Rate of CCA leaching from commercially treated decking

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Abstract

Conflicting reports on levels of arsenic in soil beneath decks treated with chromated copper arsenate (CCA) have raised concerns about arsenic exposure from this type of treated wood. This paper reports on an evaluation of the rate of release of copper, chromium, and arsenic from commercially treated lumber as a function of treatment additive (with or without water repellent) and rate of rainfall. Treated lumber was purchased from several retailers at three times over the course of a year, and exposed under laboratory conditions to simulated rainfall at rates of 2.5, 8.0, or 25.4 mm/hr., up to a total of 762 mm of rainfall. Water running off the specimens was periodically collected and analyzed for the concentration of leached arsenic, chromium, and copper. The amount of arsenic released from each specimen ranged from 0.16 percent when rainfall was delivered at 25.4 mm/hr. to 0.72 percent when rainfall was delivered at 2.5 mm/hr. The rate of arsenic release was highest initially and then stabilized at an average of 0.0143, 0.0079, and 0.0062 $\mu g/cm^2$/mm rainfall for the 2.5, 8.0, and 25.4 mm/hr. rainfall rates, respectively. The inclusion of water repellent in the CCA treatment did not have a consistent effect on leaching. In most cases, leaching of arsenic was greater in specimens containing the water-repellent additive, but the water repellent did appear to reduce leaching of copper, Using similar methodology, a secondary study was conducted to evaluate the ability of several finishes to reduce leaching. The results indicate that finishing decking with a semi-transparent water-repellent stain, latex paint, or oil-based paint will greatly reduce the leaching of arsenic, chromium, and copper.

Pressure-treated wood contains chemicals that are toxic to wood-degrading organisms. If leached from the wood in sufficient quantities, these chemicals could potentially also be toxic to non-target organisms in the surrounding environment. Because of this concern, there have been several recent studies of preservative leaching and accumulation in the environment (Stilwell and Gorny 1997; Lebow et al. 1999,2000; Brooks 2000; Morrell and Rhatigan 2000). These studies have reported widely variable amounts of leaching or environmental accumulation. It is evident that a more systematic effort is needed to evaluate the rates of preservative leaching under in-service conditions. In particular, more research is needed on the rate of preservative leaching from treated wood used in applications above the ground or above water.

Most previous studies of preservative leaching have utilized small samples to accelerate leaching or have evaluated rates of leaching from samples submerged in water. Although constant immersion might be expected to produce the most severe leaching conditions, the vast majority of treated wood is used above ground or above water, where it is not continually exposed to standing water. Conflicting reports on levels of arsenic in soil beneath decks treated with chromated copper arsenate (CCA) have raised concerns about arsenic exposure from this type of treated wood (Stilwell and Gorny 1997, Lebow et al. 2000). A recent agreement between the Environmental Protection Agency and CCA producers has curtailed the use of CCA-treated wood for many consumer applications, including decking. This action has heightened concerns about leaching from newly constructed and existing decks in both residential applications and in natural environments, such as boardwalk decking. Previous

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studies have reported a wide range of arsenic levels in soil below deck-type structures. In one study, chromium, copper, and arsenic levels were measured adjacent to CCA-treated boardwalks at several sites in southern Tasmania (Comfort 1993). The boardwalks varied from 1 to 14 years in age; the preservative retention and treating solution formulation were not reported. Arsenic levels were not found to be significantly elevated above the controls. 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 of metal detected.

Repeated samplings of soil beneath an elevated walkway in western Oregon before construction and during the first year afterward revealed that the levels of CCA components in some samples were elevated above pre-construction levels, although most samples did not contain elevated levels (Lebow et al. 2000). The maximum arsenic level detected in the upper 15 cm of soil was 36 mg/kg; 11 months after construction, the average level of arsenic was 15 mg/kg, compared with an average of 2 to 3 mg/kg before construction. Little elevation of CCA components was found in samples removed 15 cm or more away from the deck, or at depths greater than 15 cm. In this study, construction was closely monitored to ensure that sawdust and other treated wood construction debris were not deposited in the soil beneath the deck (Lebow et al. 2000).

