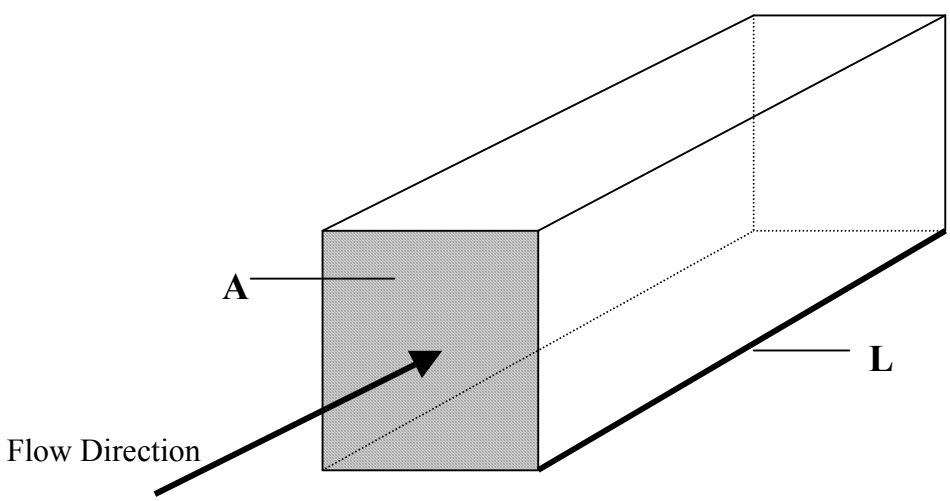

Figure 2.5. Conceptual schematic of the Poston et al. (1996) box plume. The vertical plane A represents the pilings (different piling configurations result in different values of A) and the length L is the distance that water flows away from the pilings in one day.

The volume of the plume is calculated as follows:

$$V = A \times L \qquad \text{Eq. 14}$$

where:

A	=	vertical footprint (representative of the pilings)
L	=	current velocity × 86,400 seconds/day × 1 day.

The concentration in the plume is calculated by dividing the amount of contaminant leached from all pilings in a 24-hour period by the plume volume. This yields an average concentration throughout the "box" plume. The amount of PAH leached per day is calculated as follows:

$$\text{Mass of leachate (ug)} = \text{number pilings} \times \text{surface area of piling} \times \text{leaching rate per day} \qquad \text{Eq. 15}$$

The key assumptions incorporated into the model are as follows:

- There is no lateral mixing.
- Exposure concentrations modeled for the first day do not change for at least four days.
- Leaching is constant for a period of four days at a rate of 40 $\mu g/cm^2$/day for total PAHs (Brooks, 1994). Leaching rates for individual compounds were obtained by multiplying the percent composition in creosote of the compound (as reported in Brooks, 1994) by the total PAH leaching rate.
- Each piling has a diameter of 30 cm and 10 m of submerged length with a surface area of 94,284 cm^2.
- All pilings are assumed to be installed in one day.

Model predictions

Model results are expressed in terms of exceedence of a toxic threshold. For each of the PAH compounds evaluated in the model, the model compares the predicted plume concentration to a published toxic threshold for that compound to get a toxic unit (TU). Toxic units greater than 0.1 are summed to calculate a total TU. The toxic thresholds used in the model for each PAH are

LC_{50}s, or concentrations at which 50% of test organisms are killed (Table 2.4).[2] An overall TU > 1.0 indicates an overall toxic threshold for all of the PAHs combined.

Table 2.4. LC_{50}s used to calculate toxic unit values for each PAH in the Poston model

PAH compound	LC_{50} (µg/L)
Naphthalene	3,852
Acenaphthylene	474
Acenaphthene	480
Fluorene	337
2,6-dimethylnaphthalene	172
Anthracene	140
Phenanthrene	140
Fluoranthene	18
Chrysene	4.02
Benz(a)anthracene	2.7
Benzo(a)pyrene	1.09
Dibenzo(a,h)anthracene	0.57
Benzo(k)fluoranthene	0.23
Benzo(g,h,i)perylene	0.1
Indeno(1,2,3-c,d)pyrene	0.03

Source: NMFS, 1996.

Modeled PAH concentrations increase with the number and density of pilings, and decrease with flow rate. For example:

- For the 350-piling scenario, concentrations of all PAHs modeled exceeded the 0.1 TU threshold at flows of ≤ 0.8 cm/s, regardless of footprint size. At a flow rate of 7.0 cm/s, PAH concentrations exceeded the threshold for footprints of 400 m^2 and smaller.

- For the 100-piling scenario, predicted concentrations of PAHs exceeded the 0.1 TU at all modeled flow rates for footprint areas of 800 m^2 and less.

2. Note that compounds listed in Table 2.4 do not match exactly the major creosote constituents listed in Table 1.3, which introduces some additional uncertainty regarding the applicability of the model to creosote-treated woods.

- For the 50-piling scenario, flows of 1 cm/s or less and footprint areas of 400 m^2 and less resulted in predicted concentrations greater than the threshold.

This model is a simplified transport model that depicts average concentrations in a hypothetical box plume. Sedimentation, volatilization, lateral mixing, and turbulent mixing (which would decrease concentrations in the water column) are not considered in the model. Poston et al. (1996) acknowledge that the model probably over-predicts concentrations for water column PAHs and that model results are "approximate estimates at best."

2.3.2 Comparison to field data

(i) Brooks (1997)

Brooks (1997) compared his predicted sediment concentration results to measured sediment concentrations at two sites in British Columbia. Belcarra Bay has poor circulation, a maximum tidal current of 3.9 cm/s, an average salinity of 15.7 ppt, and an average RPD of 1 cm. The newest piling was 1.5 years old. The model over-predicted sediment concentrations 1 m from the piling but under-predicted concentrations at 3 and 5 m from the piling. Approximate predicted and measured concentrations, estimated from Figure 3 in Brooks (1997), are shown in Table 2.5.

Table 2.5. Approximate predicted and actual concentrations at Belcarra Bay, British Columbia

Distance from piling (m)	Predicted PAH concentration (ppm)	Measured PAH concentration (ppm)
1	9	4
3	5.5	10
5	3	8.5
10	0	Negligible
20	0	Negligible
40	0	Negligible

Source: Figure 3, Brooks, 1997.

Westham Island Bridge had greater circulation, an average maximum tidal current of 18.1 cm/s, an average salinity of less than 2 ppt, and an average RPD of 1.25 cm. The newest piling was 8 years old. The model somewhat over-predicted sediment concentrations at 0.5 and 2.0 m from the piling. Predicted and measured concentrations were similar at 5 m from the piling (Table 2.6).

Table 2.6. Approximate predicted and actual concentrations at Westham Island Bridge, British Columbia

Distance from piling (m)	Predicted PAH concentration (ppm)	Measured PAH concentration (ppm)
0.5	0.56	0.17
2	0.17	0.03
5	0.08	0.07

Source: Figure 4, Brooks, 1997.

(ii) Goyette and Brooks (1998, 2001)

Goyette and Brooks (1998, 2001) compared modeled versus measured concentrations of PAHs in surface water and sediment for sets of six treated pilings, both weathered and unweathered, and a set of untreated pilings in a poorly flushed basin of Vancouver Island, British Columbia. They also included a no-piling control. The pilings were all Douglas fir, and the new (unweathered) pilings were treated to a retention of 27 pcf using WWPI BMP standards. The weathered pilings had an unspecified retention and were not treated to BMPs. The pilings, with an average diameter of 30-cm each, were installed in 6-piling dolphins (a dolphin is a boat-mooring structure composed of multiple closely spaced pilings) having a minimum base diameter of 2.5 m. The current direction and speed were assessed over a two-day period, and determinations of "upstream" and "downstream" sampling directions and locations were made on the basis of this assessment.

In this study, the modeled total PAHs included all PAHs leached from creosote, but the measured total PAHs included only 17 measured PAHs (potentially underestimating the total). The site was said to have been selected as a "worst-case" scenario, with low current speed, but one of the site-selection criteria involved the presence of oxic sediments (having an RPD greater than 3 cm below the sediment surface). Sediments above the RPD are oxic, which increases the rate of PAH breakdown, and sediment samples for PAH analysis were routinely collected from the top (0-2 cm) layer during the study.

Goyette and Brooks (1998, 2001) used a 1994 version of Dr. Brooks' model to predict an increase of 336 ng/L total PAH in the water column within 15 cm of individual pilings This predicted concentration was approximately 11 times greater than the maximum of 30.8 ng/L total PAH measured with semi-permeable membrane sampling devices (SPMDs). Water column results were dependent on the ability of the SPMDs to accurately reflect water column concentrations. Although method blanks are documented, no positive controls were reported, and percent recovery was not noted.

PAHs were regularly measured in the upstream and downstream directions from each dolphin, beginning at 0.5 m. Although the distribution of PAHs was observed to be patchy (there was high spatial, and between-replicate, variability, and small oily particles were observed in the sediment samples), the model generally also predicted sediment concentrations that were higher than those observed in the upstream and downstream directions. However, a single sampling event sampled sediments within the dolphins and in a direction described as "offshore" of the dolphins. This sampling event revealed far higher sediment concentrations both inside the dolphins and outside the dolphins in the offshore direction than those observed close to, but outside of, the dolphins in the upstream and downstream directions, and also far higher than model predictions (Table 2.7).

Table 2.7. Observed and predicted sediment PAH concentrations in the Sooke Basin study, day 384/385 (per Goyette and Brooks, 1998, 2001)

Dolphin type	Direction relative to dolphin	Distance from dolphin (m)	Predicted PAH concentration (all), ppm	Observed PAH concentration (17 PAHs), ppm
BMP unweathered	Downstream	0.5	~24	16.1
	Downstream	1.0	~19	5.7
	Inside dolphin	0.0	N/A	30.8
	Offshore	0.5	N/A	68.3
	Offshore	2.0	N/A	2.9
Weathered	Downstream	0.5	~24	10.8
	Downstream	2.0	~6	6.3
	Offshore	0.5	N/A	33.8
	Offshore	2.0	N/A	15.3
	Inside dolphin	0	N/A	47.4

Also, the peak of sediment concentrations occurred somewhat sooner than predicted, giving the appearance of model under-prediction earlier in the experiment followed by over-prediction later in the experiment.

The results of these comparisons of modeled to measured PAH concentration data are insufficient to make any specific quantitative conclusions about the accuracy of the model in predicting actual sediment concentrations. The variability in the results is understandable because of the many site-specific conditions and simplifying assumptions required to run the model. For instance, Brooks (1997) presents the age of the newest piling, but it is unknown whether just some, or all, of the pilings were installed or replaced at that time. Also, both the number and density of pilings, factors that the Poston et al. (1996) model considers to be important, are not included in the Brooks (1997) transport model.

2.3.3 Applicability of the models

The aquatic systems that the Brooks (1997) and Poston et al. (1996) models simulate are highly complex systems that are difficult to describe quantitatively. Numerous simplifying assumptions were necessary to construct the models. For example, tidal currents are very complex and are influenced by many highly variable factors. Turbulence, the main process by which mixing occurs in these systems, is a chaotic three-dimensional process that is notoriously difficult to model. Furthermore, the leaching rates used in the model as inputs are themselves model results with their own set of uncertainties.

Despite these uncertainties and assumptions, the leaching and transport models have value in qualitatively describing many first-order factors related to PAH leaching from treated wood and movement in the environment. For example, Brooks (1997) recognizes the importance of oxygen availability in the system, and sediments with a thin layer of oxygenated sediments (a small RPD) result in higher predicted concentrations of PAH compounds than well oxygenated sediments. Both the Brooks (1997) and Poston et al. (1996) models incorporate flow rate as a critical variable affecting concentrations in the environment, and the Poston et al. (1996) model also incorporates piling density (and thus surface area), which laboratory studies have confirmed to be important.

2.4 Conclusions

The modeling of PAH leaching rates from treated wood and the resulting environmental concentrations are important for evaluating the environmental risks from treated wood structures. Our review and evaluation of the available information and models on PAH leaching and environmental concentrations, support the following:

The rate of leaching of PAH is greater:

- In freshwater than in seawater
- At high temperatures than at low temperatures
- At high flow rates than at low flow rates
- From less dense wood than from denser wood
- From freshly treated wood than from wood that has either been stored after treatment or been exposed to water
- From end grain than from face grain

- At a higher wood surface area to volume ratio
- From wood that has not been treated to the WWPI BMPs than from wood that has been treated to the BMPs.

Also, leaching is faster for the more water-soluble compounds. Variations in the leaching rates of PAHs from same-species wood samples can be surprisingly large (Miller, 1977, as cited in Brooks, 1997; Rao and Kuppusamy, 1992). In addition to PAHs, compounds such as N-heterocycles can leach from treated wood, and this issue has not been thoroughly investigated in the literature. Most leaching studies to date, with the exception of Becker et al. (2001), have focused on PAH leaching.

