ASSESSMENT OF THE ENVIRONMENTAL RISKS ASSOCIATED WITH THE USE OF TREATED WOOD IN LOTIC SYSTEMS

Kenneth M. Brooks
Aquatic Environmental Sciences, 644 Old Eaglemount Road
Port Townsend, WA 98368

Summary

Several salmon stocks in the Columbia River system have been identified as threatened or endangered under the United States Endangered Species Act. In response, the National Marine Fisheries Service is concerned that the use of treated wood in the Columbia River may pose a threat to these threatened or endangered stocks. The United States Army Corps of Engineers (COE) uses treated wood to construct pile dikes in an effort to minimize dredging. In addition, numerous municipalities, residences and marinas rely on treated wood for a variety of structures. In 1995, the COE initiated a biological assessment (BA) to examine the use of treated wood and to define, in generic terms, those projects which will have no effect, are not likely to effect and those that are likely to effect migrating salmon. The information provided in this paper summarizes industries response to that request. While specific to the Columbia River, the model and recommendations are applicable to all flowing water.

Salmon have been shown to avoid copper concentrations exceeding 4.4 $\mu g\text{-}L^{-1}$ and chemoreception is effected by long term exposure to copper levels greater than 5.0 $\mu g\text{-}L^{-1}$. Acute, including reproductive, effects are observed only at copper concentrations exceeding 17.4 $\mu g\text{-}L^{-1}$. Washington State water quality criteria are shown to be sufficient to protect threatened and endangered species except that a lower copper standard (5.0 $\mu g\text{-}L^{-1}$) should be imposed during periods of active salmon migration.

A computer model designed specifically for flowing water is developed to predict both water column and sediment concentrations of polycyclic aromatic hydrocarbons (PAH) and copper associated with treated wood structures. Recommendations are based on the amount of treated wood proposed for the structure, water flow rates, and the oxygen tension in adjacent sediments. The results suggest that CCA treated piling can always be used safely in flowing water. Piling treated with ACZA can be safely used under all circumstances except where current flows are very slow (<0.3 $cm\text{-}sec^{-1}$). Bulkhead construction using CCA and ACZA treated lumber requires higher water flows to meet water quality criteria. However, even large leaching surface projects can be managed in a way that does not pose a risk to migrating salmon.
Creosote treated wood used in moderate currents over bottoms where the Redox Potential Discontinuity (RPD) is greater than 2.0 cm can have no effect on the food chain. However, where sediments lack sufficient oxygen and currents are slower than seven $cm\text{-}sec^{-1}$, creosote is likely to effect benthic organisms important to the food chain.

1. Introduction

Salmon stocks on the west coast of North America have been placed in jeopardy due to loss of habitat, construction of hydroelectric dams which restrict migratory patterns and over harvesting. Several stocks in the Columbia River system have been identified as Threatened or Endangered. In response, the National Marine Fisheries Service is concerned that the use of treated wood in the Columbia River may pose a threat to these threatened or endangered stocks. The United States Corps of Engineers (COE) uses treated wood to construct pile dikes in an effort to minimize dredging. In addition, numerous municipalities, residences and marinas rely on treated wood to construct a variety of structures. In 1995, the COE initiated a biological assessment (BA) to examine the use of treated wood and to define, in generic terms, those projects which will have no effect, are not likely to effect and those that are likely to effect migrating salmon. The information provided in this paper is in response to that request. The recommendations are under consideration at this time and no decision has been made.

This paper is specific to the Columbia River and other flowing waters. It includes recommendations for minimum environmental parameters to protect sensitive aquatic species. Brooks (1995a, 1995b, 1995c) has produced a series of treated wood risk assessments supported by Microsoft™ EXCEL spreadsheet models. Dilution factors in these models were optimized for marine environments where harmonically driven tidal currents interact with steady state currents. In this paper, the models are modified to optimize their predictive capability in lotic systems with reasonably constant, unidirectional flow. In addition, this paper includes a discussion of metal and PAH stress in anadromous salmonids. The reader should refer to Brooks (1995a, 1995b, 1995c) for a more general and detailed account of the underlying analysis.

The following model is conservative from the environments point of view. Laminar flows with no turbulent mixing are assumed and water column concentrations are predicted in the near field - within a few centimeters of the piling. The model assumes that PAH and copper are adsorbed to relatively large and dense particles (silt) which is deposited in close proximity to the piling or bulkhead. In reality, adsorption will be to a spectrum of particle sizes including clays and particulate organic matter with much slower settling rates. This will result in lower than predicted sediment concentrations.

Background levels of copper and PAH in the Columbia River. The current analysis integrates background levels of copper observed by Johnson and Hopkins (1991) in Columbia River water. The data in Table 1 is extracted from their report. Little information was obtained regarding Polycyclic Aromatic Hydrocarbon (PAH) levels in Columbia River sediments. Pastorok *et al.* (1994) found 22 $\mu g\text{-}g^{-1}$ (organic carbon) total PAH at reference sites on the Willamette River near its confluence with the Columbia River. Total Organic Carbon (TOC) represented 1.9% of these sediments. Therefore the reference area PAH concentration was less than 0.418 μg-g^{-1} (dry sediment weight). Sediments at the site were 65% sand and 28% silt, characteristic of low flow areas.

