Environmental concentrations of copper, chromium, and arsenic released from a chromated-copper-arsenate-(CCA-C-) treated wetland boardwalk

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Abstract

A study was conducted to evaluate environmental accumulation and mobility of total copper, chromium, and arsenic adjacent to a chromated-copper-arsenate-(CCA-C-) treated wetland boardwalk. The study was considered a severe test because it included a large volume of treated wood in a site with high annual rainfall. Soil and sediment samples were collected before construction and 0.5, 2, 5.5, 11, 24, and 60 months after construction. Increased concentrations of copper, chromium, and arsenic were detected in some soil and sediment samples. The environmental concentrations varied with time, proximity to the treated wood, and type of exposure. Concentrations of leached components in the soil developed slowly and were greatest at the 60-month sampling. Soil samples with elevated levels of copper and chromium were confined to directly under the dripline of the boardwalk, and arsenic appeared to be limited to within 0.3 m (1 ft.) of the structure. Concentrations of leached components in the sediments increased more quickly than those in the soil and reached maximum or near maximum levels within the first year. Elevated concentrations of copper, chromium, and arsenic were found in sediments as much as 3 m (10 ft.) from the boardwalk. Concentrations of these elements were also generally greater in sediment than in soil, suggesting that factors other than leaching, such as abrasion of treated wood fiber caused by foot traffic, may be contributing to environmental releases. In both soil and sediment samples, total copper and arsenic concentrations were consistently more elevated than chromium concentrations.

Because of its durability and natural appearance, preservative-treated wood is often used for construction projects in our National Forests, National Parks, and other public and private natural areas. These applications may place treated wood in pristine and/or sensitive ecosystems where contamination by significant amounts of wood preservative components could negatively affect the environment. Until recently, the most widely used wood preservative was chromated copper arsenate (CCA-C), a waterborne wood preservative that is inexpensive, leaves a dry, paintable surface, and provides protection against attack by decay fungi and insects. Another waterborne preservative, ammoniacal copper zinc arsenate (ACZA), is commonly used on the West Coast and in other areas when specifiers request wood species that are difficult to treat. Both CCA-C- and ACZA- treated wood are used extensively by the Forest Service and other government and private entities in the construction of structures such as walkways, piers, restraining walls, and bridges. In recent years, other types of wood preservatives, including alkaline copper quat (ACQ), copper azole (CA-B and CBA-A), and copper dimethyldithiocarbamate (CDDC) have been standardized for use in similar applications. There has been relatively little research on environmental effects associated with these wood preservatives in service.

Because CCA was the most widely used type of treated wood, it has been

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the subject of more research than other types of preservatives. In one directly applicable study, chromium, copper, and arsenic levels were measured adjacent to CCA-treated boardwalks of varying ages at several sites in southern Tasmania (Comfort 1993). Levels of copper and chromium adjacent to the boardwalk were significantly elevated compared with the control samples, but arsenic levels were not elevated. The highest copper level detected was 49 mg/kg (controls were between 1 and 3 mg/kg for that site), while the highest chromium level detected was 88 mg/kg, approximately 60 mg/kg above the reference sample. There did not appear to be any relationship between the age of the boardwalk and the levels detected; the highest copper levels were detected around a 1-year-old structure while the highest chromium levels were detected around the oldest structure (Comfort 1993). The elevation of chromium levels in the soil relative to copper and arsenic is surprising, because most laboratory studies have indicated that copper and arsenic are leached in greater quantities than chromium (Lebow 1996).

In a study that may also be applicable to boardwalk decking, researchers collected soil samples from beneath residential decks constructed from CCA-C-treated wood (Stilwell and Gorny 1997). Substantially higher levels of CCA-C components were detected than in the Tasmanian study discussed above. Several samples from under decks contained more than 100 mg/kg copper, and a maximum level of 410 mg/kg copper was detected under one deck. Chromium concentrations in some samples removed from under the decks were also elevated to more than 100 mg/kg, and maximum arsenic concentrations of 200 to 300 mg/kg were reported. Overall, the average copper, chromium, and arsenic levels detected under the decks were 75, 43, and 76 mg/kg, respectively, while those in nearby control areas were 17, 20, and 4 mg/kg, respectively (Stilwell and Gorny 1997). The authors also noted that the concentration of CCA components in the soil decreased rapidly with soil depth. In contrast to the Tasmanian study, Stilwell and Gorny noted an increase in soil levels with increasing age of the deck. Although these studies shed some light on the leaching characteristics of CCA-C-treated wood, they are not sufficient to resolve concerns about the use of this product in sensitive ecosystems.