Substantially higher levels of CCA-C components were detected when investigators collected soil samples from beneath residential decks constructed from CCA-C treated wood (Stilwell and Gorny 1997). Several samples contained more than 100 mg/kg copper, and a maximum level of 410 mg/kg copper was detected under one deck. In some samples, chromium concentrations were also elevated to over 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 levels 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 (Comfort 1993), Stilwell and Gorny (1997) noted an increase in soil CCA component levels with increasing age of the deck.

The finding of higher levels of arsenic beneath residential decks compared with decks built in natural areas emphasizes the importance of separating arsenic contributions caused solely by leaching from those caused by other human activities. In samples removed from beneath existing residential structures, there is typically little information on pre-construction arsenic levels or on arsenic contributions from sawdust or refinishing activities such as sanding. One objective of our study was to develop leaching rates that could be used to estimate the contribution of arsenic to soil solely from leaching.

The rate of leaching from wood exposed aboveground is not easily assessed because it is dependent on the pattern of rainfall and possibly other exposure factors such as sunshine and humidity. In addition, decking is often finished and the finish may influence leaching (Cooper et al. 1997b). Few studies have attempted to determine aboveground rates of preservative leaching, which is difficult to assess. Studies of this type have been limited to situational exposures under non-reproducible conditions.

As part of a larger wetland boardwalk study, Lebow et al. (2000) collected rainwater from end-sealed deckboard specimens that had been treated with CCA Type C (CCA-C), ammoniacal copper zinc arsenate (ACZA), or ammoniacal copper quat Type B (ACQ-B) and exposed for 1 year in western Oregon. That study presented an extreme exposure scenario because of a high number of days with precipitation. Other studies have measured preservative concentrations in rainwater run-off from treated fence boards (Cooper and MacVicar 1995), transmission poles (Cooper et al. 1997a), deck sections (Cooper et al. 1997b, Cui and Walcheski 2000), and shingles (Evans 1987). Although all of these studies have provided needed information on leaching rates under environmental conditions specific to a given site and time, it is difficult to use these data to predict leaching rates under other conditions. Studies of leaching rates under controlled, reproducible conditions are needed to allow modeling and prediction of expected releases under a wide range of exposure conditions.

This paper reports on an evaluation of the rate of release of copper, chromium, and arsenic from commercially treated lumber as a function of treatment additive (with or without water repellent) and rate of rainfall. It also reports on a secondary evaluation of the effect of three types of finishes on leaching. A subsequent paper will report on the effect of retention and wood species on leaching, and present a model for estimation of preservative leaching as a function of rate and frequency of rainfall at a particular location.

Materials and methods

Source of material

The study material was southern pine (mixed species) 38- by 140-mm (nominal 2- by 6-in.) lumber, commercially treated with CCA-C to a target retention of 6.4 kg/m^3. For replication, lumber was purchased from several retailers in the area of Madison, Wisconsin; the purchases and leaching trials were conducted in three separate batches spaced over the course of a year. Only boards free of heartwood were selected. Three boards with an incorporated water repellent and three boards without an incorporated water repellent were purchased for each trial; three defect-free 254-mm-long specimens were cut from each board. The target retention of the water repellent was 5.6 kg/m^3.

Previous studies demonstrated that the leach resistance of CCA-treated wood is dependent on the completion of a complex series of fixation reactions that occur after treatment (Lebow 1996). These fixation reactions can occur within hours at high temperatures (40"to 50°C), but may take weeks to reach completion at temperatures below 10°C. To avoid introducing variability caused by incomplete fixation, all boards were conditioned to constant weight in a room maintained at 65 percent relative humidity (RH) and 23°C. Because these short specimens had a muck higher proportion of exposed end grain than does a typical deckboard the ends of the specimens were coated with a neoprene rubber sealant to prevent leaching from the end grain.

To evaluate the effect of finishes on leaching, an additional seven 38- by

Table 1. – Volume and hours of rainfall for eight collection periods.