The current analysis assumes that total PAH levels at project sites will be 0.5 μg-g^{-1} (dry sediment weight) and TOC will be assumed to be 1.9%. The Puget Sound Protocols (PSEP, 1986) stipulate that the upper two centimeters of sediment are to be retained for chemical analysis. Therefore, when PAH concentrations are discussed in this report, they are assumed to be based on the concentration in the upper 2 cm of the sediment column.

Toxicity of copper to aquatic fauna and flora with emphasis on salmonids. Brooks (1995b and 1995c) has reviewed available copper toxicity data. Dissolved copper levels as low as 6.1 μg-L^{-1} have been associated with acute toxicity in the most sensitive marine organisms. The sperm of salmon are effected at 44.2 μg-L^{-1} dissolved copper. Coho salmon smolts have an EC_{50} of 601 μg-L^{-1} copper.

Copper can have more subtle effects on fish. Gardner and LaRoche (1973) reported olfactory damage in mummichogs (*Fundulus heteroclitus*), following even brief encounters (6 hours) with elevated copper levels. Giattina, *et al.* (1982) reported copper avoidance in rainbow trout (*Oncorhynchus mykis*) at levels of 4.4 - 6.4 μg-L^{-1} in soft water (28 μg-g^{-1} as $CaCO_3$). However, these same trout were apparently attracted to higher copper levels (334 to 386 μg-L^{-1}). These studies suggest that coho salmon and rainbow trout (two species in the genus *Oncorhynchus*) will avoid areas with copper levels elevated above 4.4 μg-L^{-1} and therefore avoid the stress associated with low levels of copper exposure.

Drummond, *et al.* (1973) observed changes in the feeding behavior of brook trout (*Salvelinus fontinalis*) when exposed to low levels of copper. Feeding was reduced for 24 hours in a constant exposure to 6 μg-L^{-1} copper and for 14 days at 12 μg-L^{-1}. These effects appeared to be transient and McKim and Benoit (1971) reported that normal feeding behavior was resumed within two weeks during a continuous exposure to 9 μg-L^{-1} copper.

Lorz and McPherson (1976) exposed ten to eighteen month old coho salmon (*Oncorhynchus kisutch*) to varying levels of copper and then released them into a tributary and observed migratory behavior. Exposure to 5 μg-L^{-1} copper for 165 days resulted in a 30% reduction in downstream migration. Short term (one to three day) exposure to low levels (<8 μg-L^{-1} copper) were not investigated. It appears that copper levels above 5 μg-L^{-1} should be avoided during periods of active salmonid migration. However, based on the work of Giattina, *et al.* (1982), salmonids would be expected to avoid localized areas with copper concentrations exceeding 4.4 μg-L^{-1}.

Sorensen (1991) reviewed the reproductive effects of copper in fish. McKim and Benoit (1971), Gardner and LaRoche (1973) and Scudder *et al.* (1988) detected a positive copper dose-response effecting hatching time and success in several species of fish. Hazel and Meith (1970) report that copper levels exceeding 100 μg-L^{-1} will kill king salmon

(*Oncorhynchus tshawytscha*) eggs. However, no mortality was observed at 8 $\mu g\text{-}L^{-1}$ copper. Scudder, *et al.* (1988) report 17% premature hatching in brook trout eggs incubated at 32.5 $\mu g\text{-}L^{-1}$ copper. No adverse effects were observed at copper levels less than 17.4 $\mu g\text{-}L^{-1}$ copper. Mount and Stephen (1969) report that while copper concentrations of 18.4 $\mu g\text{-}L^{-1}$ kill half of the fathead minnows (*Pimephales promelas*) used in reproductive studies, survival, growth, and reproduction were normal at 4.4 to 10.6 $\mu g\text{-}L^{-1}$ copper. They did observe higher NOEL (No Observed Effects Levels) in hard water (200 $mg\text{-}L^{-1}$ $CaCO_3$). Other species are more tolerant. Mummichog and silverside fry hatch in ambient levels of up to 5,000 $\mu g\text{-}L^{-1}$ copper (Gardner and LaRoche, 1973).

In summary, fresh-water species of fish are more sensitive to metals than are marine species. Higher salinity and hardness in marine environments help protect fish from copper poisoning as do factors such as pH, dissolved organic material and alkalinity which increase the potential for Cu^{+2} complexation and detoxification. It appears that growth and survival are affected at higher copper levels than is successful migratory behavior, reproduction and survival of larval stages. Copper levels greater than 17.4 $\mu g\text{-}L^{-1}$ can adversely effect the number of eggs spawned, hatchability and larval survival. At intermediate hardness values (ca. 50 $mg\text{-}L^{-1}$ $CaCO_3$) migratory impairment can occur at constant copper levels as low as 5 $\mu g\text{-}L^{-1}$. This suggests that Washington State regulatory levels for copper are adequate to insure reproductive success with the exception that more strict standards should be imposed ($\leq$ 5.0 $\mu g\text{-}L^{-1}$) during periods of active salmonid migration.

Summary for copper toxicity Most potentially toxic substances are regulated at the Federal and State Levels. It appears that regulatory levels for copper are sufficient to protect salmonids. However, long term exposure to copper levels exceeding 5 $\mu g\text{-}L^{-1}$ should be avoided during the time in which anadromous fish are migrating.