To address the concerns about preservative leaching in service, a cooperative study was initiated that included members of the wood treating industry; the USDA Forest Service, Forest Products Laboratory; Mt. Hood National Forest; and the Bureau of Land Management. The objectives of the study were to evaluate preservative release, environmental accumulation, and biological impact from treated wood used in construction of an in-service wetland boardwalk. This paper discusses the leaching and environmental accumulation of copper, chromium, and arsenic from a boardwalk constructed of CCA-C-treated wood during the 5 years after construction. A detailed discussion of the biological impacts during the first year after construction can be found in a publication by Brooks (2000).

Materials and methods

The materials and methods for this paper are a summary of the methodology used in the overall study, with emphasis on details pertaining to the CCA-C test site. For a more detailed description of site conditions, construction practices, scheduling, and sampling methodology, see Lebow et al. (2000).

Site selection

The study was incorporated into a large boardwalk construction project at a Bureau of Land Management recreation site (Wildwood) in Welches, Oregon, approximately 64 km (40 mi.) southeast of Portland. The site was considered a severe leaching scenario because of high rainfall, standing water, and the large volume of treated wood used in construction. In addition to the CCA-C-treated wood discussed in this paper, ACZA-, ACQ-, and CDDC-treated wood was also evaluated in the overall study. However, the study was not intended to directly compare the preservative systems, and soil composition, water flow rates, and shading differed slightly at each sampling location. In addition, the treated wood was not all the same wood species.

Wood treatment

Western hemlock was the species used for the CCA-C-treated wood in the section tested in this study. It was treated by Exterior Wood of Washougal, Washington, in September 1995. The lumber was treated for use in ground contact (target retention of 6.4 kg/m^3 [0.4 pcf]), as recommended by American Wood-Preserver's Association Standards (AWPA 2000). To ensure adequate post-treatment conditioning, it was also specified that the treated material be handled in accordance with the Western Wood Preservers Institute's Best Management Practices (BMPs) for wood to be used in aquatic applications (WWPI 1996). Inspections of preservative retention, penetration, and BMP conformance were conducted by an independent inspection agency, which reported that the average retention in 20 cores removed from the charge was 11.7 kg/m^3 (0.73 pcf). To verify retention, an additional 55 samples were removed from the narrow faces of joists, joist headers, support columns, and railings after construction. Analysis of these samples revealed that the average CCA-C retention in the outer 15 mm (0.6 in.) varied from 7.7 kg/m^3 (0.48 pcf) in the joist headers to 16.3 kg/m^3 (1.02 pcf) in the support columns. The overall average CCA-C retention in the samples was 10.6 kg/m^3 (0.66 pcf).

The lumber used in the tested area was also sprayed with a brown stain prior to treatment to enhance its appearance. Although this type of prestain is often used on the West Coast, its use raised concerns that the stain might affect leaching relative to nonstained wood. To address this concern, a small study was conducted to compare the release of copper, chromium, and arsenic from end-matched nonstained and prestained CCA-C-treated specimens exposed to artificial rainfall. The application of prestain prior to CCA-C treatment did appear to reduce the release rate of arsenic from the treated wood by approximately 20 to 30 percent. Most of the decrease in leaching appeared to occur early in the test, during the time when arsenic release was greatest. The prestain also appeared to slightly decrease the release of copper and chromium, but these differences were not statistically significant (Lebow and Evans 1999).

Design and construction of test section

The test section consisted of approximately 36.5 m (120 ft.) of elevated walkway, 1.8 m (6 ft.) wide, including an octagonal observation platform **(Fig. 1).** A large volume of wood was used in the construction of the test section, with either 140- by 240-mm (nominal 6- by 10-in.) or 140- by 292-mm (nominal 6- by 12-in.) columns used to support a

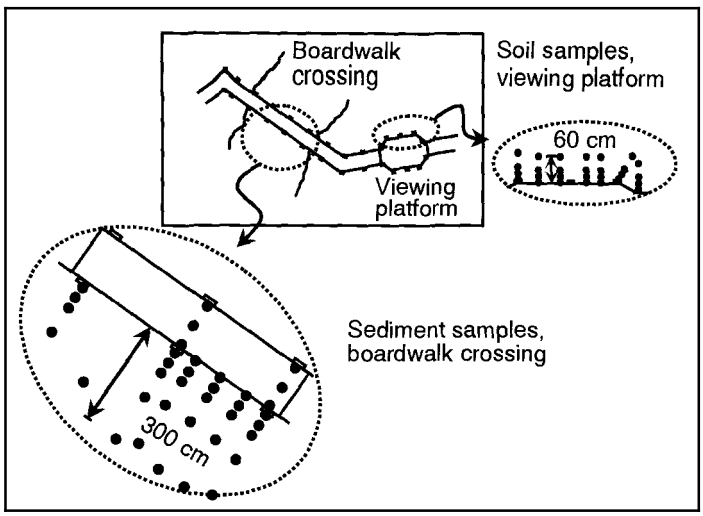

Figure 1. — Overview of CCA-C-treated boardwalk showing location of sampling transects.