The Brooks leaching model, in its most current incarnation (the CREOSS spreadsheet model) incorporates only temperature, salinity, piling age, and creosote retention factors in the calculation of leaching rates. The predicted leaching rates generally behave as expected based on the results of laboratory studies for all components considered, but agreement with laboratory observations, where comparisons can be made, could be improved, particularly at temperatures below 20°C (Figure 2.4). The model ignores the effect of water flow rate on leaching rates, relies on studies of older installations probably missing peak leaching rates, and assumes an equal migration rate of all components of creosote, which is not supported by laboratory observations. However, the model appears to be adequate for predicting many first-order factors that explain laboratory and field observations.

The transport models for predicting environmental concentrations of PAHs in surface water and sediment are based on assumptions regarding modeled leaching rates and environmental parameters such as water flow, surface area of treated wood, and sediment settling and movement (Poston et al., 1996; Brooks, 1997). The inputs needed to run these models are highly site-specific. The models can provide site-specific predictions where site-specific conditions are known, and they are useful for evaluating the relative importance of different environmental variables on environmental concentrations of PAHs. The models may not fully describe transient concentrations of PAHs, particularly shortly after installation of treated wood in water, or during severe disturbances (especially abrasion).

The transport models indicate that environmental concentrations decrease with increasing flow rates, due to increasing dilution. However, several leaching studies suggest that the rate of leaching also increases with increasing flow rates. This raises the issue of the relative contributions of leaching rate and dilution to water column concentrations of PAHs, since both are affected by changes in flow rate. As flow rate increases, both leaching and dilution increase, but their effects on water column concentration oppose one another. Available data are insufficient to answer questions regarding the net outcome of this relationship under various realistic scenarios; that is, at any point, as flow rate increases, will the increase in leaching

outweigh the increase in dilution? The results in Xiao et al. (2002) appear to show leaching doubling or more than doubling under some circumstances, when flow rate simply doubles, but this issue has not been thoroughly investigated.

The current models only incorporate flow velocity into the dilution portion of the model, and do not consider the effect that increased velocity may have on leaching rates. It is possible that, because of this omission, the models under-predict actual concentrations. However, these models do not consider lateral mixing or turbulence, both of which increase dilution and mitigate the effect of increased leaching due to increased flow rates.

3. Toxicity of Creosote to Estuarine Organisms

This chapter discusses the environmental toxicity of creosote, including constituents of creosote that are known to be toxic (Section 3.1), the routes by which toxic constituents expose organisms (Section 3.2), the toxicity of various constituents to organisms under environmentally relevant conditions (Section 3.3), and the concentrations at which biological effects begin to occur (Section 3.4).

3.1 Toxic Components of Creosote

As described in Section 1.4, the chemical composition of creosote is very complex. This compositional complexity can obscure the toxicity of the mixture and of particular constituents in environmental settings. PAHs are the dominant class of compounds in creosote, comprising 85-90% of creosote's mass. PAHs are the most comprehensively studied group of chemicals found in creosote, due largely to the potency of some as carcinogens, and to their widespread, and apparently increasing, occurrence in the environment (e.g., Van Metre et al., 2000).

Although a number of PAHs have been well studied regarding their potency as carcinogens, less is known about the non-carcinogenic toxicities of PAHs and other components of creosote to aquatic and marine organisms. This appears to be true particularly for creosote components such as alkylated PAHs and heterocycles. However, while there is little information concerning interactive effects of creosote components, there is a reasonable body of work addressing the effects of creosote per se, both in laboratory exposures and from field studies.

Many studies of PAHs and creosote compounds in aquatic and marine environments distinguish between LPAHs and HPAHs. Generally, LPAHs are PAHs with two-or three-fused benzene rings; HPAHs are PAHs containing four or more rings. In some cases, such as fluorene and fluoranthene, a 5-carbon aromatic cyclic ring replaces benzene. The focus of the rest of this chapter is the current state of knowledge about routes of exposure and the toxicity of creosote components and the mixture itself, highlighting the sensitive endpoints that drive risk assessments.

3.2 Routes of Exposure

Meador et al. (1995) provided a thorough review of the literature on factors governing the bioaccumulation of PAHs in marine organisms (invertebrates and fish). Their conclusions are supported by subsequent studies, and while they focused on parent PAHs (i.e., non-alkyl-substituted compounds), their analysis probably holds for other major components in creosote such as phenolics, alkylated PAHs, and heterocycles.

Meador et al. (1995) concluded that the major routes of exposure for marine animals were uptake of waterborne chemicals and through the diet. Waterborne chemicals include those in the interstitial water (ISW) of sediments. ISW is probably the compartment governing the bioavailability of many organic chemicals in marine systems. Direct uptake of sediment-bound chemicals (e.g., through the integument of worms and fish) appears to be negligible. This conclusion is supported by studies that demonstrate that the water-soluble fractions of contaminated sediments generally drive the toxicity of chemicals in bulk sediments (e.g., Roberts et al., 1989; Swartz et al., 1989; Padma et al., 1998). Thus, in hazard assessments of PAH-contaminated sediments, K_{oc}, which describes equilibrium partitioning between the organic carbon of sediment and the surrounding ISW, becomes a key driver for exposure assessment. K_{ow}s are often used to estimate K_{oc}s for individual compounds (see Swartz et al., 1995).

The diet can also be an important source of PAHs and related creosote chemicals (Meador et al., 1995), and particularly so for deposit-feeding invertebrates and for fish that feed on invertebrates. Malins et al. (1985) reported elevated concentrations of PAHs and related chemicals in the stomach contents of marine fish inhabiting a creosote-polluted site in Puget Sound, Washington. However, absorption efficiencies of dietary PAHs may be limited; Niimi and Dookhran (1989) reported uptake efficiencies of 2% to 32% for various PAHs.[1]

The relative roles of uptake from the water column (including ISW) and the diet vary greatly, depending on factors such as the organism's life history, physico-chemical characteristics of specific compounds (such as solubility and K_{ow}), and environmental variables (such as sediment organic carbon content). In general, water column uptake is more important for chemicals with higher solubility (or lower K_{ow}), and also is more important for filter-feeding organisms. However, as Meador et al. (1995) stress, the route of uptake is, in the long run, relatively unimportant. Over time, equilibrium among media (sediments, water, and biota) will occur and the same tissue burdens (or other measures of exposure, as described below) will occur regardless of route of exposure.

1. However, many hydrophobic organic compounds have higher uptake efficiencies than this. Niimi and Dookhran (1989) packed one gelatin capsule per day into ground trout diet, which may not be comparable to ingesting invertebrate prey.

The assessment of exposure to, and accumulation of, creosote hydrocarbons is complicated by metabolism. Halogenated hydrophobic chemicals, such as polychlorinated biphenyls (PCBs), chlorinated dioxins and furans, and chlorinated hydrocarbon pesticides, such as dichloro-diphenyl-trichloroethane (DDT), that are also of concern in marine and estuarine systems, are highly resistant to metabolism by most organisms. In contrast, creosote hydrocarbons are not halogenated and consequently are readily prone to metabolism by many organisms. Among estuarine and marine animals, metabolic capacity is generally very high in fish (and other vertebrates), intermediate in crustaceans, and very limited in bivalves (Meador et al., 1995). For this reason, tissue concentrations of creosote hydrocarbons provide a reasonably accurate measure of exposure in bivalves, but an inaccurate measure in vertebrates. Crustaceans are probably intermediate in this respect.

Vertebrate metabolism is discussed in more detail in Section 3.3. Briefly, the metabolism of hydrocarbons gives rise to relatively hydrophilic metabolites, most of which are excreted via the bile in vertebrates, and to reactive metabolites that can bind to cellular macromolecules such as DNA. Thus, measures such as concentrations of bile metabolites and DNA adducts are often used as measures of hydrocarbon (mainly PAH) exposure in vertebrates.

3.3 Toxicities

Information concerning the toxicity of creosote and constituent chemicals is not equally complete for all constituents. Much information is available concerning PAHs, particularly HPAHs, in part because of the potent carcinogens in this group. There is also some information concerning the toxicities of heterocycles and creosote. Phenolics appear to be the least studied of the key components of creosote.

Most toxicity experiments published in the peer-reviewed literature have been conducted by exposing aquatic biota either to creosote-spiked water or to sediments or sediment elutriates containing creosote, which may be either spiked with whole creosote or field-collected product.

These exposures are not directly equivalent to exposures conducted using leachates (either in water or sediment) from treated wood, for several reasons. Although all creosote exposure experiments contain PAHs and other compounds, the individual constituents and their concentrations can be heavily influenced by weathering and by the leaching process itself. Also, many creosote-spiking experiments use solvents such as acetone to increase the aqueous bioavailability of the mixture's more hydrophobic components. And, finally, sediments for use in creosote bioassays are often field-collected from sites where creosote was released from wood treatment facilities. At such sites, other toxicants such as pentachlorophenol and metals are frequently present in potentially toxic amounts, making it difficult to determine what portion of observed toxicity is attributable to the creosote in the sediments.

Plants appear to be less sensitive to creosote chemicals than animals in aquatic and marine systems (WHO, 2004). Our discussion focuses on animals, particularly invertebrates and fish. In studies with invertebrates, endpoints that have been examined most frequently include acute toxicity (mortality), phototoxicity (a distinct form of acute toxicity), and effects on populations and community structure. Studies with fishes have included investigations of acute toxicity and phototoxicity, and more basic investigations of reproduction and growth, effects on the immune system, early life stage development, and chemical carcinogenesis. The effects of creosote and creosote chemicals on key endpoints are discussed below.

3.3.1 Toxicity from acute (short-term) exposure

Under standard laboratory conditions, the acute toxicities of water-borne PAHs and alkylated PAHs to marine organisms vary widely among chemicals and test organisms (see reviews by Neff, 1985; and Eisler, 2000). For marine and freshwater invertebrates and fishes, 24- and 96-hour LC_{50}s generally range from approximately 0.1 to 4 mg/L (ppm); crustaceans tend to be relatively more sensitive and fish less sensitive in these tests. Eisler (2000) noted that these concentrations are generally orders of magnitude greater than those encountered in surface waters, including at polluted sites. Few studies of this nature examining heterocycles have been reported.

Other studies have investigated the acute toxicity of creosote itself, either in sediments or water-extracted fractions. Padma et al. (1998) exposed the mysid shrimp *Mysidopsis bahia* to either a creosote-contaminated sediment (Elizabeth River, Virginia) or to the water-soluble fraction (WSF) of this sediment. Chemical analyses were performed on both sample types. As measured by total identified aromatic compounds, they determined 24-hour LC_{50}s to be approximately 180 µg/L (ppb) and 700 µg/L for the water-extractable fraction and sediment, respectively, indicating an approximate four-fold greater toxicity of the WSF. A major difference between the two samples was higher concentrations of low molecular weight PAHs (< three rings) in the WSF compared with the sediment. N-heterocycles were also reported to be higher in the WSF, but no data were provided.

Swartz et al. (1989) measured the acute toxicity of various dilutions of creosote-contaminated sediments and ISW extracted from the sediments, collected from Eagle Harbor, Washington, to the marine amphipod *Rhepoxynius abronius*. They measured 13 PAHs in these samples; heterocycles apparently were not measured. Based on these studies, the four-day LC_{50} for total PAHs was 666 mg/kg (wet weight). The ISW LC_{50} was found to be 0.89% of the undiluted ISW. Based on data for undiluted ISW provided in Table 4 of Schwartz et al. (1989), this equates to an ISW LC_{50} of 100 µg/L. Dominant PAHs observed in both sample types included acenaphthene, fluorene, phenanthrene, fluoranthene, and pyrene.

Sved and Roberts (1995) constructed a flow-through dilutor system to continually expose the estuarine teleost, spot (*Leiostomus xanthurus*), to selected dilutions of suspended sediment mixed with commercial marine creosote. They measured over 100 compounds, including heterocycles, but provided data for only six PAHs that comprised 64% of total resolvable PAH: naphthalene (21%), acenaphthene (8%), fluorene (6%), phenanthrene (14%), fluoranthene (9%), and pyrene (6%). Based on these exposures, the 96-hour LC_{50} was determined to be 1,740 µg/L, and the no observable effects level (NOEL) was 250 µg/L. In a previous study that involved exposures of spot in this system for 14 days (Sved et al., 1992), mortality, fin erosion, and epidermal lesions were observed at total PAH concentrations as low as 76 µg/L. Induction of hepatic ethoxyresorufin O-deeethylase (EROD) activities were observed at all concentrations tested, down to 16 µg/L. In this study, concentrations of individual chemicals were not reported.

Sved et al. (1997) also used the flow-through dilutor system to compare the toxicity of commercial creosote that had been fractioned into HPAH and LPAH, with the exception that phenanthrene and fluoranthene were important components of both. In 10-day exposures of spot, mortality, fin erosion, epidermal lesions, and EROD inductions were observed in fish exposed to HPAH. Of these responses, only limited epidermal lesions were observed in fish exposed to LPAH. Dominant PAHs in the LPAH fraction were acenapthalene (14%), fluorene (12%), phenanthrene (28%), and fluoranthene (9%). Dominant PAHs in the HPAH fraction were phenanthrene (22%), fluoranthene (26%), and pyrene (15%). The authors concluded that the HPAH fraction better mirrors weathered creosote in the field and produces responses similar to field and laboratory responses to exposures to creosote-contaminated sediments.