Collection period	Rainfall	Hours of rainfall for each rate of rainfall		
		2.5 mm	8.0 mm	25.4 mm
	(mm)	(hr.)		
1	19	7	2	0.8
2	44	18	5	1.7
3	64	25	8	2.5
4	127	50	16	5
5	127	50	16	5
6	127	50	16	5
7	127	50	16	5
8	127	50	16	5
Total	762	300	95	30
Average hours per day		14.3	3.2	1.4

140-mm (nominal 2- by 6-in.) southern pine (mixed species) boards that had been commercially treated with CCA to a target retention of 6.4 kg/m^3 were purchased at a local lumber yard. The treatment did not incorporate a water repellent. The boards were conditioned to constant weight in a room maintained at 65 percent RH and 23°C; four defect-free 254-mm-long specimens were cut from each board. Because this portion of the study was intended to evaluate the effect of finishes on leaching, and not to quantify release rates that might occur in service, the end grain of these specimens was not sealed with a neoprene coating. Instead, the respective finishes were applied to all surfaces. One of the four specimens from each board was left uncoated (control); the other three specimens were brushed with either latex primer followed by one coat of outdoor latex paint, oil-based primer followed by one coat of oil-based paint, or two coats of a semi-transparent penetrating oil water-repellent deck stain. Each coating combination was replicated seven times.

Assay for preservative retention

Each specimen was assayed for arsenic, copper, and chromium content in a manner similar to that used to determine retention in commercial charges. Samples of wood 9.5 mm in diameter and 15 mm in depth were removed from the narrow faces of each specimen and digested and analyzed in accordance with AWPA Standard A21-00 (AWPA 2001). The AWPA standard density value for southern pine (512 kg/m^3) was used to calculate preservative concentration on a weight/volume basis (AWPA 2001). The resulting holes in the specimens were plugged with rubber stoppers. The samples were not assayed for Water-repellent content.

Leaching methodology

Unfinished specimens. — The methodology used in this study was intended to quantify leaching from treated wood exposed to a range of rainfall rates under controlled conditions. The leaching trials were conducted in three replicate batches over the course of a year, corresponding to the three replicate purchases of treated lumber. For each replicate, end-matched specimens cut from each board were exposed to 3 weeks of simulated rainfall at one of three rainfall rates. The assignment of specimens to each rainfall rate and the placement of specimens within the rainfall chamber were randomized in each case. The leaching trials were conducted at ambient room temperature (21° to 25°C).

A device was constructed to spray deionized water on the specimens, with the rate of rainfall controlled by adjusting the ratio of air to water pressure supplied to the nozzles. Each specimen was placed horizontally in an individual tray with a wide face oriented upwards. The trays were equipped with drains so that all water running off the specimens could be collected. Specimens were supported so that they did not contact standing water in the tray. To simulate the wetting and drying of rainfall episodes, specimens were sprayed with fine droplets of deionized water at flow rates of 2.5, 8.0, or 25.4 mm/hr. over a period of 3 weeks. The hours of spray were adjusted **(Table 1)** so that specimens were exposed to the equivalent of 762 mm of rainfall, which approximates the national average annual rainfall (NOAA 2001). The rainwater run-off from each specimen was analyzed at eight intervals during the 3-week exposure. At each interval, the water in the collection container was weighed, acidified with nitric acid, and sub-sampled for analysis. The collection container was then emptied before reattachment to the specimen tray. The water was not reused or recirculated. The leachate samples were analyzed for arsenic, chromium, and copper by inductively coupled plasma (ICP) emission spectrometry. The detection limits of the method were approximately 5 µg/L for arsenic and 2 µg/L for chromium and copper.

Finished specimens.—The finished specimens were exposed to leaching by simulated rainfall in the manner described for unfinished specimens, except that only one rainfall rate (8.0 mm/hr.) was evaluated and the leaching trial was not replicated.

Statistical methods

The experimental design for this experiment was a strip plot with the main "strip" factors of flow rate and commercial treatment type. The strip plot was repeated three times in a block-type manner. Repeated measurements were made for each specimen, as indicated in **Table 1.**

Because several of the repeated measurements fell below the detection limits of the instrument, total leaching for some elements of these specimens were assumed to fall within a certain interval as calculated from the detection limits. Means and standard deviations for the totals were estimated by maximum likelihood methods using proc Lifereg (SAS Institute 1999), with interval censoring, and assuming an underlying normal distribution. Because of small sample sizes, standard deviations were not bias adjusted, but they can be biased adjusted by multiplying by $(n/(n-1))^{1/2}$ to give unbiased estimates for these parameters in the uncensored treatment groups.