Table 1. — Sampling schedule and rainfall amounts.

Sampling date	Months after construction	Rainfall since construction (mm[in.])
May 1996	Pre-construction	
June 1996	0.5	20 [0.8]
August 1996	2	109 [4.3]
November 1996	5.5	668 [26.3]
May 1997	11	2743 [108.0]
May 1998	24	4658 [183.4]
June 2001	60	10,244 [403.3]

pair of 89- by 292-mm (nominal 4- by 12-in.) joist headers. Five joists (38 by 292 mm [nominal 2 by 12 in.]) were run parallel to the boardwalk and attached to the joist headers using joist hangers. Decking (38 by 140 mm [nominal 2 by 6 in.]) was fastened across the joists, perpendicular to the direction of the boardwalk. Hand rails were constructed from 38- by 191-mm (nominal 2- by 8-in.) boards attached to the tops of the support columns and to 140-by 140-mm (6- by 6-in.) support posts at midspan. In areas with firm footing, the support columns were set on 140- by 240- by 610-mm (5.5- by 9.5- by 24-in.) treated sill pads. In areas of soft sediment or where footing for the support posts was generally poor, a pinned-piling foundation system was used to brace the support columns. Extra cross-bracing, comprised of 38- by 191-mm (nominal 2- by 8-in.) boards, was also used in these areas.

To minimize field modifications during construction, a cooperating mill performed as much fabrication of the wood members as possible prior to pressure treatment. During boardwalk construction, most sawing and drilling was conducted on tarps away from the test areas. However, in some cases, such as bolt connections to support columns and cutting the columns to height, fabrication within the test site was necessary. In these cases, a combination of trays, tarps, and vacuum was used to collect the shavings and sawdust and minimize their contact with the water or soil at the test site. Field treatment of cuts or holes in the test sections was minimal; in cases where treatment was judged necessary, a copper naphthenate solution (2% copper as metal) was brushed on.

Scheduling of construction and sampling

The CCA-C-treated boardwalk test section was constructed in late May and early June 1996. Two weeks prior to the start of construction, sampling was conducted to determine total background concentrations of copper, chromium, and arsenic. The first post-construction sampling was conducted June 21, 1996, after approximately 20 mm (0.8 in.) of rain had fallen on the boardwalk. Samples were also removed at 2, 5.5, 11, 24, and 60 months after construction **(Table 1).**

Method of sampling

Soil samples were removed to a depth of 305 mm (12 in.) with a 32-mm- (1.25-in.-) diameter stainless steel soil recovery probe. The cores were removed from the sampler in sections corresponding to depths of 0 to 150 mm (0 to 6 in.) and 150 to 300 mm (6 to 12 in.) from the soil surface and placed into prelabeled polyethylene bags. During sediment sampling, care was taken to minimize disturbance of sediments. Sediment samples were collected in 406-mm- (16-in.-) long and 19-mm- (0.75-in.-) diameter acetate tubes. The sediment samples were taken by removing the caps from each end of the tubes and then inserting them, by hand, into the sediment to a depth of at least 102 mm (4 in.). The filled tubes were kept upright and frozen for shipment and handling. The sediment cores were subsequently divided into two assay zones representing depths of 0 to 25 mm (0 to 1 in.) and 25 to 102 mm (1 to 4 in.) from the sediment surface.

Soil and sediment sampling locations

After trails were cleared but before construction of the test sections, 16 soil and 9 sediment samples were removed to determine background levels of copper, chromium, and arsenic. These samples were taken from locations that matched as closely as possible the post-construction sampling area, although the exact placement of the boardwalk was not known. In addition, a large composite soil sample was obtained from the area before construction and was homogenized. This composite sample was used as a reference, or calibration standard, for each post-construction sample analysis.

At each sampling following construction, soil samples were removed in transects starting directly under the edge of the viewing platform, and extending to distances of 0.15, 0.3, and 0.6 m (6, 12, and 24 in.) away from the platform **(Fig. 1).** These transects were replicated seven times. The same transects were used at each inspection but were shifted slightly to avoid sampling soil disturbed in previous inspections. Transects were selected to minimize slope and other features that might direct rainfall runoff away from the sampling zones. In addition, four control samples were taken

from a distance of at least 3 m (10 ft.) from the boardwalk.