The identity of key chemicals responsible for the acute toxicity of creosote (as well as some other endpoints described below) remains unresolved. In his review, Neff (1985) concluded that only PAHs in the molecular weight (MW) range of naphthalene (MW = 128) to fluoranthene and pyrene (MW = 202) demonstrated significant acute toxicity to aquatic organisms, and within this range, bioaccumulation increases with increasing molecular weight. A number of subsequent studies, including some described above, support this conclusion. However, Padma et al. (1999) concluded that more water-soluble LPAH, perhaps including heterocycles, dominated toxicity in their study. Kuehl et al. (1990) used a fractionation scheme to determine key chemicals in a creosote mixture that were acutely toxic to the water flea *Ceriodaphnia dubia.* They concluded that PCP and low molecular weight heterocycles in the mixture were probably the chemicals responsible. However, in a study of creosote-contaminated sediments in Finland, Hyotylainen and Oikari (1999) noted that, over time, the sediments became enriched in very high molecular weight PAHs, such as benzo[a]pyrene (MW = 252). They concluded that the high molecular weight PAHs appeared to be primarily responsible for the toxicity of the sediments to *Daphnia magna* and the photoluminescent bacterium *Vibrio fischeri*. In a study attempting to elucidate the fractions of weathered middle-distillate oils (a petroleum product that contains many of the chemical components in creosote) toxic to *Mysidopsis bahia*, Barron et al. (1999) concluded that

aromatic compounds (including "classic" PAHs and substituted PAHs) were not primarily responsible for toxicity. However, the relevance of that study to creosote is unclear.

Clearly, assessing the toxicity of complex mixtures such as creosote is very challenging. However, at least for PAHs common in creosote, considerable effort has focused on predicting the cumulative toxicity of PAHs in sediments, which is the key reservoir for creosote-derived chemicals in aquatic and marine systems. One of the proposed approaches that appears to be very useful, and that includes measurements and predictions of acute toxicity of PAHs, is the ΣPAH model of Swartz et al. (1995). This model incorporates 10-day acute toxicity tests (for acenaphthene, phenanthrene, and fluoranthene) with several sensitive marine and estuarine amphipods (including *Rhepoxynius abronius*), quantitative structure-activity relationship (QSAR) predictions of the toxicities of 10 additional PAHs (naphthalene, acenaphthylene, fluorene, anthracene, pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, and benzo[a]pyrene), field chemistry data (sediment concentrations of these 13 PAHs and organic carbon content), and equilibrium partitioning to predict ISW concentrations of each PAH.

Swartz et al. (1995) predicted the 10-day LC_{50}s for these PAHs to range from 0.17 µg/L for benzo[k]fluoranthene to 3,500 µg/L for naphthalene. Their analyses and predictions support the notion that acute toxicity increases with increasing molecular weight (between 2- and 4-ring structures). This might be important in creosote-contaminated systems where higher molecular weight compounds appear to persist and eventually dominate the sediment profile relative to lower molecular weight compounds.

3.3.2 Phototoxicity

Concentrations of PAHs in surface waters rarely approach the concentrations associated with acute toxicity of these compounds under standard laboratory testing protocols (Eisler, 2000). A potentially important exception to this is the enhancement of the acute toxicity of some PAHs to various aquatic invertebrate and fish species examined under ultraviolet (UV) radiation. UV radiation is largely absent in normal indoor lighting. QSAR models have been developed that are reasonably accurate in predicting the phototoxic potencies of aromatic compounds (Ankley et al., 1997). Among the PAHs found to be highly phototoxic are anthracene, fluoranthene, pyrene, benzo[a]pyrene, benz[a]anthracene, and benzo[k]fluoranthene (Newsted and Giesy, 1987). The degree of enhancement of PAH toxicity is dramatic, with measures of acute toxicity generally increasing by one to two orders of magnitude. In animals, phototoxicity is thought to require bioaccumulation of the phototoxic chemical (Weinstein and Oris, 1999). It has also been shown that UV radiation can transform some PAHs (such as anthracene, phenanthrene, and benzo[a]pyrene) into products such as quinones that are more toxic than parent PAHs (Huang et al., 1993). Very recently, it has been reported that some photo-products of anthracene, such as

2-hydroxyanthroquinone, are estrogenic and occur at much greater concentrations than the parent compound in natural waters (Kurihara et al., 2005).

While many studies of phototoxicity have examined water-column-inhabiting organisms, the phenomenon has also been shown to occur in sediment-inhabiting invertebrates. For example, UV-enhanced phototoxicity has been demonstrated in oligochaetes (*Lumbriculus variegatus*) and amphipods (*Rhepoxynius abronius*) exposed via PAH-amended sediments (Ankley et al., 1994; Swartz et al., 1997), as well as in *Lumbriculus variegatus* and the amphipod *Hyalella azteca* exposed to field collected PAH-contaminated sediments (Ankley et al., 1994). UV exposure was also shown to markedly increase the acute toxicity of creosote-contaminated sediments from the Elizabeth River, Virginia, in larvae of the estuarine killifish, *Fundulus heteroclitus* (Meyer and Di Giulio, 2003).

The ecological relevance of UV-mediated PAH toxicity in the environment remains controversial, with some contending that factors operating in the environment ameliorate PAH phototoxicity (McDonald and Chapman, 2002). For example, humic acids that are often abundant in natural waters but generally minimal in most laboratory studies can reduce PAH bioaccumulation and attenuate UV light penetration, and thereby greatly reduce phototoxicity (Weinstein and Oris, 1999).

3.3.3 Carcinogenesis

From the standpoint of human health, the greatest concern for creosote constituents, particularly PAHs and aromatic amines, is the potency of many as mutagens and carcinogens. There is also a very substantial literature concerning chemical carcinogenesis, including PAHs, in fish. The mechanisms by which PAHs produce cancers are very similar in mammals and fish, and fish models have been used extensively in cancer research. Cancer, and the steps leading to it, comprise a key endpoint relevant to chronic exposures of vertebrates to PAHs, and might be important in assessing environmental risks of creosote in aquatic systems.

Many of the epizootics of cancer (predominantly liver neoplasms) described in fish populations in North America have been in areas contaminated by PAHs and associated aromatics such as N heterocycles (Landahl et al., 1990; Johnson et al., 1993; Baumann and Harshbarger, 1995; Myers et al., 2003). Among these are cases where creosote was strongly indicated as the source of the chemicals underlying the observed liver cancers, including cancers in English sole (*Pleuronectes vetulus*) in Puget Sound, Washington (Malins et al., 1985) and in *Fundulus* spp. in the Elizabeth River, Virginia (Vogelbein et al., 1990). In a more recent (2001) survey of Elizabeth River *Fundulus* spp. from the former Atlantic Wood creosote site (which closed in about 1990), Vogelbein and Unger (2003) observed hepatic neoplasm rates of 8% and altered hepatocellular foci (a precancerous lesion) rates of 65%. These rates were diminished somewhat

from earlier surveys. They provided quantitative data for sediment concentrations of 10 LPAHs and 8 HPAHs. Total mean PAH concentration was approximately 490,000 ng/g (ppb), dry weight, of which approximately 440,000 ng/g were HPAHs, including fluoranthene (approximately 125,000 ng/g), pyrene (approximately 71,000 ng/g), and the carcinogens benzo[a]pyrene (approximately 56,000 ng/g), benz[a]anthracene (approximately 41,000 ng/g), chrysene (approximately 60,000 ng/g), and dibenz[a,h]anthracene (approximately 12,000 ng/g). These data support the relative persistence of creosote-derived HPAHs, including carcinogenic PAHs, over time.

Laboratory studies have confirmed a causal link between PAHs and liver cancer and associated lesions in fish, including dibenzo[a,l]pyrene in rainbow trout (*Onchorhynchus mykiss*) (Williams et al., 2003), and benzo[a]pyrene and 7,12-dimethylbenzanthrace (DMBA) in Japanese medaka (*Oryzias latipes*) and guppy (*Poecilia latipes*) (Hawkins et al., 1990). There appears to be variability in sensitivity to chemical carcinogenesis among fish species. However, most species involved in epizootics are benthic species, such as English sole and winter flounder (*Pleuronectes americanus*) in marine systems, and brown bullhead (*Ameriurus nebulosus*) in freshwater systems. These species are frequently in contact with sediments; their life history behavior is thought to increase their exposure to carcinogens and thereby play a role in their sensitivity.

The mechanisms by which PAHs cause tumors appear to be similar in mammals and fish. They are briefly summarized here due to their relationship to the assessment of exposure and effects of creosote hydrocarbons in estuarine and marine systems. To initiate cancer, PAHs must first be metabolized into reactive products that can bind to or otherwise damage DNA. DNA damage occurs when the base sequence is altered and the alteration is passed along during subsequent cell divisions, i.e., a mutation has occurred (see review by Pitot and Dragan, 2001). For a resulting mutation to initiate cellular events leading to cancer, it must occur at a critical site in a gene that codes for a protein that serves a role in cellular growth, regulation, differentiation, or signaling. For example, benzo[a]pyrene has been shown to produce mutations in the DNA-binding regions of the tumor suppressor gene, p53, which leads to loss of the DNA damage surveillance function of the p53 protein (Denissenko et al., 1996). The processes occurring between initiation (DNA damage) and cancer, including promotion and progression, are complex and beyond the scope of this report.

However, mechanisms underlying initiation merit consideration here. Benzo[a]pyrene is the most well studied PAH in terms of DNA damage and cancer initiation, but mechanisms underlying these phenomena generally apply to other genotoxic PAHs also. Benzo[a]pyrene is oxidized mainly in the liver of vertebrates by cytochrome P450 (CYP); in fish the dominant enzyme catalyzing PAH oxidations is CYP1A (Stegeman and Hahn, 1994). Various oxidations to phenolics and epoxide metabolites can occur on the benzo[a]pyrene molecule, and the majority of these oxidations lead to their excretion via the bile due to enhanced water solubility. However,

specific metabolites can be highly reactive with cellular macromolecules, including DNA. In the case of benzo[a]pyrene, the 7,8-diol, 9,10-epoxide (benzopyrene diol epoxide, BPDE) is the best characterized genotoxic metabolite that covalently binds to DNA bases, such as guanine. Cells are equipped with DNA repair machinery that can excise and replace damaged bases. However, bulky adducts such as PAHs can elicit misrepair, with the wrong base inserted to replace the damaged one. If the cell containing the resulting altered base sequence remains viable and able to divide, mutation has occurred, with the potential for carcinogenesis, as described above.

These processes have been used in the biomonitoring of PAHs in environment and risk assessments (Myers et al., 1998). Expression of the CYP1A protein is regulated by the aryl hydrocarbon receptor (AHR). Ligands for the AHR can elicit very marked up regulations of CYP1A that can be readily measured, for example by the EROD enzyme activity assay mentioned earlier, which is highly specific for CYP1A activity. A number of PAHs, particularly HPAHs, are effective AHR agonists that elicit CYP1A inductions. Thus, EROD activity provides a very sensitive biomarker for vertebrate exposures to PAHs, and it has been effective in field studies. This is important for PAHs because they are so readily metabolized by vertebrates and hence not amenable to standard tissue residue analysis. One downside of CYP1A measures is that there are other potent AHR agonists that also induce the protein, including polyhalogenated aromatics such as dioxins and PCBs. An assay that gets around this issue is the measure of PAH metabolites in the bile, which, though somewhat more difficult and less sensitive than EROD, can be very useful. DNA adducts to DNA can also be measured; this is accomplished in field studies principally by the ^{32}P-post-labeling assay (Myers et al., 1998). This is a much more involved assay than the previous two, but very powerful in that it has a clear relationship to cancer. Finally, hepatic anomalies, including pre-neoplastic lesions (lesions suggestive of carcinogenesis) and frank neoplasms can be quantified by standard histopathologic methods. Myers et al. (1998) provide a detailed example from Puget Sound of the integrated use of these markers for biomonitoring, in which the NOAA NMFS laboratory in Seattle, Washington, has been involved for many years.

Thus, the mechanisms underlying PAH metabolism and genotoxicity provide for an array of useful biomonitoring tools, or biomarkers, including:

- CYP1A
- Bile metabolites
- DNA adducts
- Lesions
- Cancer.

Sensitivity and ease of measurement generally decline from the top to the bottom of this list, but biological importance, and perhaps regulatory clout, increases from top to bottom.

3.3.4 Development

The effects of PAHs and related hydrocarbons on early life stage development have emerged as important issues relatively recently. In contrast to cancer, where concerns originated in the context of human health and subsequently spread to concerns for aquatic and marine systems, developmental effects have been primarily the purview of environmental studies. Field and laboratory investigations aimed at elucidating the impacts of the *Exxon Valdez* oil spill in Prince William Sound identified significant effects of petroleum hydrocarbons on development in endemic species such as the Pacific herring (*Clupea pallasi*) (Hose et al., 1996; Marty et al., 1997; Middaugh et al., 1998; Carls et al., 1999). Effects observed in exposed embryos included decreased hatching success, DNA damage, reduced heart rates, and gross morphological abnormalities such as scoliosis, pericardial edema, and cranio-facial abnormalities.