For mean comparisons, half the detection limit was substituted (by simple imputation) for censored observations. The data were then analyzed using a repeated measurement mixed-effects model, assuming an exponential spatial (one-dimensional) correlation structure. Means of total leaching were estimated and then compared via linear contrasts. The estimated mean totals from these models were in good agreement with those

Table 2. – Concentration of arsenic, chromium, and copper in treated specimens.[a]

Rainfall	Water repellent	Trial 1 As	Cr	Cu	Element total	Oxide total	Trial 2 As	Cr	Cu	Element total	Oxide total	Trial 3 As	Cr	Cu	Element total	Oxide total
(mm/hr.)		(kg/m³)														
25.4	No	1.637	1.958	0.980	4.575	7.489	1.580	1.777	0.957	4.313	7.024	1.536	1.526	0.794	3.856	6.272
		0.261	*0.288*	*0.125*	*0.674*	*1.084*	*0.519*	*0.579*	*0.324*	*1.421*	*2.309*	*0.087*	*0.130*	*0.099*	*0.316*	*0.498*
	Yes	1.196	1.282	0.618	3.096	5.065	1.497	1.544	0.796	3.837	6.250	1.083	1.121	0.625	2.829	4.590
		0.415	*0.419*	*0.191*	*1.025*	*1.670*	*0.465*	*0.474*	*0.257*	*1.197*	*1.941*	*0.153*	*0.152*	*0.088*	*0.393*	*0.636*
8.0	No	1.492	1.930	1.050	4.471	7.300	1.595	1.751	0.972	4.318	7.017	1.469	1.443	0.762	3.674	5.970
		0.363	*0.439*	*0.199*	*1.000*	*1.634*	*0.528*	*0.581*	*0.338*	*1.448*	*2.342*	*0.111*	*0.134*	*0.071*	*0.316*	*0.516*
	Yes	1.133	1.293	0.732	3.158	5.132	1.447	1.495	0.805	3.747	6.090	1.117	1.119	0.622	2.857	4.634
		0.373	*0.415*	*0.259*	*1.047*	*1.688*	*0.382*	*0.409*	*0.228*	*1.019*	*1.652*	*0.152*	*0.155*	*0.114*	*0.421*	*0.673*
2.5	No	1.594	1.893	1.004	4.490	7.327	1.518	1.692	0.904	4.113	6.700	1.455	1.492	0.819	3.766	6.115
		0.280	*0.348*	*0.094*	*0.722*	*1.194*	*0.517*	*0.524*	*0.316*	*1.356*	*2.191*	*0.184*	*0.216*	*0.128*	*0.528*	*0.850*
	Yes	0.989	1.045	0.529	2.563	4.180	1.494	1.585	0.782	3.860	6.305	1.067	1.194	0.643	2.905	4.730
		0.370	*0.372*	*0.202*	*0.944*	*1.530*	*0.246*	*0.269*	*0.138*	*0.653*	*1.064*	*0.111*	*0.108*	*0.086*	*0.305*	*0.483*

[a] Each value is the average of three replicates. Numbers in italics represent one standard deviation about the mean.

Table 3. – Amount of arsenic, chromium, and copper leached from specimens with or without water repellent,[a]