Post-construction sediment samples were removed in transects starting directly under the edge of the boardwalk and extending downstream to distances of 0.3, 0.6, 1.5, and 3.0 m (1, 3, 5, and 10 ft.) away from the boardwalk **(Fig. 1).** These transects were replicated six times. The same transects were used at each inspection but were shifted slightly to avoid sampling sediments disturbed in previous inspections. Another set of six samples was removed from directly under the walkway. A minimum of four control samples were also removed at a minimum distance of 10 m (33 ft.) from the boardwalk.

Determining copper, chromium, and arsenic in samples

Soil samples were refrigerated until they could be air-dried to a uniform moisture content in a room maintained at 27°C (80°F) and 30 percent relative humidity. The dried samples were then passed through a 2-mm (0.08-in.) screen and the larger material discarded. The remaining sample was ground using a ceramic mortar and pestle. Sediment Samples were stored frozen and then sectioned into 0- to 25-mm (0- to 1-in.) and 25- to 100-mm (1- to 4-in.) depths from the sediment surface while still frozen. The samples were then weighed, thawed, allowed to air-dry in a room maintained at 27°C (80°F) and 30 percent relative humidity, and reweighed. The dried samples were then ground similarly to the soil samples. Ground soil and sediment samples were extracted using a microwave-assisted version of EPA Method 3050B, which is intended for determination of total arsenic, chromium, and copper in sediments and soils (EPA 1995). A reference soil sample, retained from before construction, was extracted and analyzed with each batch of soil and sediment samples. For samples collected during the first 24 months after construction, copper and chromium concentrations in the resulting extract were determined by flame atomization atomic absorption spectroscopy, while arsenic was analyzed using furnace atomization. Samples collected at 60 months were analyzed using inductively coupled plasma (ICP) emission spectrometry. Values obtained for the reference standard soil were used to normalize concentrations in samples to compensate for variability in extraction and analysis during the 5-year time period. In occasional samples, arsenic levels were below the detection limit of the method. These samples were assigned a concentration of one-half the detection limit, which resulted in soil or sediment concentrations between 0.1 and 0.3 mg/kg.

Use of geometric mean

The levels of preservative components in the soil and sediments varied greatly, even at equivalent distances from the treated wood. While the levels of most samples remained relatively low, a few samples had much higher levels of preservative components. This type of lognormal distribution is common in environmental sampling. Because of the lognormal distribution, the average value of preservative levels was higher than most of the actual values. To overcome this problem, this report will use the geometric mean of the values at any given distance from the treated wood. The geometric mean is the estimated median of a population with a lognormal distribution.

Results and discussion

Background levels of CCA-C components

Background levels of copper varied from 20 to 43 mg/kg in the soil and 17 to 24 mg/kg in the sediment. Background levels of chromium varied from 6 to 8 mg/kg in soil and 7 to 14 mg/kg in sediment, while background levels of arsenic ranged from 1 to 3 mg/kg in soil and 1 to 4 mg/kg in sediment. These concentrations are within the reported range of naturally occurring copper, chromium, and arsenic levels. Chromium levels ranging from undetectable to as high as 10,000 mg/kg have been reported in soils, with average levels ranging from 6 to 200 mg/kg (Brown 1986, McGrath and Smith 1990). Copper levels in soil are also variable, with reports ranging from 8 to 300 mg/kg and average levels ranging from 15 to 30 mg/kg (Baker 1990, Brown 1986). Natural levels of arsenic in soils typically range between 1 and 40 mg/kg, with most soils falling in the lower half of this range (O'Neill 1990). In agricultural areas, soil arsenic levels are often much higher because of the widespread use of arsenical insecticides in the past.

Soil concentrations adjacent to the viewing platform

Concentrations of copper, chromium, and arsenic in the lower 150- to 300-mm (6- to 12-in.) assay zone of soil samples were consistently less elevated than those in the upper 0- to 150- mm (0- to 6-in.) assay zone. Accordingly, this paper will focus on concentrations detected in the upper assay zone.

Copper concentrations in the soil directly under the dripline of the viewing platform gradually increased during the 5 years after construction, reaching a geometric mean concentration of 52 mg/kg **(Table 2).** Most of this increase occurred over the much longer intervals of the later sampling episodes, with little increase noted until a sample containing 56 mg/kg copper was removed at the 11-month collection. The maximum copper concentration detected was 73 mg/kg at 24 months after construction, but a similar concentration (72 mg/kg) was also detected 60 months after construction. Movement of copper away from the viewing platform through the soil was very limited. With the exception of two samples removed 0.15 m (6 in.) away from the platform at the 11- and 60-month samplings, elevated copper concentrations were not detected except in the dripline area.