Copper is clearly the metal of most concern in both fresh water and marine environments. From a purely biological point of view, the cupric ion should be maintained below 6 $\mu g\text{-}L^{-1}$ in marine environments (Brooks, 1995b and 1995c). Either the current EPA limit of 2.4 $\mu g\text{-}L^{-1}$ (dissolved copper), or the Washington State marine standard of 2.5 $\mu g\text{-}L^{-1}$ appear adequate to protect marine life. In fresh water, at hardness values of 50 $mg\text{-}L^{-1}$ ($CaCO_3$), the No Observed Effect Level (NOEL) for copper appears to be in excess of 8.0 $\mu g\text{-}L^{-1}$. Acute effects are observed at significantly higher levels in all fish species studied (50 to 200 $\mu g\text{-}L^{-1}$). However, reproductive success can be impaired at copper levels as low as 17.4 $\mu g\text{-}L^{-1}$ and migratory behavior (primarily chemoreception) is effected by long term exposure to copper levels greater than 5.0 $\mu g\text{-}L^{-1}$. Salmonids have been shown to avoid copper concentrations exceeding 4.4 $\mu g\text{-}L^{-1}$. Therefore, unless the avoidance reaction causes a change in migratory patterns, the Washington State water quality criteria are adequate to protect salmon - except during periods of active migration when total dissolved copper levels should be restricted to 5 $\mu g\text{-}L^{-1}$.

Water column copper standards. Washington State, in Chapter 173-201A WAC, defines water quality standards for surface waters. The WAC states that toxic substances shall not be introduced above natural background levels in waters of the state which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the Department of Ecology. Table 2 lists criteria established for the protection of aquatic life in Washington State calculated at 50 mg-L^{-1} hardness ($CaCO_3$).

The Washington State chronic copper standard of 5.6 µg-L^{-1} copper at 50 mh-L^{-1} hardness is slightly higher than the minimum level (5.0 µg-L^{-1} Cu) associated with migratory dysfunction in salmonids. Therefore, it may be appropriate to modify this standard to read, "not to exceed 5.0 µg-L^{-1} copper during the period in which anadromous or catadromous fish are migrating."

Toxicity of Polycyclic Aromatic Hydrocarbons to aquatic fauna and flora with emphasis on salmonids. Brooks (1995a) has reviewed the available literature regarding PAH toxicity in aquatic environments. The lowest levels of dissolved PAH found to be toxic to aquatic organisms was 8 µg-L^{-1} naphthalene for the larvae of the Dungeness crab (*Cancer* magister) and 18 to 21 µg-L^{-1} for mysids (*Mysidopsis bahia*). At levels this low, PAH have been found to stimulate plant growth (Boney, 1974 cited in Neff, 1979).

Vertebrates readily metabolize most PAH and elicit acute toxic responses only at very high levels. Borthwick and Patrick (1982) found a 96-h LC_{50} of 3,500 µg-L^{-1} (unspecified PAH) in Sheepshead minnows (*Cyprinodon variegatus*) and of 150,000 µg-L^{-1} naphthalene in mosquito fish *(Gambusia affinis*).

Pastorok *et al.* (1994) investigated the effects of sedimented PAH associated with a creosote treating plant located on the Willamette River in Oregon. They observed total sedimented PAH as high as 540 µg-g^{-1} (TOC) or 10.26 µg-g^{-1} (dry sediment weight assuming 1.9% TOC). These author's assessed the effects on organisms at this site by conducting Microtox and *Hyalella* bioassays. In addition to sediment chemistry, bioaccumulation studies in fish (*Catastomus macrocheilus*) and crayfish (*Pacifastacus leniusculus*) were complimented with a histopathological survey of the livers of the large-scale sucker (*Castastomus macrocheilus*). The author's conclude that,

"The data on liver histopathology of large-scale sucker collected as part of the remedial investigation and available histopathological data on carp collected at river mile 7 as part of a separate study suggest that risk to fish populations attributable to chronic toxicity from contamination at the site is low. . . . . . . There is no evidence of adverse biological effects throughout most of the main channel of the river. Evaluation of tissue contaminant data for crayfish and large-scale sucker and comparisons of sediment chemistry data for three PAH compounds (acenaphthlene, phenanthrene, and fluoranthene) with available sediment-quality criteria proposed by the U.S. Environmental Protection Agency support this conclusion."

The literature does not provide clear guidance regarding the levels of sedimented PAH which are injurious to aquatic organisms. Brooks (1995a) reviewed the potential for PAH induced cancer in fish. Included in that review are discussions regarding PAH induced enzyme systems. Taken all together, the literature suggests that PAH metabolizing enzymes are induced at sediment PAH levels between 1.0 and 4.0 $\mu g\text{-}g^{-1}$ (dry sediment weight). There is clear evidence of increased hepatic disease in fish chronically exposed to sediment levels above 25 $\mu g\text{-}g^{-1}$ PAH (dry sediment weight).

It appears that the best currently available guide lies in the Apparent Effects Threshold (AET) based Marine Sediment Quality Standards adopted by Washington State in WAC 173-204-320. Standards have not been adopted for fresh water sediments. This analysis will use the marine standards in the analysis that follows. They are summarized in Table 3.

2. Methodology

Modeling sediment concentrations of metals and polycyclic aromatic hydrocarbons in lotic systems. The models presented in Brooks (1995a, 1995b and 1995c) were optimized for poorly circulated marine environments where harmonically driven tidal currents interact with weak steady state currents. The dilution algorithms for these models are modified in the following paragraphs to provide more accurate predictions in lotic systems. This dilution model assumes that water is passing a piling with constant velocity. Turbulence associated with the piling creates the geometry described in Figure 1. In this model we let $dA = 2R_p dD + 2D\varphi dD$, where:

- dA = the incremental area
- R_p = radius of the piling
- dD = the incremental distance along transect D
- φ = the angle representing turbulent mixing = 15° = 0.2618 radians

Simplifying, we obtain: $dA = 2(R_p + 0.2618D)dD$

substituting $D = h(V_{ss}/V_v)$ and $dD = (V_{ss}/V_v)dh$, where:

- V_{ss} = the steady state current velocity at the site
- V_v = the vertical velocity of silt to which the metal or PAH is adsorbed.