The morphological abnormalities observed are very similar to those described for fish embryos exposed to polyhalogenated hydrocarbons, particularly 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD; Walker et al., 1991). This effect, ultimately associated with drastic declines in Great Lakes lake trout populations (Cook et al., 2003), is referred to as blue sac disease, due to the appearance imparted by pericardial edema. Recent studies using zebrafish (*Danio rerio*) as a model have investigated the pathologies and mechanisms underlying TCDD-mediated blue sac disease. TCDD is among the most potent ligands for the AHR and is a very potent inducer of CYP1A. Using gene silencing techniques with antisense morpholinos to block translation of specific genes, it has been shown that activation of the AHR is required for the effects on cardiovascular development that underlie blue sac disease, but the role of CYP1A is unresolved (Prasch et al., 2003; Carney et al., 2004). Given that some PAHs are also effective AHR ligands and CYP1A inducers, petroleum and creosote might have similar developmental effects.

Incardona et al. (2004) investigated the effects of selected PAHs, including an S-substituted heterocycle, on cardiovascular development in the zebrafish. They investigated 2- to 4-ring PAHs, abundant in crude oil, singly and in mixtures. PAHs studied were naphthalene, fluorene, anthracene, phenanthrene, dibenzothiophene, chrysene, and pyrene. Among those, the chemicals exhibiting the most severe effects on cardiovascular development were phenanthrene, dibenzothiophene, and pyrene. Phenanthrene and dibenzothiophene produced particular effects on cardiac conduction resulting in reductions in circulation, which appeared primary to subsequent effects on cardiovascular development. The effects of pyrene were distinct and included anemia, peripheral vascular defects, and neuronal cell death; these effects resemble effects associated with TCDD. Coincidentally, 4-ringed pyrene is an AHR agonist (though far weaker than TCDD), while 3-ringed phenanthrene and dibenzothiophene are not. Incardona et al. (2004) suggested that pyrene may be acting through mechanisms similar to those by which TCDD acts, while the 3-ringed PAHs are directly perturbing atrioventricular conduction. They provide a convincing argument that narcosis is not a likely mechanism for the cardiovascular effects produced by these compounds. Relatedly, Billiard et al. (1999) reported blue sac disease

in rainbow trout and zebrafish embryos exposed to the alkylated 3-ringed PAH, retene (7-isopropyl-1-methylphenanthrene).

In a study directly addressing the effects of creosote on development, Vines et al. (2000) placed Pacific herring embryos in seawater containing creosote-treated wood, with seawater alone and seawater containing untreated wood as controls. Embryos collected from creosote-treated pilings in San Francisco Bay were also examined. This species spawns on a variety of substrates including pilings. In the laboratory studies, all embryos adhering directly to treated wood, and approximately 40-50% of those not adhering, failed to develop beyond the first few days of incubation. Surviving embryos displayed a 93% reduction in heart rate, and moderate to marked arrhythmia. Approximately 15-20% of the embryos exposed to creosote hatched, but all of these exhibited deformities including scoliosis, pericardial edema, and ascites. These effects were not observed in untreated wood or seawater controls. Also, similar effects were observed in embryos collected from the Bay, which displayed a 72% decrease in hatching success and similar deformities in surviving larvae.

Vines et al. (2000) measured total hydrocarbons diffusing from the treated wood by UV fluorescence, and individual components were measured in C-18 extractions of seawater by GC-MS. They concluded that 92.5% of this extract was composed of four 3-ringed PAHs – anthracene, phenanthrene, fluorene, and diphenlethyne – and lesser amounts of furans and non-aromatics. These results are somewhat surprising because the pilings used as the source for the treated wood had been placed in a marina about 40 years before the studies. Based on their results, the authors calculated the LC_{50} for hatching success to be 0.05 mg/L (total hydrocarbons in seawater). A sublethal exposure of 0.003 mg/L significantly reduced hatching success and increased abnormalities in surviving larvae (gross morphology and reduced heart rates); these effects were largely independent of three test salinities (8, 16, and 28 ppt – low, optimal, and high).

Wassenberg and Di Giulio (2004b) exposed *Fundulus* spp. embryos to dilutions of water extracts of sediments from the creosote-impacted portion of the Elizabeth River and observed significantly elevated EROD activities at all dilutions tested (ratios of extract to seawater ranged from 1:5,000 to 1:4). They observed deformities, including pericardial edema, deformed hearts, and shortened tails, at the 1:4 dilution. Addition of the PAH-type CYP1A inhibitor α-naphthoflavone, which had no effects on development by itself, effectively inhibited EROD activities at all dilutions studied and greatly enhanced the teratogenic potency of the extract, with significant effects seen down to the 1:1,000 dilution. Subsequent studies examining the interactive effects of a model PAH-type AHR agonist (β-naphthoflavone) and CYP inhibitor (α-naphthoflavone) demonstrated a potent synergy between these chemicals. Such synergy has also been demonstrated for creosote-associated PAHs (Wassenberg and Di Giulio, 2004a; Wassenberg et al., 2005). For example, fluoranthene, carbazole, and dibenzothiophene were shown to be effective CYP1A inhibitors that markedly enhanced the effects of the AHR agonist

benzo[a]pyrene on cardiovascular development in *Fundulus* spp. Collectively, these studies bring into question current assumptions of additivity for PAH mixtures (Barron et al., 2004) and hence may have relevance for ecological risk assessments of these mixtures, including creosote.

The laboratory studies described above tested aqueous exposures; this is probably an important route of environmental exposure. For example, Petersen and Kristensen (1998) measured bioconcentration factors (BCFs) in the range of 3.25 (naphthalene) to 4.32 (benzo[a]pyrene) for several PAHs in the eggs of several freshwater and marine fishes following aqueous exposures. However, these compounds can be transferred from the mother to the egg, as well. For example, adult female *Fundulus* spp. exposed to benzo[a]pyrene transferred parent compound and metabolites to developing eggs, with the compounds transported in associated with vitellogen that entered the eggs during oogenesis (Monteverdi and Di Giulio, 2000a, 2000b).

3.3.5 Immunotoxicity

PAHs have been shown to impact function of the immune system in mammals (White et al., 1994). Studies with fish, some involving creosote exposures, show similar impacts. Payne and Fancey (1989) exposed winter flounder to sediments contaminated with a petroleum source of PAHs. They observed reduced numbers of melanomacrophage centers (primitive analogs of mammalian lymph nodes and important for the cellular immune system of fish) at exposure levels down to approximately 25 mg/kg, total sediment PAH. Faisal et al. (1991) found that anterior kidney and splenic leukocytes from *Fundulus* spp. captured from a creosote-contaminated site in the Elizabeth River had less cytotoxic activity against a tumor cell line than leukocytes from *Fundulus* spp. from a reference site. Karrow et al. (1999) studied the effects of liquid creosotes added to microcosms on immune responses of rainbow trout exposed for up to 28 days to a range of creosote concentrations (5-100 µl/L). Major effects were concentration-dependent reductions in leukocyte oxidative burst response and in the number of surface immunoglobin positive (sIg+) peripheral blood leukocytes. Major chemicals identified in the microcosms were fluoranthene, pyrene, fluorene, and anthracene, with fluoranthene and pyrene exhibiting the strongest associations with immune system effects. They calculated the lowest observable effects concentration (LOEC) for these effects to be 17 µl/L, corresponding to a total PAH concentration of 611.63 ng/L.

3.3.6 Community effects

Several microcosm and field studies have investigated the effects of creosote on phytoplankton and invertebrate communities. Sibley et al. (2001a, 2001b) examined the effects of marine-grade creosote on freshwater microcosms applied at concentrations ranging from 0.06 to 109 mg/L with a single application. These studies involved about 200 species of phytoplankton and

86 species of zooplankton. Creosote caused a concentration-dependent reduction in zooplankton abundance and number of taxa that were maximal at 5-7 days; most taxa recovered within the 83 days of observation following the application. Community composition varied with time and creosote composition, and interspecific competition appears to have played a factor in the population decline and reduced recovery of rotifera relative to cladocera and copepoda; however, rotifera were generally more tolerant to increased creosote exposure. Based on their results and measured concentrations of total PAH, the authors calculated the EC_{50} for total zooplankton abundance (day 7) to be 2.9 µg/L, and the no observable effects concentration (NOEC) for community effects ($NEC_{community}$) to be 3.7 µg/L. In contrast, creosote had no direct adverse effects on phytoplankton communities. Instead, increases in total abundance and number of taxa were observed, apparently in response to reduced grazing pressure by zooplankton. A similar study was subsequently performed, in which Douglas fir pilings impregnated with the same creosote used in the above studies served as the contaminant source (Sibley et al., 2004). The effects on zooplankton and phytoplankton communities in this study mirrored those observed with direct creosote applications; the NOEC for zooplankton community effects was calculated to be 11.1 µg/L total PAH.

In a controlled field study, Goyette and Brooks (1998, 2001) examined the effects of creosote-treated pilings placed in an uncontaminated marine system (Sooke Basin, Vancouver Island, British Columbia). They investigated the effects of these pilings on endpoints including 10-day amphipod (*Eohaustorius washingtonianus*) toxicity; bacterial toxicity (Microtox^R); echinoid fertilization; *in situ* assays in deployed blue mussels (*Mytilus edulis*) for growth, spawning, larval development, and PAH accumulation; and benthic community analysis. Some of these endpoints were tracked for up to 1,540 days post-deployment of the pilings. In the first of these reports covering baseline studies and the first 535 days of the piling deployment, Goyette and Brooks (1998) reported significant sediment PAH accumulation up to 7.5 m downstream of pilings (18 µg/g and 7.5 µg/g total PAH at 0.5 m and 7.5 m, respectively), significant toxicity in laboratory tests with sediments collected within 0.65 m of pilings, and significant effects on PAH accumulation and reduced growth rates in mussels deployed within 15 cm of the pilings. Based on Washington State guidelines, they concluded that the greatest risks were posed by phenanthrene, followed by fluorene, acenaphthene, fluoranthene, and chrysene. In the later report covering sampling dates 1,360 and 1,540 days post-deployment, Goyette and Brooks (2001) reported sharply reduced PAH concentrations in sediments and mussels, and toxicity of sediments to amphipods was attributed to elevated sulfide due to anoxic conditions created by the pilings and associated biological communities.

3.3.7 Other effects

Other deleterious effects in estuarine and marine organisms have been noted for creosote and creosote-related compounds, including effects on growth and specific organ systems (Eisler,

2000; WHO, 2004). For example, Borthwick and Patrick (1982) found a 96-hour EC_{50} for reduced shell deposition in eastern oysters (*Crassostrea virginica*) of 710 µg/L. Also, Rice et al. (2000) observed severe impacts on growth in English sole fed polychaete worms that had ingested PAH-contaminated sediment (other contaminants in the sediment were not reported). Most of the sediment PAHs came from creosote released from a wood treatment plant. PAH concentrations in the worms were 11.3 ppm dry weight. Field-contaminated sediment fed to the worms was first diluted with clean sediment, producing a final concentration (3.3 ppm dry weight) that was 0.1% of the original sediment concentrations. Rice et al. (2000) conducted two similar experiments with this sediment. Although both experiments resulted in severe growth impairment, only the first was significantly different from control, possibly due to low statistical power in the second experiment.

Although a full review of all of these other toxicological endpoints is beyond this scope of this report, the response measures described in the preceding sections of this chapter appear to be appropriate and reasonably protective of aquatic receptors in evaluating wood-treating projects.

3.4 Conclusions: Biological Effects Concentrations

Based on the forgoing review of toxicities, acute toxicity to sediment-inhabiting invertebrates, and chronic effects on reproduction, development, the immune system, and the liver (i.e., effects generally leading to liver cancer) in fish merit consideration as adverse effects thresholds (as concentrations in sediment or water). Section 3.4.1 discusses biological effects concentrations in surface water; Section 3.4.2 in sediment.

3.4.1 Biological effects concentrations – surface water

Of the quantitative data available, some are given in terms of sediment concentrations, and some are provided as water column or ISW concentrations. When chemical-specific concentrations are provided in one media, equilibrium partitioning based on K_{ow}s and/or K_{oc}s can be used to make predictions in other media. Unless otherwise noted, concentrations are presented below in terms of total chemical concentrations; these are generally the sums of compounds identified and measured in a given sample, usually TPAH. For water concentrations, some representative effects concentrations are shown in Table 3.1.