Chromium levels in the soil remained low throughout the course of the study **(Table 2).** The highest chromium concentration detected was 23 mg/kg in a sample removed from under the dripline of the viewing platform 60 months after construction. Chromium release from CCA-C-treated wood is generally lower than that of copper or arsenic, and the rate of release from the platform was apparently not great enough to allow significant accumulation in the soil. Both copper and chromium movement in soil is limited by their strong reactivity with soil components. Thus, it is unlikely that copper or chromium leached into the soil is being diluted below detectable levels.

Arsenic soil concentrations showed little change until 5.5 months after construction, when a maximum of 36 mg/kg was detected under the dripline of the viewing platform **(Table 2).** However, geometric mean concentrations in that area did not appear to increase until 11 months after construction, at which time the geometric mean concentration was 12 mg/kg. Arsenic levels in the dripline area then declined to a geometric mean of 2 mg/kg 24 months after construction, before increasing to 48 mg/kg months after construction. At the 60-month sam-

Table 2. — Total copper, chromium, and arsenic concentrations (mg/kg) in the upper 150 mm of soil samples removed from adjacent to the viewing platform (geometric mean and maximum).

	Distance from walkway									
	0 m (dripline)		0.15 m		0.3 m		0.6 m		Controls	
Months after construction	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
	(mg/kg)									
Copper										
0.5	22	23	22	25	19	27	21	24	23	24
2	26	32	22	24	23	27	23	25	22	24
5.5	26	34	21	25	21	22	20	23	19	22
11	31	56	25	38	23	29	21	24	20	22
24	37	73	29	33	22	26	24	27	22	24
60	52	12	28	37	24	29	26	28	30	32
Chromium										
0.5	7	8	8	9	8	9	7	8	8	10
2	9	9	8	8	9	10	9	10	8	9
5.5	9	11	8	10	10	13	8	10	8	9
11	10	13	8	12	13	20	10	12	8	10
24	13	17	14	16	13	17	12	13	13	15
60	20	23	16	21	14	18	15	17	14	15
Arsenic										
0.5	4	6	1	2	1	2	1	1	1	1
2	2	6	2	5	2	4	1	2	1	1
5.5	7	36	2	7	2	3	1	3	1	3
11	12	29	7	14	4	7	3	5	3	2
24	2	24	3	10	1	1	1	2	1	2
60	48	117	10	32	5	13	4	5	2	4

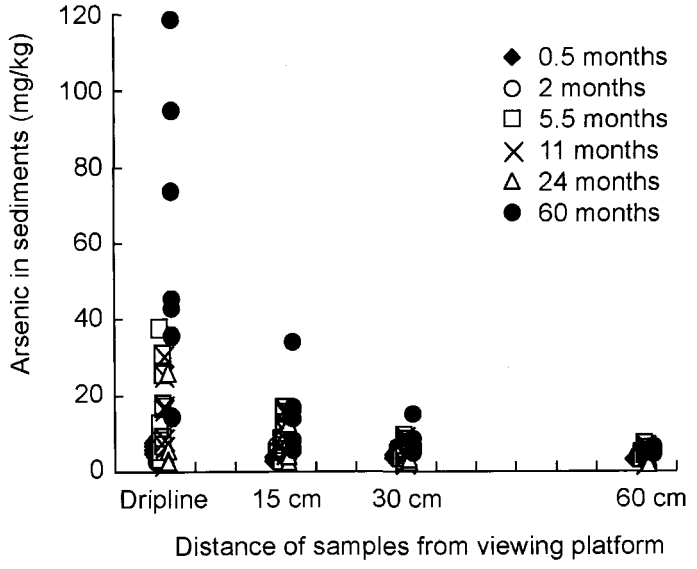

Figure 2. — Total arsenic concentrations (mg/kg) detected in soil samples removed adjacent to the CCA-treated viewing platform.

pling, five of the seven samples collected from the dripline area contained more arsenic than any previous soil sample **(Fig. 2).** The reason for the decline in arsenic concentration at 24 months is unclear. Leached CCA components are not uniformly distributed in the soil, and it is possible that the samples removed at 24 months did not happen to encounter pockets of contamination. Arsenic leaching may have also been lower during the second year of the study because less rainfall occurred than in the first year **(Table 1)** and because the rate of arsenic leaching from CCA-treated wood is typically highest initially and then declines to a lower plateau with time (Lebow 1996). However, this reasoning would not explain the much higher arsenic levels detected 60 months after construction. The increase at 60 months may be partially attributable to the addition of an interpretive display on the railing directly above the sampling area shortly after the 24-month sample collection. The presence of the display probably increased foot traffic and subsequent abrasion of particles into the sampling zone.