Rainfall	Water repellent	Trial 1[b] As	Cr	Cu	Trial 2[b,c] As	Cr	Cu	Trial 3[c] As	Cr	Cu	Combined averages[d] As	As	Cr	Cr	Cu	Cu
(mm/hr.)		(mg)										(%)	(mg)	(%)	(mg)	(%)
25.4	No	3.746	2.854	5.203	0.334	0.347	1.877	6.370	2.521	3.424	3.476	0.162	1.907	0.080	3.501	0.285
		0.350	*0.784*	*1.338*	*0.078*	*0.384*	*1.898*	*0.796*	*0.552*	*0.717*	*2.531*		*1.262*		*1.953*	
	Yes	6.323	1.976	2.752	0.101	0.016	0.269	10.286	3.261	3.208	5.579	0.328	1.761	0.099	2.076	0.226
		1.918	*0.708*	*0.573*	*0.003*	*10.001*	*0.104*	*4.415*	*2.036*	*1.571*	*5.020*		*1.816*		*1.614*	
8.0	No	3.809	3.195	6.909	1.201	0.144	1.015	9.625	3.285	5.969	4.878	0.238	2.208	0.096	4.631	0.369
		1.397	*0.862*	*2.181*	*1.207*	*0.142*	*1.156*	*0.817*	*0.515*	*0.872*	*3.709*		*1.574*		*2.995*	
	Yes	6.896	1.36[c]	0.653	0.343	0.172	0.291	11.054	3.931	4.909	6.097	0.366	1.822	0.104	1.951	0.201
		2.715	*1.317*	*0.798*	*0.300*	*0.114*	*0.200*	*3.052*	*1.475*	*1.129*	*5.005*		*1.941*		*2.242*	
2.5	No	9.100	4.719	8.314	7.505	0.100	4.492	14.063	3.764	6.613	10.222	0.497	2.861	0.125	6.473	0.527
		2.016	*2.418*	*2.952*	*3.302*	*<0.001*	*2.324*	*1.503*	*0.718*	*1.914*	*3.679*		*2.467*		*2.893*	
	Yes	8.148	2.737	3.063	4.896	0.259	1.807	21.562	8.584	8.110	11.535	0.721	3.860	0.224	4.327	0.491
		1.093	*1.204*	*1.120*	*2.954*	*0.223*	*0.742*	*5.917*	*3.315*	*1.224*	*8.187*		*4.044*		*2.919*	

[a] Numbers in italics represent one standard deviation about the mean (biased).
[b] Each value represents the average of three replicates.
[c] Includes interval censored observation (see Methods.)
[d] Each value represents average of nine replicates

estimated by the previously described censoring methods.

Results and discussion

Preservative concentration in wood

Analysis of preservative concentration in the wood revealed that specimens without an incorporated water repellent were relatively close to the target retention of 6.4 kg/m^3, but specimens cut from boards with water repellent tended to be below this target **(Table 2).** A portion of this difference might be attributable to the slightly higher density of the lumber with an incorporated water repellent (an increase of 5.6 kg/m^3), or it may reflect differences in the treatment process such as the use of lower CCA solution concentrations. Within each replicate and type of treatment, the retentions of specimens exposed to the three rainfall rates were fairly uniform, reflecting the end matching of specimens cut from longer boards.

Effect of rate of rainfall on leaching

Leaching of arsenic, chromium, and copper was greatest at the slowest rainfall rate **(Table 3, Fig. 1).** This effect was most evident for arsenic; two to three times more arsenic was released at a rainfall rate of 2.5 mm/hr. than at 25.4 mm/hr. The amounts of copper and chromium leached were less sensitive to the rate of rainfall, although the effect was still noticeable. It also appears that the effect of rainfall rate is not linear **(Fig. 2).** Increasing the rate of rainfall from 2.5 to 8.0 mm/hr. cut the amount of arsenic leached in half, whereas further increasing the rate of rainfall to 25.4 mm/hr. caused only a slight reduction in the amount of arsenic released. This finding indicates that leaching from CCA-treated decking may be greatest in