The biological effects thresholds for total PAHs in water (Table 3.1) fall within a relatively small range, considering the differences in organisms and endpoints. The lowest value is for immune system effects in rainbow trout (Karrow et al., 1999), but the relationship of this effect to fish health is unclear since the study did not address disease susceptibility. A slight increase in the ratios of liver weights to body weights were observed at 1.0 µg/L. Complete mortality was

Table 3.1. Effects thresholds for PAHs in surface water (concentrations in µg/L)

Organism	Exposure source	Toxicity endpoint	Concentration	Citation
Mysidopsis bahia	Elizabeth River, Virginia, sediment extracts	24-hr LC_{50}	180	Padma et al., 1999
Rhepoxynius abronius	Eagle Harbor, Washington, sediment extracts	96-hr LC_{50}	100	Swartz et al., 1989
Pacific herring	PAHs leaching from ~ 40 year old pilings	LC_{50} for hatching success	50	Vines et al., 2000
Zooplankton	PAHs leaching from pilings placed in microcosms	No effects concentrations (NEC) for communities	11.1	Sibley et al., 2004
Zooplankton	Commercial creosote added to microcosms	NEC for communities	3.7	Sibley et al., 2001b
Pacific herring	PAHs leaching from ~ 40 year old pilings	Significant reduction in hatching success and increased abnormalities in surviving larvae	3	Vines et al., 2000
Zooplankton	Commercial creosote added to microcosms	EC_{50} for abundance	2.9	Sibley et al., 2001b
Trout	Commercial creosote added to microcosms	LOEC for immune effects	0.6	Karrow et al., 1999

observed within three days of the initiation of the experiment at the highest concentration of creosote tested, which appears to have been approximately 6 µg/L at the outset of the study. Control mortality was 23% in the course of the 28-day experiment, and no LC_{50} calculations were presented.

3.4.2 Biological effects concentrations – sediment

The biological effects of PAHs in sediment have been widely studied. A complete review of sediment PAH studies and a compilation of calculated threshold concentrations is outside the scope of this report. However, several studies summarize sediment quality guidelines (SQGs) for PAHs. Swartz (1999) includes many thresholds from many studies, and he compares those to his proposed SQG based on the sum of the PAH concentrations (∑PAH). The Oak Ridge National Laboratory compiled sediment toxicity benchmark data in 1997 (Jones et al., 1997). The U.S. EPA has provided guidance for determining sediment toxicity thresholds, including guidance for the use of equilibrium partitioning (e.g., Di Toro and McGrath, 2000) to determine

sediment quality guidelines (Hansen et al., 2003). Thresholds calculated according to this guidance do not carry regulatory authority at this time. Other U.S. EPA publications, such as Ingersoll et al. (2000) and Hellyer and Balog (1999), summarize sediment toxicity thresholds from many other studies, in an attempt to find some consensus.

Similarly, NOAA has compiled sediment toxicity thresholds for PAHs for consideration (not formally adopted), including an analysis of over 1,000 toxicity data points from the early 1990s (Long et al., 1998), and has published Screening Quick Reference Tables (SQuiRTs) that provide a quick reference to four freshwater sediment and five saltwater sediment threshold concentrations for many PAHs, as well as total PAHs (NOAA, 1999a). MacDonald et al. (2000) provide a thorough compendium of sediment quality benchmarks; Appendix III of their report contains well over 100 pages of sediment quality criteria and guidelines from the United States and Canada. Cormack (2001) provides a detailed review of sediment toxicity thresholds and their relation to sediment criteria in U.S. state and federal, and Canadian national and provincial, policies.

Table 3.2 lists an important subset of SQGs for PAHs that are well known and often cited, and/or promulgated and enforceable criteria. Each study in Table 3.2 contains threshold endpoints with acronyms for that threshold. An explanation of those thresholds follows.

- Effects Range-Low (ER-L) and Effects Range-Median (ER-M) are the lower 10th percentile and the 50th percentile, respectively, of a database of effects thresholds originally compiled by Long and Morgan (1991). NOAA guidance states that these are not derived as toxicity thresholds; rather, they were intended to be estimates of concentrations below which toxicity is least likely. They are meant to be used for ranking and prioritizing sites with contaminated sediments (NOAA, 1999b).

- Toxicity Effect Level (TEL) and Probable Effect Level (PEL) were derived for the promulgation of sediment quality criteria for the State of Florida (MacDonald, 1994). They divided their biological effects database into a database of effects concentrations and a database of no effects concentrations. They then calculated the TEL as the geometric mean of the 15th percentile of effects concentrations and the 50th percentile of no effects concentrations, and calculated the PEL as the geometric mean of the 50th percentile of the effects concentrations and the 85th percentile of the no effects concentrations (MacDonald, 1994). The Canadian Council of Ministers of the Environment (2003) copied MacDonald's Florida criteria for the Canadian Environmental Quality Guidelines, though they renamed the TEL the Interim Sediment Quality Guideline (ISQG).

Table 3.2. Sediment quality guidelines or criteria for marine/estuarine sediment. See text for explanation of acronyms and the thresholds they represent. MW = molecular weight (g/mol). Concentrations in ppb dry weight (see below).

		NOAA		FL and Env. Canada		WA	BC		Swartz, 1999	
Parameter	**MW**	**ER-L**	**ER-M**	**TEL**	**PEL**	**AET[a]**	**$SedQC_{scs}$**	**$SedQC_{tcs}$**	**∑PAH TEL[a]**	**∑PAH LC_{50}[a]**
Naphthalene	128.2	160	2,100	34.6	391	990	240	470	130	710
2-methylnaphthalene	142.2	70	670	20.2	201	380				
Acenaphthylene	152.2	44	640	5.87	128	660	80	150	30	150
Acenaphthene	154.2	16	500	6.71	88.9	160	55	110	40	230
Fluorene	166.2	19	540	21.2	144	230	89	170	170	900
Anthracene	178.2	85	1,100	46.9	245	2,200	150	290	210	1,140
Phenanthrene	178.2	240	1,500	86.7	544	1,000	340	650	290	1,550
Fluoranthene	202.3	600	5,100	113	1,494	1,600	930	1,800	690	3,710
Pyrene	202.3	665	2,600	153	1,398	10,000	870	1,700	900	4,810
Benzo(a)anthracene	228.3	261	1,600	74.8	693	1,100	430	830	210	1,110
Chrysene	228.3	384	2,800	108	846	1,100	520	1,000	310	1,690
Benzo(a)pyrene	252.3	430	1,600	88.8	763	990	470	920	330	1,790
Dibenz(a,h)anthracene	278.4	63	260	6.22	135	120	84	160		
Sum LPAH		552	3,160	312	1,442	3,700			870	4,680
Sum HPAH		1,700	9,600	655	6,676	9,600			3,060	16,460
Sum TPAH		4,022	44,792	1,684	16,770		10,000	20,000	3,930	21,140

a. Threshold concentrations originally in ppm organic carbon (OC). We assumed 1% OC to convert to ppb dry weight.

Sources: MacDonald, 1994; NOAA, 1999b; Swartz, 1999.
State of Washington: WAC 173-204-320.
Province of British Columbia: B.C. Reg 375/96 Schedule 9.
Canadian Council of Ministers of the Environment, 2003.

- Apparent Effects Thresholds (AETs) are thresholds above which statistically significant biological effects always occur (Swartz, 1999). These threshold concentrations are considerably higher than other thresholds, because they indicate concentrations where deleterious biological effects *will* occur, rather than concentrations where effects might occur, or concentrations below which effects are not likely to occur. The sediment criteria for Washington State are AETs (Gries and Waldow, 1996).

- British Columbia promulgated two separate criteria for PAHs in marine sediment, with a criterion for sediment in a "typical" environment ($SedQC_{tcs}$) and a more conservative criterion for sediment in a "sensitive" environment ($SedQC_{scs}$). These criteria are listed online in Schedule 9 of the Environmental Management Act Contaminant Sites Regulation (B.C. Reg 375/96) (http://www.qp.gov.bc.ca/statreg/reg/E/EnvMgmt/EnvMgmt375_96/375_96.htm; British Columbia Ministry of Labour and Citizen's Services, 2005). We have no guidance for the derivation of these criteria. The $SedQC_{tcs}$ concentrations are similar to the TEL from Florida, and the $SedQC_{scs}$ fall between the TEL and PEL (Table 3.2).

- While at the U.S. EPA, Swartz (1999) proposed sediment criteria based on the ∑PAH model of toxicity to marine and estuarine amphipods. Using data from other studies and translating other thresholds into his ∑PAH metric, Swartz derived a low effects threshold similar to the TEL that he called the "∑PAH toxicity threshold" (which we called the ∑PAH TEL in Table 3.2). He also derived a "∑PAH mixture LC_{50}" at which the concentrations of individual compounds, LPAH, HPAH, or TPAH are sufficient to cause 50% mortality in amphipods (Swartz, 1999).

Table 3.2 shows the wide disparity in sediment quality guidelines for PAHs. As discussed earlier, scientists at the NOAA NMFS Laboratory in Seattle, Washington, have examined the effects of pollutants, particularly PAHs, on benthic fish in Puget Sound for many years, allowing them to derive guidelines using their extensive data set. Here, we summarize some of their work. As described in Section 3.3.3, the liver is an important target for PAHs in some benthic fishes. The worst-case manifestation is cancer, but various biochemical and physiological effects precede the development of cancer, and many of these have been the focus of biomonitoring. Drawing on NOAA's data sets, Horness et al. (1998) developed "hockey stick" regressions to determine sediment thresholds for effects in benthic fish. The analysis focused on liver lesions in English sole in relation to TPAHs in sediments for approximately 30 sites in the Puget Sound comprising a wide gradient of PAH concentrations. Liver lesions evaluated were neoplasms, specific degenerative/necrotic lesions, such as megalocytic hepatosis and nuclear polymorphism, proliferative lesions, and foci of cellular alteration (FCA). Threshold concentrations are the sediment TPAH concentrations (based on dry weight of whole sediments) above which lesions are predicted to occur above background incidences. Threshold values ranged from 54 ng/g (ppb) for FCA to 2,800 ng/g for neoplasms. Values for other lesions ranged between 230 and 940 ppb.

The very low FCA value, however, was deemed insignificant because the confidence interval did not lie entirely within the data range, and it was suggested that FCAs may be a non-threshold response. Among the other thresholds, the most sensitive was 230 ppb, the threshold value for proliferative lesions.

Johnson et al. (2002) built on the hockey stick approach developed by Horness et al. (1998) to incorporate additional endpoints (DNA damage and endpoints associated with reproduction) and to explicitly calculate a sediment quality threshold for PAHs. Again, data for English sole provided the basis for their analysis, and they incorporated the results for liver lesions from the Horness et al. (1998) paper. Threshold values for three reproductive endpoints that were relatively sensitive (inhibition of spawning, infertile eggs, and abnormal larvae) were all calculated to be 630 ppb. The threshold value for DNA damage, measured as PAH-DNA adducts, was 288 ppb. Based on their overall analysis, Johnson et al. (2002) concluded that at sediment concentrations greater than 1,000 ppb, there is a substantial increase in the risk of liver disease and reproductive impairment, and suggested that 1,000 ppb be used as a SQG for TPAH in estuarine systems. This SQG is less than the TPAH criteria shown in Table 3.2, though it is close to the 1,684 ppb TPAH criterion for the Florida TEL and Environment Canada's ISQG. Based on the foregoing, a sediment effects concentration of 1 ppm total PAH appears to be a reasonable screening value for use in the evaluation of potential creosote applications. Chapter 4 discusses how this threshold and other toxicity information presented in this chapter can be used in tandem with leaching and mobility information from Chapter 2 to assess the risk to the environment of various creosote treatments and applications.

4. Risk Evaluation

Having established in previous chapters that significant amounts of PAHs (and other contaminants) can leach from creosote-treated wood under environmentally relevant conditions, resulting in toxicity to organisms exposed to nearby surface waters and sediments, this chapter discusses further the risk to aquatic biota, including NOAA trust resources, from the use of creosote-treated wood. Two alternative lines of evidence are available to evaluate potential impacts. Section 4.1 briefly presents the results of previous ecological risk assessments of treated wood products, and Section 4.2 uses the results of the leaching and environmental distribution models described in Chapter 2 in a separate risk evaluation. Section 4.3 discusses the results of empirical laboratory and field studies (including many of the studies discussed in Chapters 2 and 3) designed to evaluate potential biological and/or ecological effects. Section 4.4 discusses factors that should be considered for site-specific risk assessments.

4.1 Previous Risk Assessments

Sinnott (2000) developed a simulation model to evaluate ecological risks from creosote-treated wood. Using leaching rates from Ingram et al. (1982) and Hochman (1967), as cited by Kelso and Behr (1977), and degradation rates from the U.S. EPA (1979), the author estimated average daily concentrations of naphthalene, phenanthrene, and anthracene for the first month following immersion, and for the subsequent 11 months of immersion, in a 6-foot deep pond. Sinnott concluded that much of the leaching occurs shortly after immersion of treated wood in water, that the PAHs dissipate rapidly or are not present in high enough concentrations to cause harm, and that treated wood is not generally a toxicological problem in aquatic environments. The predicted sum of these compounds in the water column was below New York State water quality standards.

Brooks (1995) conducted an assessment of risks to T&E species in the Columbia River Basin from PAHs released from creosote-treated wood using a version of his leaching and environmental distribution model described in Chapter 2. The author compared predicted sediment PAH concentrations, given two pilings spaced 1 m apart, against then-current Washington State sediment quality criteria (total PAH of 1,330 in ppm TOC, or 25.3 ppm sediment dry weight, at 1.9% TOC), and made the following recommendations:

1. Creosote-treated wood products can be used without further risk assessment when:

    a. The RPD (a depth measure of the transition between oxic and anoxic sediment) is greater than or equal to 0.5 cm and current speeds are greater than 10.0 cm/sec.

b. The RPD is greater than or equal to 1.0 cm and the sum of the RPD in cm and the current speed exceeds 7.0 cm/sec.