Leached arsenic did appear to have greater soil mobility than copper or chromium, because occasional elevated samples were found as much as 0.3 m (1 ft.) from the dripline. This was most evident at the 60-month sample collection **(Fig. 2).** Studies of the movement of CCA constituents in soils with varying compositions generally agree that although

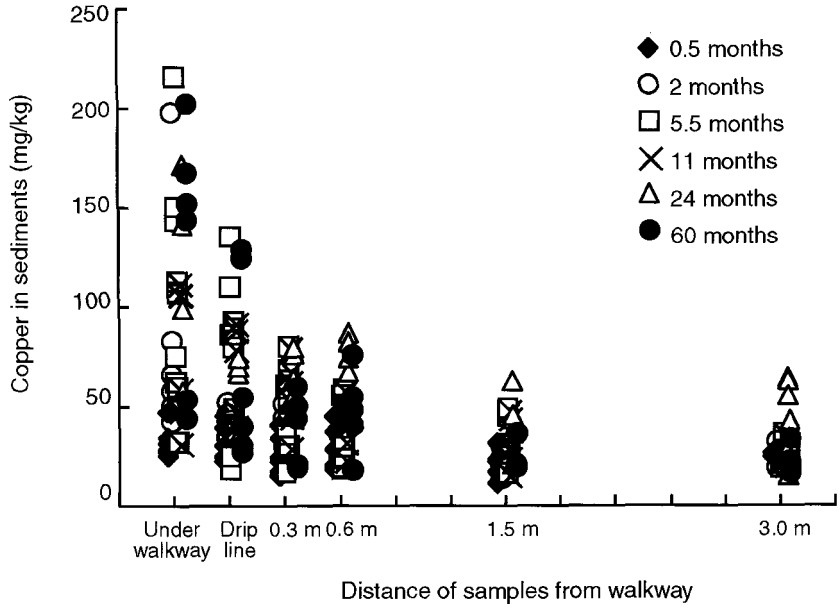

Figure 3. — Total copper concentrations (mg/kg) detected in sediment samples removed adjacent to the CCA-treated walkway.

the constituents are not highly mobile, significant movement of arsenic may occur in sandy soils (Chen and Walters 1979, De Groot et al. 1979, Bergman 1983, Brown 1986, Bergholm and Dryler 1989, Bergholm 1990, Murphy and Dickinson 1990, Lund and Fobian 1991, Holland and Orsler 1995). Holland and Orsler (1995) evaluated the ability of various soil types to adsorb CCA components from a 3 percent solution. They found that a sandy, free-draining soil adsorbed very little if any of the CCA components, while sphagnum peat, containing 98 percent organic material, readily adsorbed all three CCA components. Two loam/clay soils adsorbed copper and arsenic but very little chromium, while a third loam/clay soil adsorbed only arsenic and to a lesser degree than the other two loam/clay soils. The authors concluded that although a high organic content was generally associated with the capability to adsorb all three CCA components, other factors such as pH or inorganic constituents must also play a role. The relatively poor adsorption of chromium found in the study is somewhat surprising, although the concentration of CCA components used by Holland and Orsler was many times greater than might be expected to result from CCA leaching in service.

Holland and Orsler's (1995) arsenic adsorption results generally agree with studies of contaminated soils around treating plants, in which the highest levels of arsenic were retained in the soils with high levels of clay or organic matter (Bergman 1983, Bergholm and Dryler 1989, Bergholm 1990). One other study of CCA-contaminated soils in Denmark also reported that virtually all of the chromium and the majority of copper and arsenic were deposited within the first 250 mm (10 in.) of soil, the area high in organic carbon (Lund and Fobian 1991). A similar Swedish study reported that elevated copper, chromium, and arsenic levels were found only in the top 100 to 400 mm (4 to 15.7 in.) of contaminated soil and that levels were highest in soils with a high proportion of organics (Bergman 1983). A subsequent Swedish study reported that the retention capacity of arsenic in fine sand was approximately 100 mg/kg, while that in clay soil was about 500 mg/kg and that in marsh peat soil was about 5,000 mg/kg (Bergholm and Dryler 1989).

The soil at the site for this study was classified as sandy loam, with approximately 70 percent sand, 20 percent silt, and 6 to 7 percent clay (Lebow et al. 2000). Based on previous studies, the sandy nature of the soil at this site may have allowed leached arsenic components to be relatively mobile, while the relatively high cation exchange capacity (24 to 30 milliequivalents) may be responsible for limiting the movement of copper and chromium.