The expression becomes $dA = 2(R_p + 0.2618hV_{ss}/V_v)V_{ss}/V_v$

When this is combined with the appropriate algorithm describing PAH or copper loss per square centimeter (m) provided in Brooks (1995a, 1995b or 1995c), we have an expression for the sediment deposition of copper or PAH.

$$\text{Deposition} = M/dA = 2\pi R_p m/[2(R_p + 0.2618hV_{ss}/V_v)(V_{ss}/V_v)dh]$$

This expression can be further simplified by substituting $h = DV_v/V_{ss}$ to obtain the final form of the algorithm describing sediment deposition.

$$\text{Deposition } (\mu g\text{-}cm^{-2}day^{-1}) = \pi R_p m V_v/[(R_p + 0.2618D)V_{ss}]$$

The sediment accumulation of copper or PAH is predicted by combining this dilution algorithm with the total copper or PAH lost from the piling. Brooks (1995b, 1995c) has shown that copper accumulation in sediments is a very small fraction of the allowable (WAC 173-205) sediment copper standard in Washington State. Therefore only the results of PAH accumulation in sediments will be discussed here.

$$\text{PAH accumulation} = \pi R_p V_v(24.4 + 0.78T - 0.58S)\exp^{-(\text{age}/10)} \times \exp^{-(\text{actual retention}/22.4 - 1)/2} \; 0.225 \times 0.047T\exp^{[(4 - \text{RPD})/3]}/[V_{ss}(R_p + 0.2618D)]$$

3. Results and Discussion

Modeling water column concentrations of PAH in lotic systems. A conservative model for PAH concentrations in lotic systems assumes that the PAH lost from a piling are diluted in a column of water defined by the current speed and the diameter of the pile. The following equation defines such a dilution zone after converting velocities from centimeters per second to centimeters per day to correspond with the algorithm used to define PAH migration rates.

$$\text{Dilution} = 2R_pV_{ss}86{,}400$$

The dilution zone is not a function of the depth of water because we assume that currents are equal at all depths. Therefore the PAH lost from an incremental piling height is diluted in an incrementally high volume of water defined by the piling diameter and steady state current flow. Combining this dilution volume with the predicted PAH migration rate gives a very conservative prediction of the water column concentration of PAH associated with a creosote treated piling:

$$\text{PAH}_{\text{Water Conc.}} = \pi(24.4 + 0.78T - 0.58S)\exp^{-(\text{age}/10)} \times \exp^{-(\text{actual retention}/22.4 - 1)/2} \times 0.225 \times 0.047T\exp^{[(4 - \text{RPD})/3]}/(86400V_{ss})$$

Modeling water column concentrations of copper associated with CCA treated wood in lotic systems. The dilution model for water column concentrations of PAH derived in the preceding section are used to predict water concentrations of copper herein. When combined with the copper loss algorithm provided in Brooks (1995b), we obtain:

$$\text{Copper}_{\text{Water Conc. (CCA)}} = 0.51\exp^{-0.048*\text{time (days)} + 0.02*\text{Salinity (ppt)}} \times (0.55 + 0.65\ \ln(0.71\text{Retention})) / 2R_pV_{ss}86{,}400$$

Modeling water column concentrations of copper associated with ACZA treated wood in lotic systems. The dilution model for water column concentrations of copper associated with ACZA treated wood combines the copper loss algorithm developed in Brooks (1995c) and the steady state flow dilution model developed in this report.

$$\text{Copper}_{\text{Water Conc. (ACZA)}} = 1908.6\exp^{-0.429 \times \text{Days} - 0.383 \times \text{pH}} / 2R_pV_{ss}86{,}400$$

Predicted environmental levels of polycyclic aromatic hydrocarbons and copper associated with the use of pressure treated wood piling in lotic systems. Based on the background information presented earlier in this report, the following assumptions were used in making predictions of copper concentrations in receiving waters and PAH accumulation in receiving sediments.

1. Water Temperature = 15°C
2. Salinity = 0.0 ppt
3. Hardness = 59.5 mg-L^{-1} ($CaCO_3$)
4. Sediment Total Organic Carbon[1] = 1.0 percent
5. CCA and ACZA retention[2] = 1.0 pcf (15.6 kg-m^{-3})
6. Creosote retention[2] = 17.0 pcf
7. Background water column copper levels = 1550 ng-L^{-1}
8. Background sediment PAH levels[3] = 0.5 µg-g^{-1}

Notes:

[1] The 1.9 percent TOC value reported by Pastorok (1994) for the Willamette River seems high in the author's experience. In this analysis we will assume that sediment TOC is 1.0 percent. While this value would be high in areas of high current, this report will focus on a worst case analysis which involves slow currents, fine sediments and higher levels of TOC. In these areas, a value of 1.0 percent is considered conservative.

[2]These are the retention's prescribed for fresh water use by AWPA (1992).

[3]This value is consistent with the report of Pastorok (1994) and with observed background PAH levels in undeveloped areas of Puget Sound. Because of the bedload movement in most areas of the Columbia River, and high sediment deposition, observed values are expected to be lower, except in heavily industrialized areas.