2. An individual project risk assessment should be required when:

   a. The RPD is less than 0.5 cm deep or when current speeds are less than or equal to 2.0 cm/sec.
   b. A project uses more than four pilings installed in a line parallel to the currents at inter-piling distances less than 1 m.
   c. The sum of the RPD and the current speed is less than or equal to 5.0 cm/sec.
   d. A new project is located within 10 m of an existing creosote-treated wood project.

3. Creosote projects should not be constructed in areas where current speeds are less than or equal to 1.0 cm/sec without further assessment.

4.2 Risk Assessments Using PAH Leaching Models

Chapter 2 described several PAH leaching and environmental distribution models that have been developed to predict the environmental concentrations of PAHs that result from the use of treated wood. Since the models contain many variables, specific scenarios must be assumed to generate model predictions. Table 4.1 lists model predictions for the specific scenarios described in Chapter 2 where the model authors were comparing the results of their models to measured PAH concentrations in specific field settings. Table 4.1 also includes the results for a specific model run for a hypothetical single-piling scenario.

As shown in Table 4.1, in most of the scenarios modeled, the predicted sediment PAH concentrations are well above the 1.0 mg/kg total PAH threshold discussed in Chapter 3. The single exception is the model predictions of Brooks (1997) for the pilings of the Westham Island Bridge in British Columbia that are at least eight years old and are in an area of high tidal velocity. For the other scenarios, concentrations greater than 1.0 mg/kg are predicted for areas within several meters of the pilings. In the model for Belcarra Bay, British Columbia, Brooks (1997) predicts that the sediment concentration of 9 mg/kg at 1 m within the piling decreases to approximately 0 within 10 m of the piling.

In addition to the results shown in Table 4.1, the model of Poston et al. (1996) also predicts that concentrations of PAHs in the water column may be toxic around newly installed pilings of relatively high density (as described in Chapter 2). However, the Poston et al. (1996) model is a simplistic model that most likely overestimates PAH concentrations in the water column. On the other hand, they use toxic thresholds for many individual PAH compounds that are most likely too high, based on the review provided in Chapter 3.

Table 4.1. Environmental PAH concentrations predicted by PAH leaching and distribution models

Source	Scenario description	Environmental medium	Distance from piling/structure (m)	Predicted PAH concentrations mg/kg (dw)
Brooks, 1997	Belcarra Bay, British Columbia; > 1.5 year-old pilings	Sediment	1 3 5 10 20 40	9 5.5 3 0 0 0
Brooks, 1997	Westham Island Bridge, British Columbia; > 8 year old pilings; low salinity water; high tidal current	Sediment	0.5 2 5	0.6 0.2 0.1
Chapter 2 (using model of Brooks, 1997)	Single, 13-inch piling in seawater, 2.5 cm/s tidal current	Sediment	0.25 1	5.9 2.0
Goyette and Brooks, 1998, 2001	6-piling dolphins in Sooke Basin, British Columbia; unweathered	Sediment	0.5 2.0	24 19
	6-piling dolphins in Sooke Basin, British Columbia; weathered	Sediment	0.5 2.0	24 6

In conclusion, these results indicate that the available models on PAH leaching and environmental distribution predict that PAHs that leach from treated wood are present at concentrations that are predicted to be toxic to aquatic biota under realistic environmental scenarios. The models predict that these affects will be relatively localized around pilings (within approximately 5 m, depending on the specific conditions).

The predictive models applied here and described in Chapter 2 appear to capture the available laboratory data on PAH leaching reasonably well under certain conditions. However, for a variety of reasons discussed in Chapter 2, there is uncertainty in applying the results of laboratory study-based leaching models to field conditions. Depending on the specific field application, the laboratory-based leaching models appear to be more likely to under-predict than over-predict leaching under field conditions, at least for the initial leaching period that occurs within the first hours and days after construction. Furthermore, there is much uncertainty in modeling actual environmental concentrations from the leaching study models, as also described in Chapter 2. Therefore, the results of the predictive risk assessment models should be interpreted carefully, as they may have substantial (and unquantified) uncertainty. Finally, by their nature, models use simplifying assumptions that may miss uncommon but important

conditions that result in temporary or localized concentration spikes that could affect marine organisms.

4.3 Laboratory and Field Studies

Several laboratory and observational field studies have been performed to evaluate the potential impacts of creosote-treated wood products on aquatic biota. These studies allow for a direct assessment of the potential adverse effects and ecological risk associated with use of creosote-treated wood in aquatic habitats.

This section evaluates the potential impacts of creosote leaching first by looking at three highly relevant areas of research: (1) large-scale studies showing creosote leaching from sites where dozens or hundreds of pilings are clustered together, specifically the Charlestown Navy Pier in Boston, Massachusetts, and the Naval Station San Diego (NAVSTA) in San Diego Bay, California; (2) creosote leaching studies performed under the auspices of Dr. Kenneth Brooks, including a study of creosote leaching effects in the Fraser River Estuary in British Columbia and several subsequent studies; and (3) laboratory studies of creosote leaching in aquatic microcosms by University of Guelph researchers. We then provide reviews of several other field and laboratory studies that provide ancillary evidence of creosote leaching in the environment.

4.3.1 Large-scale studies: Charlestown Navy Pier and Naval Station San Diego

In 1987, the National Park Service (NPS) replaced about 90 creosote piles at Pier #2 of the Charlestown Navy Yard in Boston (Graham and Johnsen, 2002). The NPS rejected many of the piles because of insufficient retention. The re-treated piles were then over-impregnated to an average retention that was 25% higher than BMPs specified. The result was a noticeable slick of creosote from the new pilings after installation (Graham and Johnsen, 2002).

Costa and Wade (1989) collected samples and provided analyses of the Pier #2 creosote leachate, including chromatography analyses and sea urchin toxicity tests. The chromatography analyses showed that the surface sheen emanating from the pier was unquestionably creosote, as the peaks in the slick matched the peaks in creosote for all major PAHs except the lightest, most volatile ones. Dissolved PAH concentrations were high in the surface sheen and relatively high in water directly above the sediment, but dissolved PAHs were undetectable in samples from within the water column below the surface slick. Target PAH concentrations in the water near the sediment were 0.87 to 1.7 µg/L, about 8-14 times higher than the concentrations at a control site near a different pier. The PAH concentration of the surface slick was up to 5,350 µg/L – the authors stated that “it can be presumed that the surface slick is toxic to organisms residing in the surface layer” (Costa and Wade, 1989).

The concentrations of the target creosote PAHs in sediment near Pier #2 pilings were 250 times greater than the concentrations at a control site, with total target PAH concentrations as high as 6,390 µg/g dry weight. The samples were described as having a strong creosote odor (Costa and Wade, 1989). Surface sediment PAH concentrations decreased rapidly with distance from the pilings, reaching background concentrations between 6 and 21 feet from the creosote pilings.

Costa and Wade (1989) collected the leachate in the surface slick and attempted to fertilize sea urchin eggs in the presence of the leachate. Over 50% of the eggs failed to fertilize in all tests in which the test water contained at least 1% leachate. The authors calculated the LOEC at 0.38% leachate, or 20 µg/L PAH, and the NOEC at 0.19% leachate. Their results show that at 0.09% leachate (4.8 µg/L PAH), the most dilute test they performed, 21% of the eggs failed to fertilize, compared to 0.3-0.7% failure using control water. The difference was not statistically significant.

In summary, the approximately 90 new pilings at the Charlestown Navy Pier exuded a surface slick with PAH concentrations of 5,350 µg/L, several orders of magnitude greater than concentrations predicted to impact sea urchin reproductive success. Samples of the slick caused significant toxicity to sea urchins in a reproductive endpoint test at mixtures of 0.38% slick. PAH concentrations in water near the sediment interface were up to 1.7 µg/L, and were not detected in the water column between the sediment and water surface. The sediment near the pilings contained PAH concentrations 250 times greater than the concentrations at a nearby control site (Costa and Wade, 1989).

At NAVSTA in San Diego Harbor, the U.S. Navy made important operational changes in the 1990s in an effort to reduce PAH contamination in San Diego Bay. Specifically, the Navy stopped discharging bilge water directly to the bay, and they made a concerted effort to replace all creosote pilings at the base. In 1997, Katz (1998) examined the changes in dissolved PAH concentrations in the bay after approximately 50% of the creosote pilings had been replaced with plastic, concrete, or untreated pilings.

Katz (1998) compared historical surface water PAH concentrations from 1990 to 1994 with concentrations measured in the summer and fall of 1997. In all studies from both time periods, PAH concentrations were higher near the Navy piers than in other areas within San Diego Bay. In the early 1990s, the two sample sites adjacent to the piers contained average total PAH concentrations of 1.2 and 1.7 µg/L, including a sample at one site that exceeded 8 µg/L in a surface slick. The average total PAH concentration from 36 samples collected near NAVSTA piers from 1990 to 1994 was 1.1 µg/L, compared to an average of 0.16 µg/L for the 65 samples collected away from the piers. In 1997, after 50% of the pilings were replaced with non-creosote alternatives, the total PAH concentrations in the surface water near the pilings were an order of magnitude lower than the average concentrations between 1990 and 1994, with concentrations between 0.1 and 0.2 µg/L (Katz, 1998). Total average PAH concentrations decreased to 0.12 µg/L at NAVSTA and 0.06 µg/L at non-NAVSTA sites in 1997. Chromatograms of the

water samples showed PAHs that matched the pattern for creosote from samples at the Navy pier (Katz, 1998). Unfortunately, this study did not include analyses of sediments or biota in the bay. However, the study does suggest that creosote pilings at NAVSTA were at least partly responsible for elevated PAH concentrations in the surface water of San Diego Bay, and that the program to replace those pilings led to measurable decreases in dissolved PAH concentrations in the Bay.

4.3.2 Fraser River estuary and related studies

In 1994, EVS Consultants (1994) conducted a creosote evaluation project for the Fraser River Estuary Management Program in British Columbia. They examined sediment PAH concentrations and conducted toxicity tests on amphipods and bacteria near creosote piling installations at Belcarra Bay and at Westham Island in the Fraser River estuary. The pilings at the Belcarra Bay wharf ranged from 2 to 20 years old, and the pilings closest to the Westham Island study site were 8 years old. At Belcarra Bay, sediment PAH concentrations within 10 m of the pilings were significantly higher than reference concentrations, and the survival of amphipods and bacteria exposed to the sediment in laboratory toxicity tests was significantly diminished. Total sediment PAHs were as high as 19.7 µg/g, about 10 times higher than reference concentrations. By contrast, at Westham Island, total sediment PAH did not exceed 0.5 µg/g and was not significantly different than background concentrations. Amphipod survival was similar in sediment collected from the Westham Island site and the control site. EVS Consultants (1994) attributed the different results at Westham Island compared to Belcarra Bay to a higher water flow rate at Westham Island that carried leached creosote away from the site. Furthermore, the newest pilings at the Westham Island site were over 8 years old, compared to the 2 year old pilings at the Belcarra Bay site.

The EVS study in the Fraser River estuary led to a Phase II study (Goyette and Brooks, 1998, 2001) in the Sooke River Basin on Vancouver Island, examining more closely the possible impacts of creosote leaching. Sooke Basin conditions were similar to Belcarra Bay in the Fraser River estuary but with less background PAH contamination. The Sooke Basin site was away from intense human activity, with weak tidal currents (1.89 cm/s) and no freshwater runoff input. The study consisted of three tests using 6-piling dolphins, one containing a dolphin with newly treated pilings, one with 8 year old weathered pilings, and one with untreated pilings. As at Belcarra Bay, sediment PAH concentrations near the creosote-impregnated test dolphins in Sooke Basin were elevated compared to background. Table 4.2 shows the sediment PAH concentrations near the weathered piling dolphins. Figure 4.1 shows sediment PAH concentrations near the newly treated dolphins, including the changes in PAH concentration with time (Figure 4.1a) and the changes in PAH concentration with distance from the pilings (Figure 4.1b). It should be noted that surficial samples in this study were collected as the top 2.0

Table 4.2. Summary of sediment PAH concentrations near dolphins containing six weathered creosote pilings in the Sooke Basin, British Columbia. (+) is downstream, (-) is upstream of the pilings. Concentrations immediately before installation are listed as 0 days since installation. PAH concentrations in µg/g.

Distance from pilings (m)	Days since installation	Mean % TOC	Mean LPAH	Mean HPAH	Mean TPAH
0	0	0.9	0.03	0.1	0.13
0.5	0	1	0.04	0.16	0.19
0	384	0.7	5	42.3	47.4
+0.5	14	1.3	34	71	105
+0.5	180	0.9	2.9	11.2	14.1
+0.5	180	1.3	6.2	11.6	17.8
+0.5	384	0.7	1.3	9.5	10.8
+0.5	384	0.6	4.6	29.2	33.8
+2.0	14	1.3	0.8	2.1	2.9
+2.0	180	1.3	0.9	3.9	4.8
+2.0	384	0.6	0.8	5.6	6.3
+2.0	384	0.9	3	12.2	15.3
-2.0	14	1.2	0.6	0.7	1.3
-2.0	180	1.1	0.4	1.1	1.5
-2.0	384	0.7	0.5	3.8	4.3
+5.0	384	0.6	0.3	2	2.3
+10.0	384	1.2	0.1	0.8	0.9

Source: Goyette and Brooks, 1998; Appendix VI(B).

to 2.5 cm, and therefore evaluation of the accumulation of creosote in the surficial sediments at a scale finer than the top 2.0 to 2.5 cm is not possible. Nevertheless, the results of the study document that increased creosote accumulation in sediment was observed downstream of the pilings.