The biological implications of the detected soil concentrations of arsenic, copper, and chromium are unclear. The geometric mean copper and chromium soil concentrations remained relatively low compared with control concentrations, but the geometric mean arsenic concentration immediately under the dripline of the viewing platform exceeded control concentrations by more than a factor of 10. Although the effects of various arsenic concentrations on soil organisms is not well known, soil microorganisms are generally thought to be capable of tolerating relatively high levels of arsenic (Eisler 1988). A screening benchmark concentration for the toxicity of arsenic to earthworms of 60 mg/kg has been proposed by Efroymson et al. (1977), while a slightly higher screening benchmark (100 mg/kg) has been proposed for toxicity to soil microorganisms and microbial processes (Efroymson et al. 1997). Only one sample removed during the course of the study exceeded these benchmarks, and the geometric mean concentrations of arsenic remained below both benchmarks, even under the dripline of the viewing platform.

Sediment concentrations adjacent to the elevated walkway

Concentrations of total copper, chromium, and arsenic in the lower 25- to 100-mm (1- to 4-in.) assay zone of sediment samples were consistently less elevated than those in the upper 0- to 25-mm (0- to 1-in.) assay zone. Accordingly, this paper will focus on concentrations detected in the upper assay zone.

Increased copper concentrations were detected in wetland sediment samples 0.5 months after construction, and geometric mean concentrations under the walkway and in the dripline area were elevated to 75 and 43 mg/kg, respectively, 2 months after construction **(Table 3).** Concentrations in these areas remained elevated at each subsequent inspection, with the greatest geometric mean level found at the 60-month sampling. Occasional elevated samples were also found at distances of up to 3 m (10 ft.) from the walkway **(Fig. 3),** and geometric mean concentrations were elevated at 0.3 and 0.6 m (1 and 2 ft.) from the walkway. Elevation of concentrations in samples at 0.6, 1.5, and 3 m (2, 5, and 10 ft.) from the walkway was greatest 24 months after construction, but in the other sampling areas, concentrations were less affected by time of sampling.

Elevated chromium concentrations were detected under the walkway 2 months after construction, when a maximum concentration of 104 mg/kg was

Table 3. Total copper, chromium, and arsenic concentrations (mg/kg) in the upper 25 mm of sediment samples removed from adjacent to the elevated walkway (geometric mean and maximum).

	Distance from walkway													
	Under		0 m (dripline)		0.3 m		0.6 m		1.5 m		3 m		Controls	
Months after construction	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.	Mean	Max.
	(mg/kg)													
Copper														
0.5	34	49	33	48	27	43	31	48	22	34	28	28	23	29
2	75	201	43	55	35	54	31	48	24	32	28	35	24	26
5.5	98	219	58	138	40	64	30	59	23	28	25	27	20	23
11	73	115	63	95	57	83	44	61	33	51	30	38	31	60
24	86	174	58	77	63	82	68	90	42	66	41	67	--	--
60	113	205	59	132	38	63	46	79	26	39	24	36	25	32
Chromium														
0.5	14	23	18	37	13	21	16	27	10	17	12	12	10	12
2	33	104	21	33	17	38	15	29	13	17	13	14	10	11
5.5	27	55	19	38	16	30	13	23	10	13	12	15	9	12
11	21	37	17	32	18	40	14	24	11	14	14	18	9	11
24	20	25	22	57	19	32	22	30	13	22	14	19	--	--
60	32	45	21	47	15	23	20	60	11	13	14	22	9	9
Arsenic														
0.5	10	16	11	32	6	18	10	24	5	10	12	12	3	4
2	41	130	19	34	14	28	10	24	7	13	16	22	4	6
5.5	39	82	17	88	12	35	8	39	5	9	8	15	2	4
11	38	65	33	58	36	78	25	42	14	24	13	18	6	10
24	8	24	4	33	7	23	9	31	4	24	8	33	-	-
60	49	165	36	167	10	47	21	51	4	6	9	74	2	3

detected **(Table 3).** Chromium levels generally stabilized or declined at subsequent sample collections. Occasional elevated samples were also detected in the dripline sampling zone and 0.3 and 0.6 m (1 and 2 ft.) away from the walkway. As in the soil samples, chromium concentrations in the wetland were generally lower than those for copper and arsenic.

Arsenic concentrations in sediments under the walkway also noticeably increased within 2 months after construction, with a maximum of 130 mg/kg detected **(Table 3).** Elevated concentrations were also detected in samples removed at all tested distances away from the walkway except control locations. During the remainder of the first year, arsenic concentrations appeared to remain relatively stable under the walkway, while they gradually increased in samples removed at greater distances from the walkway. This trend was reversed at the 24-month sampling, when geometric mean arsenic concentrations decreased for all sampling locations. At the 60-month inspection, arsenic concentrations were again elevated to levels similar to those found at the 11-month inspection. The steep drop in arsenic concentration at the 24-month sampling is similar to that observed in the soil samples removed from adjacent to the viewing platform. Again, the reason for this dip is unclear. The effect could be explained if flooding washed sediments in the area downstream, but no similar 24-month decrease was observed for copper or chromium.