Polycyclic aromatic hydrocarbon predictions and recommendations. Table 4 provides a summary of maximum predicted PAH accumulation in sediments associated with two creosote treated piling spaced one meter apart. The closest point of approach to the piling computed in these calculations was 5 cm.

This analysis is based on the Washington State Apparent Effects Threshold based Marine Sediment Quality Standards. If there is significant documentation demonstrating the need for lower levels, then those levels should be substituted in this analysis as soon as steps are initiated to change the Washington Administrative Code.

The **No Effect level** has been set at a sediment PAH level that is $\leq$ 25% of the sediment standard less anticipated background (0.25 x 13.3 - 0.5 = 2.3 $\mu g\text{-}g^{-1}$ TPAH; dry sediment basis).

The **Not Likely to Adversely Effect Level** is set at the Sediment Standard less background and a 25% safety margin (13.3 x 0.75 - 0.5 = 9.5 $\mu g\text{-}g^{-1}$ TPAH; dry sediment basis at 1% TOC) .

Projects for which predicted sediment PAH exceeds the Not Likely to Adversely Effect Level but do not reach the Likely to Adversely Effect Level (12.8 $\mu g\text{-}g^{-1}$ TPAH dry sediment weight) should be required to conduct an individual risk assessment.

The **Likely to Adversely Effect Level** is highlighted with a dark background. These predictions exceed Washington State Marine Sediment criteria. The Washington State Marine Sediment Standard for 1.0 TOC sediments is 13.3 $\mu g\text{-}g^{-1}$ Total PAH (dry sediment weight). Subtracting the anticipated background (0.5 $\mu g\text{-}g^{-1}$ TPAH dry sediment weight) indicates that a creosote treated wood project could add 12.8 $\mu g\text{-}g^{-1}$ TPAH without exceeding the criteria. If predictions suggest that this level will be exceeded, then alternate materials should be recommended unless the project is of such nature that a Sediment Impact Zone is appropriate.

Creosote Summary. The following generalities can be deduced from Table 4. They provide simple guidelines for permitting creosote treated wood projects:

Recommendation 1. Creosote treated wood projects can be permitted without further risk assessment in the following instances:

a. when the RPD is $\geq$ 0.5 cm and current speeds are greater than 10.0 cm/sec

b. when the RPD is $\geq$ 1.0 cm and the sum of the RPD (measured in cm) and the current speed (measured in $cm\text{-}sec^{-1}$) exceeds 7.0.

Recommendation 2. An individual project risk assessment should be required in the following circumstances:

a. when the RPD is < 0.5 cm deep or when current speeds are $\leq$ 2.0 cm/sec
b. for projects in which more than four piling are installed in a line parallel to the currents at interpiling distances less than 1.0 meter. This would include dolphins with more than 4 piling. Table 4 was developed using two piling. In the worst case, adding two additional piling in line with the current (spaced one meter apart)

would add an additional 3.2 $\mu g\text{-}g^{-1}$ at the downstream piling resulting in a total predicted TPAH accumulation of 13.9$\mu g\text{-}g^{-1}$ which is just over the Washington State Standard.

c. when the sum of the RPD and the current speed is ≤ 5.0.
d. when a new project is located within 10 meters of an existing creosote treated wood project.

Recommendation 3. Creosote projects shall not be constructed in areas where current speeds are ≤ 1.0 cm-sec^{-1} without a Sediment Impact Zone authorization.

Copper predictions and recommendations for the use of ACZA treated piling. The following analysis assumes that installation of the project occurs within a single day. Predictions are made at the completion of the project (day 1).

The analysis is based on Washington State water quality criteria published in WAC 173-201. The copper criteria (6.54 $\mu g\text{-}L^{-1}$) is based on a water hardness of 59.5 mg-L^{-1} $CaCO_3$ which is the average value reported by Johnson and Hopkins (1991) for the Lower Columbia River. This analysis is appropriate for those periods when salmonids are not actively migrating in the area of the project. An alternate criteria of 5.0 ppb copper should be imposed on projects constructed within one week of an active salmonid migration.

Background levels are assumed to be 1.55 $\mu g\text{-}L^{-1}$ which is the average reported by Johnson and Hopkins (1991). Thirty centimeter diameter piling, treated to 1.0 pcf (15.6 kg-m^{-3}) are assumed to be installed in fresh water with a pH of 8.11. The steady state dilution model developed in this report is used to predict copper concentrations immediately adjacent to the piling. Water column copper concentrations for a variety of current speeds are predicted in Table 5.

Based on this analysis, it does not appear that the use of ACZA treated piling presents a threat to aquatic resources when used in open systems with flushing currents ≥ 0.5 cm-sec^{-1}. If ACZA piling are installed in an enclosed area (non flushing), then a minimum surface area of 3,041 square feet is required per piling. That is approximately 14 piling per surface acre. This will maintain water column copper levels at less than Washington State water quality criteria for the conditions described. If more than 14 piling per surface acre are required in a closed water body, then installation should proceed in steps with a maximum of 14 piling installed in any one week period.

It should be emphasized that copper is a natural component of the earth's surface. At an average water column concentration of 1.55 $\mu g\text{-}L^{-1}$, the Columbia River carries 4,370 kilograms of copper past an ACZA project every seven days. This is the period in which most of the copper is lost from the piling (see Brooks, 1995b). On the basis of mass loading, an ACZA piling project consisting of 100 piles, standing in 5 meters of water, would contribute an additional 0.893 kilograms of copper. This increases the Columbia

River's load by 0.020 percent. Very little metal is lost from ACZA after this initial period. Note that this analysis does not include the Columbia's bed load of copper.