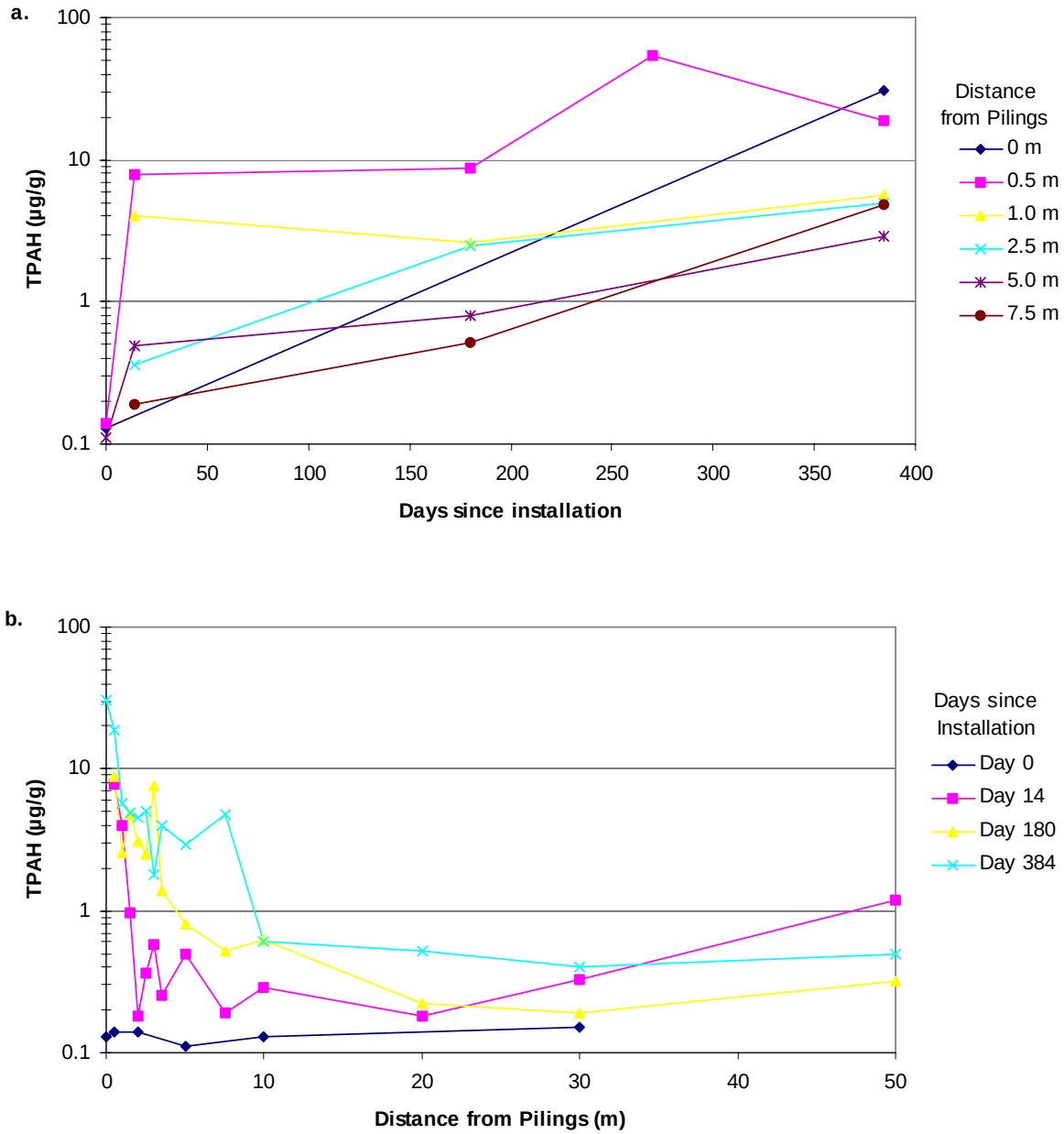

Figure 4.1. Sediment total PAH concentrations downstream (downcurrent) of newly treated pilings in the Sooke Basin study, as they varied with (a) time and (b) distance from the pilings. Note the logarithmic scale for TPAH.

Source: Goyette and Brooks, 1998.

The data in Table 4.2 and Figure 4.1 clearly show increases in sediment PAH concentrations within two weeks after installation, with elevated PAH concentrations remaining over a year after installation and extending up to 50 m from the pilings. The following summarizes the conclusions of Goyette and Brooks (1998) after one year of data from the Sooke Basin study:

- Two weeks after installation of the weathered piling dolphin, the sediment PAH concentration 0.5 m downstream of the pilings (where downstream is the dominant direction of current flow) was over 100 µg/g dry weight, nearly three orders of magnitude greater than the concentration before installation (Table 4.2). The authors suggest that physical abrasion of the treated wood surface during installation may have caused an initial release of creosote.

- Surface sediment PAH concentrations were statistically significantly higher than baseline concentrations to a distance of 7.5 m from the newly treated pilings. Smaller PAH increases occurred at a distance of 50 m (Figure 4.1b).

- The proportion of HPAH to LPAH in the sediment increased notably between Day 14 and Day 384 (Table 4.2), suggesting the preferential loss of the LPAH through solubilization.

- The surface sediment PAH concentrations were highly variable, with poor correlation amongst replicate samples in some cases.

- No significant changes in benthic community structure were observed.

- Toxicity tests on mussels (*Mytilus edulis*) showed slightly elevated PAH body burden and slightly less growth in the presence of sediments contaminated with PAHs leached from the pilings. There were no adverse effects to mussel survival or viability.

In 2001, Goyette and Brooks (2001) published an addendum to the Sooke Basin study, showing results four years after the installation of the dolphins. This study showed a significant decline in PAH concentrations between Year 1 (384 days) and Year 4. An active invertebrate community had become established, with the pilings serving as an artificial reef. Mussels living on pilings contained PAH concentrations less than background concentrations. The limiting factor on biota was reported to be low oxygen and high sulfur due to the accumulation of detritus near the pilings.

Dr. Brooks, who was part of the steering committee for the Fraser River Estuary study and was co-author of the Sooke Basin study, published several more reports examining creosote leaching into the environment. They include a study showing the leaching of PAHs from bridge timbers into an aquatic environment (Brooks, 2000) for the USDA Forest Service (USFS), a study of PAH leaching from creosote timbers in Puget Sound (Brooks, 2003) for the Creosote Council, an

industry group, and a study examining PAH leaching from railroad timbers into wetlands (Brooks, 2004b) for the USFS. His results and conclusions for each of these studies are similar to the results and conclusions from Belcarra Bay (EVS Consultants, 1994), and the Sooke Basin study (Goyette and Brooks, 1998, 2001). Brief summaries of these studies are provided below.

Brooks examined sediment PAH concentrations in Pipe Creek, Indiana, immediately downstream of two bridges built with creosote timbers (Brooks, 2000). At the time of the study, one bridge was 2 years old and one was 17 years old. The results of the study showed the following:

- Sediment PAH concentrations at the older bridge increased from undetectable (< 0.11 µg/g) upstream of the bridge to a maximum of 2.3 µg/g 1.8 m downstream of the bridge. Beyond 1.8 m, PAH concentrations generally decreased with distance downstream of the bridge, though were still detectable (0.5 µg/g) at 10 m, the most downstream location.

- Sediment PAH concentrations at the newer bridge increased from undetectable (< 0.23 µg/g) upstream of the bridge to a maximum of 5.5 µg/g 1.8 m downstream of the bridge. PAHs were still detectable (0.5 µg/g) at 6 m downstream, and were undetectable at 22.8 m downstream.

- The highest PAH concentrations downstream of the newer bridge exceeded toxicity threshold effect levels, whereas none of the concentrations downstream of the older bridge did.

- Despite the toxicity threshold exceedences, the biological data that was collected did not reveal adverse effects on biota from PAHs at either the newer bridge site or the older bridge site (Brooks, 2000).

Brooks (2003) conducted a comprehensive study of sediment PAH concentrations and the effects on biota at several locations in Puget Sound, Washington State, in a manner similar to the Sooke Basin study. This study included wharfs with dozens of creosote-impregnated piers and sites with dolphins similar to Sooke Basin. The results, summarized below, are similar to the results of his previous studies.

- At a long wharf at Fort Worden, total PAH concentrations in sediment were 16 µg/g closest to the pier, 11 µg/g at 2.5 m distance, and 5.4 µg/g at 7.5 m distance. Background concentrations were 0.5 µg/g or less. Within 2 m of the densest cluster of pilings, sediment PAH concentrations were as high as 34 µg/g, compared to 0.07 µg/g at background sites, though some of the PAHs at 2 m were specific HPAHs that are more

characteristic of heavy oil than they are of creosote. Samples from between 0.5 and 2 m from the pilings exceeded the Washington State SQGs for PAHs.

- Near a three-piling dolphin at Fort Ward, the sediment PAH concentration was 11.7 µg/g within 0.5 m of the dolphin and decreased to 0.7 µg/g at 2 m. Background samples contained elevated PAHs at this site.

- Sediment PAH concentrations from around a single piling at Fort Ward and around a three-piling dolphin at Port Townsend's city pier were not significantly higher than at reference sites. However, the reference sites themselves contained PAHs in the sediment (1.9 to 7.6 µg/g).

- At Fort Worden, weak negative correlations were found between the abundance of some invertebrate species and PAH concentrations. Weak positive correlations were also found, particularly between nematodes and PAHs, most likely because nematodes tend to populate the organic-rich sediment found at the base of the pilings. The author states that the effects of biodeposits from the abundant epifaunal community that populates the pilings has a much larger effect on the overall benthic community than do the PAHs that leach from the pilings and accumulate in the sediment.

The most recent study from Dr. Brooks (Brooks, 2004b) examined creosote leaching from railroad ties in wetland areas, with an examination of both PAHs migrating to the railroad bed ballast and PAHs migrating into the wetland. The results of this study showed very little PAH contamination in the wetland. In the second year of the study, PAH concentrations increased by an average of 0.3 µg/g, which was not statistically significant. In 16 wetland sampling events over two years, PAHs were only detected once, and the concentrations were well below toxicity thresholds.

4.3.3 University of Guelph microcosm studies

Researchers at the University of Guelph in Ontario conducted laboratory (microcosm) studies of the distribution of contaminants within the microcosm when exposed to creosote. These include a study where liquid creosote was added directly to the water (Bestari et al., 1998a, 1998b; Sibley et al., 2001b), and another study where recently treated Douglas fir pilings were added to the microcosm (Bestari et al., 1998a; Sibley et al., 2004).

Bestari et al. (1998b) applied 14 different doses of liquid creosote to an aquatic microcosm in a 12,000 L tank, then over the course of several weeks measured the concentration of 15 priority PAHs in water, sediment, and on polyvinyl chloride (PVC) strips within the sediment. In a concurrent study (Bestari et al., 1998a), they applied 6 different doses of creosote to similar microcosms, but rather than apply creosote directly, they used recently impregnated Douglas fir

pilings where the creosote leached from the pilings. The results of each study were similar and are summarized below.

- PAH concentrations in water were dose-dependent. In the timber study, the dissolved PAH concentration ranged from 7.3 µg/L with one-half of a piling in the microcosm up to 97.2 µg/L with six pilings in the microcosm.

- PAH concentrations in water decreased exponentially with time after initial dosage. The PAH concentration after the highest liquid creosote dosage decreased from 5,800 µg/L on Day 2 to 13.9 µg/L on Day 84. The 6-timber treatment decreased from the maximum of 97.2 µg/L at Day 7 to 6.7 µg/L at Day 84.

- When liquid creosote was applied at concentrations exceeding 590 µg/L, sediment PAH concentrations increased until Day 28, then decreased thereafter in all but the highest dose. The increase in sediment PAHs was dose-dependent. In contrast, in the piling treatment study there was no increase in sediment PAHs at any of the treatment levels at any time during the study or at any distance from the pilings, though none of the water concentrations approached 590 µg/L in that study. The authors suggested that in the piling treatments the HPAHs adsorbed to the PVC liners, and LPAHs were lost to volatilization and possibly to biodegradation in sediment occurring in equilibrium with the PAH removal rate.

Sibley et al. (2001b, 2004) report the effects of these creosote treatments on phytoplankton and zooplankton communities. The responses were similar for both liquid creosote application and creosote leaching from pilings. Zooplankton abundance decreased after the introduction of creosote in a dose-dependent manner, just as the aqueous PAH concentrations increased in a dose-dependent manner. At concentrations greater than 1,100 µg/L, which were found only in the liquid creosote study, zooplankton species composition changed significantly, perhaps due to a drop in rotifer density (Sibley et al., 2001b). For liquid creosote, the estimated NOEC for the zooplankton community was 13.9 µg/L total PAHs after five days and 5.6 µg/L total PAHs after seven days (Sibley et al., 2001b). For leached creosote, the NOEC was 11.1 µg/L total PAHs (Sibley et al., 2004).