During the course of this study, elevated arsenic levels were consistently detected 3 m (10 ft.) downstream from the walkway. After only 0.5 months, geometric mean arsenic levels at the 3-m (10-ft.) location appeared to be greater than at the 0.3- and 1.5-m (1- and 5-ft.) locations, which suggests that this area may have been contaminated during construction activities. Still, it is apparent that arsenic moved at least 1.5 m (5 ft.) from the walkway and may have traveled 3 m (10 ft.) from the walkway by the 11-month inspection.

Arsenic is generally thought to have greater environmental mobility than copper or chromium because it is more water soluble and less likely to be adsorbed (Lebow 1996). Arsenic reactivity in sediments is most strongly related to inorganic constituents; iron oxide, aluminum, calcium, and clay minerals are important in binding arsenic (Fordham and Norrish 1974, Frost and Griffin 1977). Conversely, copper and chromium deposited in sediments are usually complexed with organic compounds (Giesking 1975, Tan 1993), and the quantity of fine sediments at the site, as well as the localized pattern of their distribution, suggests that the majority of copper and chromium released from the wood rapidly becomes associated with sedimentary material. Further mobility is likely to occur primarily when the sediments themselves are dislodged by high water or other types of disturbances.

It is interesting that sediment concentrations of all three CCA components reached maximum or near maximum levels within the first year after construction, because it was during this time span that aquatic invertebrate populations in the vegetation and sediments were monitored (Brooks 2000). A comparison of the invertebrate community present during baseline sampling with that observed during post-construction spring and summer sampling indicated that no taxa were excluded or significantly reduced in number by the boardwalk construction. Because of its aquatic toxicity, copper was considered to be the element of primary concern, but there appeared to be little if any correlation between sediment copper levels and the number or diversity of aquatic invertebrates. Brooks hypothesized that the lack of impact in those cases was related to type of invertebrates present. He noted that invertebrates that live in sediments associated with slow, stagnant water tend to be more robust and less sensitive to pollutants than those living in areas with rapidly moving water (Brooks 2000). Because leached preservative components generally only reached elevated levels in the sediments of slow-moving water, if at all, it appears unlikely that elevated preservative levels and highly pollutant-sensitive invertebrates would be found in the same location.

Comparison of soil and sediment concentrations

Total chromium, copper, and arsenic concentrations in the sediments were generally much higher than those detected in soil. This is somewhat surprising, because one might expect that CCA-C components released into water would be more rapidly dispersed to lower levels than those that drip directly onto a localized area of soil. The single greatest cause of this disparity may be the difference in sampling zones. The greater depth of the soil sampling zone (150 mm [6 in.] compared with 25 mm [1 in.] for sediments) may have contributed to the lower soil concentrations. Another possible explanation is that a larger volume of wood was used in construction of the boardwalk over the sediments. The vertical columns are much taller in this portion of the boardwalk, and extensive cross-bracing was employed because of the height of the boardwalk. It is also probable that the portions of the columns exposed to standing water released CCA-C components at a faster rate than their counterparts above the soil that were exposed to leaching only during rainfall events. A third possibility is that abrasion from foot traffic caused a greater release of treated particles into the sediment area. The soil samples were removed from the edge of a viewing platform, where foot traffic was probably relatively light. The sediment samples, in contrast, were removed under and downstream from an elevated portion of the walkway itself, where foot and bicycle traffic was probably much greater.

Conclusions

The results of this study demonstrate that, when used in an area of high rainfall, CCA-C-treated wood structures can cause measurable increases in environmental concentrations of total copper, chromium, and arsenic in close proximity to the treated wood. The environmental concentrations varied with time, proximity to the treated wood and type of exposure. Concentrations of leached components in the soil developed slowly and were greatest at the 5-year sampling event. Concentrations of leached components in the sediments increased more quickly than in the soil, reaching maximum or near-maximum levels within the first year. As discussed in an earlier report (Brooks 2000), sediment concentrations detected within the first year did not have a measurable impact on aquatic invertebrate populations. Sediment concentrations were also generally greater than those found in soil. This may be a function of the deeper sampling zone for the soil, or it may suggest that factors other than leaching, such as abrasion caused by foot traffic, may be contributing to environmental releases. As expected, the environmental mobility of leached CCA components was much lower in soil than in the sediments. Soil samples with elevated levels of copper and chromium were confined to directly under the dripline of the viewing platform, and arsenic appeared to be limited to within 0.3 m (1 ft.) of the structure. In contrast, elevated concentrations of copper, chromium, and arsenic were found in sediments as much as 3 m (10 ft.) from the elevated walkway. In both soil and sediment samples, copper and arsenic concentrations were consistently more elevated than chromium concentrations.

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