These recommendations protect the migratory fidelity of salmonids. There is an additional safety factor in that olfactory rosette compromise reported by McPherson (1976) occurred following exposure to 5.0 ppb copper for 165 days. Most ACZA metal loss occurs within the first few days following emersion and a return to background levels is anticipated within seven days. In fact, the Washington State chronic copper criteria applied in this analysis is, "A 4-day average concentration not to be exceeded more than once every three years on the average." The four day average copper concentration associated with ACZA treated piling is only 88.7% of the predicted values for day 1. This provides another safety factor in this analysis.

Lastly, reproductive effects in salmonids have not been reported at copper levels less than 17.4 $\mu g\text{-}L^{-1}$ copper. Hazel and Meith (1970) reported that copper levels exceeding 100 $\mu g\text{-}L^{-1}$ will kill king salmon (*Oncorhynchus tshawytscha*) eggs and that no mortality was observed at 8 $\mu g\text{-}L^{-1}$. All of these effects levels are significantly higher than those predicted for ACZA treated wood at current speeds $\geq$ 0.4 $cm\text{-}sec^{-1}$.

The previous predictions are based on average hardness and copper background copper levels in the Columbia River. The proposed criteria are also adequate to protect salmonids at the highest ambient copper levels (2.20 ppb) reported by Johnson and Hopkins (1991), and they are within Washington State fresh water quality criteria at the lowest reported hardness level (49 $mg\text{-}L^{-1}$ $CaCO_3$).

ACZA Recommendations. This analysis suggests that the use of ACZA treated wood in the Columbia River presents No Effect to aquatic resources including threatened or endangered salmon species at current speeds greater than 0.5 $cm\text{-}sec^{-1}$. The following should be consider Not Likely to Effect projects for which individual risk assessments are recommended:

1. When greater than 100 piling are to be installed in any one week period.
2. When piling are to be installed in a closed, or very poorly flushed, body of water (current speeds < 0.5 cm-sec) with a density of greater than one piling per 3,041 square feet of surface area.
3. When projects are proposed in close proximity to known sources of copper which result in localized increases in background copper levels.

Copper predictions and recommendations for the use of CCA treated piling. CCA treated piling is not common on the west coast of the United States because Douglas fir is difficult to treat with CCA. However, CCA is a very common wood preservative in other areas of the country and an analysis of its effects on the Columbia River are included for completeness.

The following analysis assumes that installation of the project occurs within a single day. Predictions are made at the completion of the project (day 1). The analysis is based on Washington State water quality criteria published in WAC 173-201. The copper criteria (6.54 $\mu g\text{-}L^{-1}$) is based on a water hardness of 59.5 $mg\text{-}L^{-1}$ $CaCO_3$ which is the average value reported by Johnson and Hopkins (1991) for the Lower Columbia River. This analysis is appropriate for those periods when salmonids are not actively migrating in the area of the project. An alternate criteria of 5.0 $\mu g\text{-}L^{-1}$ copper should be imposed on projects constructed within one week of an active salmonid migration.

Background copper levels are assumed to be 1.55 $\mu g\text{-}L^{-1}$ which is the average reported by Johnson and Hopkins (1991). Thirty centimeter diameter southern yellow pine piling, treated to 1.0 pcf (15.6 $kg\text{-}m^{-3}$) are assumed to be installed in fresh water with a pH of 8.11. The steady state dilution model developed in this report is used to predict copper concentrations immediately adjacent to the piling. Water column copper concentrations for a variety of current speeds are predicted in Table 6.

These data indicate that CCA treated piling use in the Columbia River present a No Effect application. If CCA treated piling is used in enclosed waters, a total of 20 square meters of pond surface area is required for each piling. A total of 207 CCA treated piling per acre is required to reach the Washington State water quality criteria of 6.54 $\mu g\text{-}L^{-1}$ copper at 59.5 mg-L $CaCO_3$ hardness.

To put the copper losses from CCA in perspective, consider that a project involving 100 CCA treated piling, installed in five meters of water would add 74.9 grams of copper to the Columbia River during the first 30 days when most of the loss occurs. During those 30 days, the Columbia river transports 18,730 kg of copper in the water column. The copper lost from 100 CCA piling during the first 30 days is equal to the natural copper contained in 10.4 seconds of Columbia River flow.

CCA Recommendations. In open lotic systems, CCA treated southern yellow pine piling does not present a risk to aquatic resources and is a No Effect use.

CCA and ACZA treated wood bulkheads. Large surface area projects, such as bulkheads present a greater risk. Models have been developed to assess these risks by Brooks (1995b, 1995c). These models can be used to determine the behavior of CCA and ACZA treated wood in flowing water with the physical and chemical characteristics of the Columbia River. The results of this analysis are presented in Table 7. It is assumed that three days are required to construct the bulkhead. Computations are for day 3.
ACZA losses decline rapidly after the wood is placed in the water. CCA losses are initially lower but reductions in loss rates occur more slowly. In Table 8. the models have been used to predict the elapsed time before the water next to a bulkhead project will meet Washington State water quality criteria. Note that a very conservative model is used in Brooks (1995b, 1995c) to define the mixing width along a bulkhead.