By contrast, the phytoplankton abundance and diversity increased in all treatments in both studies, with phytoplankton abundance increasing to up to twice that in the control microcosms (Sibley et al., 2001b, 2004). The authors attribute this to decreased zooplankton grazing pressure and possibly to growth stimulation from compounds in the creosote. Based on these data, the authors conclude that creosote leaching from pilings may cause short-term toxicity to limnetic or benthic communities shortly after deployment, but that long-term effects are unlikely as PAH concentrations decrease exponentially with time (Sibley et al., 2004).

4.3.4 Other studies

Over the past 30 years, many studies have examined the leaching of creosote from impregnated timbers and the resultant environmental concentrations of PAHs near creosote timbers. Short summaries of some of these studies are included below (some are also discussed in Chapter 2, as relevant to leaching).

- Zitko (1975) found elevated PAH concentrations in mussels, clams, periwinkles, and whelks near a wharf in New Brunswick, Canada. Zitko states that creosote-treated wharf timbers are the only source of PAHs to the bay.

- Dunn and Stich (1976) reported benzo(a)pyrene concentrations three to four times higher in mussels growing on creosote timbers than on nearby rocks and concrete in Vancouver Harbor, British Columbia.

- Ingram et al. (1982) conducted studies of creosote leaching from treated pilings in laboratory tanks, using many different treatments. Dissolved PAH concentrations increased for all 15 PAHs they studied, in both fresh and saltwater. Six compounds (naphthalene, phenanthrene, acenaphthene, dibenzofuran, fluorene, and 2-methylnaphthalene), which comprised 70-80% of their test creosote, were the dominant contaminants in the water. Higher concentrations of leached PAHs were found in freshwater treatments than in saltwater treatments, and higher concentrations emanated from newly treated timbers than from aged timbers. Maximum PAH concentrations occurred within 48 hours of treatment, then concentrations decreased for the remainder of the study.

- Harrington and Crane (1994) found slightly elevated PAH concentrations in clams at and just downstream of a ferry dock in the Sacramento River delta. PAHs were not detectable in surface water or in clams upstream of the dock. PAHs were as high as 0.45 mg/kg in clams on the dock, and 0.20 mg/kg in clams downstream of the dock. The authors concluded that these concentrations were insufficient to cause an adverse effect to the clams.

- Wendt et al. (1996) found slightly elevated PAH concentrations in sediment and oysters growing near creosote-impregnated dock pilings in South Carolina compared with control sites. Oyster growth was somewhat less near the pilings compared to control sites. None of the differences were statistically significant.

- Graham and Johnsen (2002) describe a surface slick from a dock in Poughkeepsie, New York, that required the dock owners to deploy a boom to contain the spill. Creosote-impregnated pilings at the dock were given as the cause of the slick. No specific data were given.

4.3.5 Conclusions

Overall, the laboratory and field studies described above indicate that treated wood structures can leach PAHs and other toxic compounds into the environment. However, the degree of PAH accumulation to sediment associated with these structures appears to be relatively minor in many settings, particularly in well-circulated waters and over time. PAH accumulation also appears to be relatively limited spatially (within approximately 10 m of the structure) and has not generally been associated with measured, significant, biological effects except in close proximity to the structures. The duration of any biological effects also appears to become attenuated within several months of construction (the time period when leaching rates are likely to be highest).

Nevertheless, there are several factors that suggest that a precautionary principle might be applicable to certain treated wood uses. First, the above studies typically have evaluated responses at the community level (e.g., the benthic invertebrate studies) or to tolerant life stages (e.g., adult oysters and mussels). However, the level of environmental protectiveness applied to T&E species (such as endangered salmonids) should occur at the *individual* rather than the *population* or *community* level. Moreover, field studies have indicated that PAHs can accumulate to potentially deleterious concentrations in poorly circulated water bodies or when the density of treated wood structures is high compared to the overall surface area of the water body. As a result, site-specific evaluations of risk should be conducted for treated wood projects that are proposed for areas containing sensitive life stages, species of special concern, or where water circulation and dilution are potentially low. We discuss considerations associated with such site-specific risk assessments below.

4.4 Factors to be Considered in Aquatic Risk Assessments

The analyses presented in this report demonstrate that PAHs that leach from creosote-treated wood have the potential to accumulate in abiotic media and aquatic biota and to cause toxicity to biota. However, the risk of adverse toxicological effects may be limited in spatial scale and time in many environmental settings and treated wood uses, and vary dramatically depending on case-specific factors such as the nature of the wood and its treatment, environmental conditions, and species of concern. Therefore, in certain settings, site-specific risk assessments should be performed to ensure that projects avoid unnecessary risks to sensitive species or species of

special concern. Conditions that should prompt consideration of a site-specific risk assessment include:

- Low current velocities (e.g., current speeds < 1 cm/sec) and/or relatively little expected mixing coupled with a relatively high density of construction materials
- The presence of sensitive life stages (typically larvae and juveniles) of aquatic organisms, particularly T&E or special status species, in the project location.

When conducting such site-specific risk assessments, Hutton and Samis (2000) identify the following factors that should be considered:

- **Background water quality variables such as salinity**

  The salinity of the receiving environment should be considered because leaching increases with decreasing salinity, as in estuarine environments.

- **Current velocity and direction**

  Although total leaching rates from treated wood can be relatively low, potential environmental effects will be dictated by local water mixing, with poorly mixed waters at greater risk. Information on current velocities – at the specific micro-environment – of the project location (including the influence of the structure itself on ambient current velocities) should be developed and integrated into a site-specific risk evaluation.

- **Proximity to sensitive fish habitat**

  The presence of sensitive life stages, especially T&E species or their essential prey species, should prompt an evaluation of potential risks at that location. Essential fish habitats for Pacific salmon include all streams, lakes, and other water bodies currently or historically accessible to salmon. This includes essentially all estuarine and marine waters of the Pacific Coast. The most sensitive life stages for these species are fry (particularly post swim-up) and juveniles. Because the initial leach rates are higher for treated wood, risk assessments should consider the timing of PAH releases relative to periods when sensitive life stages of fish are present.

- **Timing of proposed construction**

  Because initial leach rates tend to be greater, the timing of proposed construction should be considered with respect to the presence of sensitive life stages of aquatic receptors, water flow rates and temperature, environmental and climatic factors that can influence

mixing and dilution, and the relationship between season, annual hydrograph, and water quality conditions.

- **Size of proposed structure**

  As discussed previously, environmental effects are likely to be greatest when the size of the proposed structure is large relative to the receiving environment. Factors to consider include number and size of pilings, surface area of exposed wood area relative to a mixing zone, density of pilings relative to the mixing zone (to evaluate potential behavioral avoidance responses), and potential effects of structure size on current flows.

- **Application methods**

  Treatment and application methods should be confirmed to meet industry BMPs.

- **Proximity of other treated-wood structures and other sources of contamination that may contribute to cumulative effects**

  In evaluations of site-specific risks, assessments should consider potential effects in light of the cumulative effect of the proposed structure relative to other existing environmental perturbations at the site.

In addition, the Los Angeles District of the U.S. Army Corps of Engineers uses standard permit conditions that apply to creosote-treated pilings placed in navigable waters of the United States. The standard conditions include the following (personal communication, D.J. Castanon, U.S. Army Corps of Engineers, Los Angeles District, November 30, 2004).

- Creosote-treated pilings shall not be placed in navigable waters or waters of the United States unless all of the following conditions are met:
  - The project involves the repair of existing structures that were originally constructed using wood products.
  - The creosote-treated pilings are wrapped in plastic.
  - The use of plastic-wrapped creosote pilings is restricted to marine waters.
  - Measures are taken to prevent damage to plastic wrapping from boat use. Such measures may include installation of rub strips or bumpers.
  - The plastic wrapping is sealed at all joints to prevent leakage.

- The plastic material is expected to maintain its integrity for at least 10 years, and plastic wrappings that develop holes or leaks are repaired or replaced in a timely manner.

These conditions were developed by the Army Corps of Engineers in coordination with the California Department of Fish and Game and NOAA. Furthermore, as presented in Chapter 1, other agencies with jurisdiction over marine waters have begun replacing and restricting the use of creosote-treated wood, including: Washington State Ferries; the Port of Port Angeles, Washington; the Oregon Department of Environmental Quality, State Marine Board; the CCC; the Delaware Department of Natural Resource and Environmental Control; the New York State Legislature; and the Rhode Island Coastal Resources Management Program.

Theses various initiatives, restrictions, and standard permit conditions show that regulatory agencies are increasingly recognizing that creosote treatments in marine environments can cause ecological harm under common enough circumstances that new structures should avoid the use of creosote-treated wood, and creosote should be isolated from the environment wherever it is used. Based on the findings of this report that creosote moves into the environment under a variety of realistic conditions, and environmental levels of contaminants originating from creosote-treated wood are often toxic, precautions to avoid creosote-treated wood where practical, and measures to isolate potential toxic effects appear to be justified. We recommend that similar precautions be implemented by regulating agencies throughout the United States.

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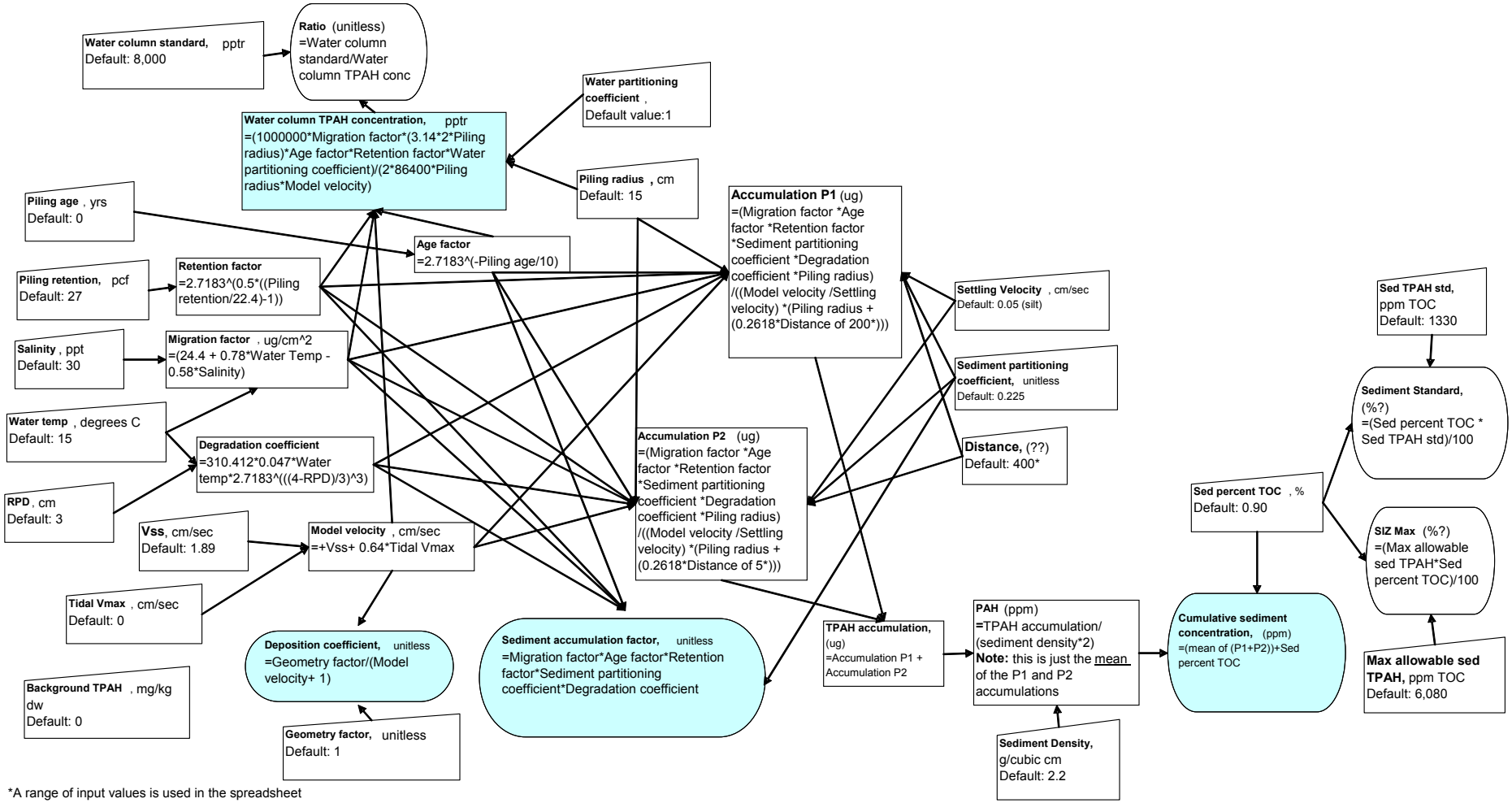
Appendix: CREOSS Model, Dr. K. Brooks



*A range of input values is used in the spreadsheet
Units in parentheses are assumed (not explicit)

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