Bulkhead Recommendations. When Columbia River current speeds do not meet the minimum requirements listed in Table 7, an individual risk assessment should be conducted. That risk assessment should include an analysis of the potential movement of salmonids through the area within 30 days following project completion.

When current speeds exceed 3.5 cm-sec^{-1}, the use of CCA treated wood will maintain copper within water quality criteria at all times. Higher current speeds are required to meet copper criteria on day 1 when ACZA treated wood is used
(18.5 cm -sec^{-1}).

4. Summary and Conclusions.

A broad range of conditions have been addressed in this analysis. Creosote use is dictated by currents and the availability of oxygen in sediments. However, there is a significant range of projects and environments where creosote can be considered to have No Effect on aquatic organisms. Care should be exercised in the use of creosote where sediments have low oxygen tensions or currents are slower than 2.0 cm-sec^{-1}.

The waterborne treatments (ACZA and CCA) release copper at low levels. In flowing water, the use of piling presents minimal risk to aquatic organisms and the total copper released by piling is a tiny fraction of the natural copper load in the Columbia. In most uses, CCA and ACZA piling should be considered No Effect. In very poorly circulated or closed bodies of water, copper can accumulate in the water column to levels exceeding the Washington State copper criteria and individual risk assessments should be required when surface area requirements are not met.

Large surface area structures (such as bulkheads) can contribute a significant amount of copper over a relatively short period of time. Rather restrictive criteria are proposed to insure the integrity of aquatic resources. When the minimum flow criteria presented in Table 7 are not met, an individual risk assessment should be required.

Proper Fixation. The metal loss rates used in this analysis were developed from testing of properly fixed CCA and ACZA treated wood. The data were presented as part of the EPA registration of these preservatives and is of very high quality. It should be emphasized that high environmental performance is dependent on proper fixation of the chemicals which is time and temperature dependent. The Western Wood Preservers Institute and the Canadian Institute of Treated Wood have developed best management practices (BMPs) for the production of treated wood products used in aquatic environments. It is recommended that all permits allowing treated wood use in aquatic environments be conditioned to require production in accordance with these BMP's.

The data used to develop PAH migration rates from creosote treated wood is based on conventionally treated products. It is anticipated that creosote BMP's will improve the environmental performance of creosote treated piling. Creosote treated wood projects should also be conditioned to require production using BMP's.

5. Literature

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Table 1. Columbia River flows, water hardness and background copper concentrations. Total (unfiltered) copper is reported.

	Date			
Parameter	**January 9**	**May 30**	**September 25**	**Average**
Flow (CFS)	139,000	253,000	126,000	172,670
Copper ($\mu g\ L^{-1}$)	1.8 to 2.2	1.2 to 1.5	1.3 to 1.3	1.55
Hardness ($mg\text{-}L^{-1}$ $CaCO_3$)	49 to 75	52 to 57	60 to 64	59.5

Table 2. Water Quality Standards for Surface Waters of the State of Washington. Values are expressed in $\mu g\text{-}L^{-1}$. A hardness of 50 $mg\text{-}L^{-1}$ was used for values requiring computation. See WAC 173-201A-040 for details.

Contaminant	Fresh Acute	Fresh Chronic	Marine Acute	Marine Chronic
Arsenic	360	190	69	36
Chromium (VI)	16.0	11.0	1,100.0	50.0
Copper	8.0	5.6	2.9	-
Zinc	58.0	52.5	84.6	76.6

Table 3. Washington State Apparent Effects Threshold Based Sediment Criteria for Polycyclic Aromatic Hydrocarbons(HPAH = high molecular weight PAH; LPAH = low molecular weight PAH).

Compound Class	**Criteria** (in $\mu g\text{-}g^{-1}$ TOC)	**Criteria at 1.9% TOC** (expressed in $\mu g\text{-}g^{-1}$ sediment dry weight)
HPAH	960	18.2
LPAH	370	7.0
TOTAL PAH	1,330	25.3

Current Speed (cm-sec^{-1})	Depth of RPD (cm)					
	0.5	1.0	1.5	2.0	3.0	4.0
0.5	192.19	106.75	70.05	52.8	40.75	39.27
1.0	96.1	53.4	35.0	26.4	20.38	19.6
2.0	48.1	18.3	17.5	13.2	10.2	9.8
3.0	32.0	17.8	11.7	8.8	6.8	6.6
4.0	24.0	13.3	8.8	6.6	5.1	4.9
5.0	19.2	10.7	7.6	5.3	4.1	3.9
6.0	16.0	8.9	5.8	4.4	3.4	3.3
7.0	13.7	7.6	5.0	3.8	2.9	2.8
8.0	12.0	6.7	4.4	3.3	2.6	2.5
9.0	10.7	5.9	3.9	2.9	2.3	2.2
10.0	9.6	5.3	3.5	2.6	2.0	2.0
11.0	8.7	4.8	3.2	2.4	1.9	1.8
12.0	8.0	4.4	2.9	2.2	1.7	1.6
13.0	7.4	4.1	2.7	2.0	1.6	1.5
14.0	6.9	3.8	2.5	1.9	1.5	1.4
15.0	6.4	3.6	2.3	1.8	1.4	1.3
20.0	4.8	2.7	1.8	1.3	1.0	1.0
25.0	3.8	2.1	1.4	1.1	0.8	0.8
30.0	3.2	1.8	1.2	0.9	0.7	0.6

Likely to Effect. Requires a Sediment Impact Zone or Alternate Material
Not Likely to Effect. However, project requires an individual assessment
Not Likely to Effect. Does not require further assessment
No Effect

Table 5. Water column copper concentrations immediately adjacent to a 30 cm diameter piling, treated with ACZA to a retention of 15.6 kg-m^{-3}, as a function of current speed. Ambient pH is 8.11, background copper levels are 1.55 μg-L^{-1}, and the salinity is 0.0 ppt. Washington Standard = 6.540 μg-L^{-1} Cu.

Current Speed (cm-sec^{-1})	Total Predicted Copper (ppb)	Copper added by ACZA project (ppb)
0.3	[illegible]	[illegible]
0.4	6.606	5.056
0.5	5.595	4.045
1.0	3.572	2.022
2.0	2.561	1.011
3.0	2.224	0.674
4.0	2.056	0.506
5.0	1.954	0.405
10.0	1.752	0.202
15.0	1.685	0.135

Solid black	Likely to effect for one to two days.
Hatched	Not Likely to Effect
Open	No Effect

Table 6. Water column copper concentrations of copper immediately adjacent to a 30 cm diameter southern yellow pine piling, treated with CCA to a retention of 15.6 kg-m^{-3}, as a function of current speed. Ambient pH is 8.11, background copper levels are 1.55 μg-L^{-1}, and the salinity is 0.0 ppt.

Current Speed (cm-sec^{-1})	Total Copper (μg-L^{-1})	Copper increase associated with CCA treated piling (μg-L^{-1})
0.1	1.924	0.374
0.5	1.625	0.075
1.0	1.587	0.037
2.0	1.569	0.019
3.0	1.562	0.125
4.0	1.559	0.009
5.0	1.558	0.007
10.0	1.554	0.004
15.0	1.552	0.003

Table 7. Minimum flow past newly installed CCA and ACZA treated bulkheads required to meet Washington State copper water quality standards in the lower Columbia River.

Preservative	Minimum Flow to Meet Washington State Water Quality Standards On Day 1
ACZA	18.5 cm sec^{-1}
CCA	3.5 cm sec^{-1}

Table 8. Time required to meet Washington State copper water quality criteria next to newly installed ACZA and CCA treated bulkheads as a function of current speed. These data are relevant to background conditions found in the lower Columbia River.

Current Speed	Time to meet Washington State fresh water copper standards	
	ACZA	CCA
1 cm sec^{-1}	15 days	52 days
5 cm sec^{-1}	7 days	meets standard on day one
10 cm sec^{-1}	3 days	meets standard on day one

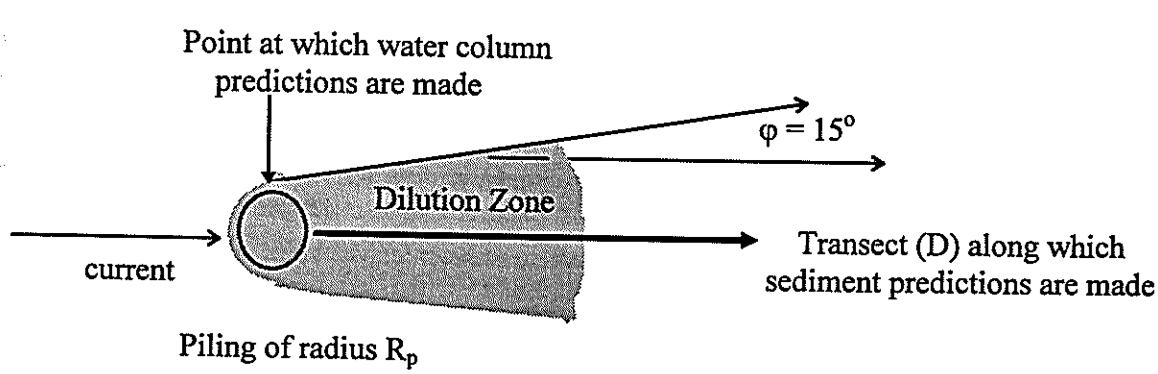

Figure 1. Dilution zone geometry used to predict copper and PAH concentrations in the water column and sediments associated with the use of treated wood.

Table 5. Water column copper concentrations immediately adjacent to a 30 cm diameter piling, treated with ACZA to a retention of 15.6 kg-m^{-3}, as a function of current speed. Ambient pH is 8.11, background copper levels are 1.55 μg-L^{-1}, and the salinity is 0.0 ppt. Washington Standard = 6.540 μg-L^{-1} Cu.

Current Speed (cm-sec^{-1})	Total Predicted Copper (ppb)	Copper added by ACZA project (ppb)
0.3	8.291	6.741
0.4	6.606	5.056
0.5	5.595	4.045
1.0	3.572	2.022
2.0	2.561	1.011
3.0	2.224	0.674
4.0	2.056	0.506
5.0	1.954	0.405
10.0	1.752	0.202
15.0	1.685	0.135

Likely to effect for one to two days.
Not Likely to Effect
No Effect

Table 6. Water column copper concentrations of copper immediately adjacent to a 30 cm diameter southern yellow pine piling, treated with CCA to a retention of 15.6 kg-m^{-3}, as a function of current speed. Ambient pH is 8.11, background copper levels are 1.55 μg-L^{-1}, and the salinity is 0.0 ppt.

Current Speed (cm-sec^{-1})	Total Copper (μg-L^{-1})	Copper increase associated with CCA treated piling (μg-L^{-1})
0.1	1.924	0.374
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