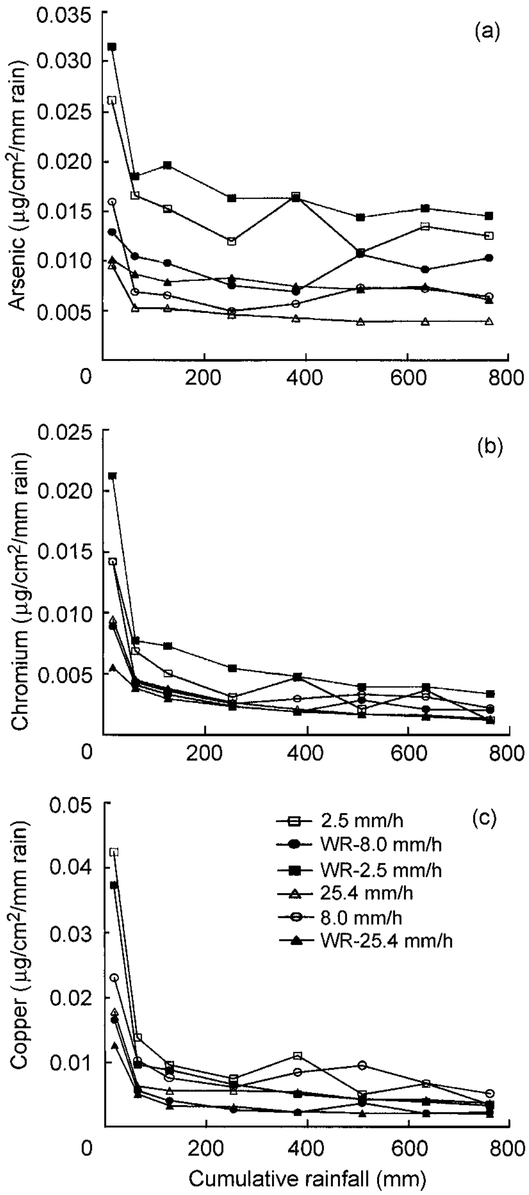

Figure 1. – Rate of release of CCA components over the course of the leaching trial; (a) arsenic, (b) chromium, (c) copper. WR = water repellent.

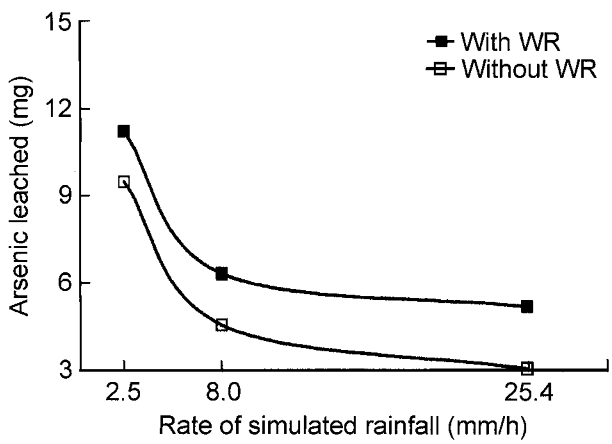

Figure 2. – Relationship between rate of rainfall and total amount of arsenic leached from specimens with and without water repellant. All replicates averaged.

climates with extended periods of light, drizzly rainfall. A previous study of sections of CCA-treated decking exposed in this type of climate (western Oregon) (Lebow et al. 2000) reported slightly higher release rates than those detected in the slowest rainfall rates evaluated in the study reported here. In contrast, leaching would be minimized in climates where rainfall tends to occur in short, heavy showers.

It is not surprising that for a given amount of rainfall, more leaching would occur at slower rainfall rates. At faster rates, the water would have less contact time with the wood, and a higher proportion of water would run off the specimens without causing leaching. Previous researchers have theorized that this may be the case. Evans (1987) found that run-off from CCA-treated pine roof boards contained higher concentrations of copper, chromium, and arsenic when exposed to drizzling rain compared with heavy showers. A similar effect was suggested by Cockroft and Laidlaw (1978).

The effect of rate of rainfall suggests that time between rainfall events may also affect leaching. Because wetting and diffusion take time, intermittent rainfall with periods of diffusion may be more efficient at causing leaching than continuous rainfall for a given volume of rain. This effect is being investigated and will be reported in a subsequent paper.

Effect of incorporated water repellent

The incorporation of a water repellent with the CCA treatment produced conflicting effects on leaching. A water repellent might be expected to reduce leaching by slowing the movement of water into the wood. However, the amount of arsenic leached from these specimens was generally greater than that from specimens that did not contain a water repellent **(Table 3).** For the first trial, leaching of chromium was lower from specimens with the incorporated water repellent. For the third trial, however, leaching of chromium appeared to be greater from specimens with an incorporated water repellent. For the first and second trials, leaching of copper was much lower from specimens with water repellent, but this effect was not apparent in the third trial.

The conflicting nature of these results makes it difficult to draw general conclusions about the effect of water repellents on leaching, and this study was not designed to directly quantify this effect. The two types of treatments were produced by different treating facilities, and there are probably differences in the treating process that are unrelated to the water repellents. However, it is apparent that commercially treated lumber with an incorporated water repellent does not necessarily have better leach resistance than does lumber treated without a water repellent. The differential leaching of arsenic, chromium, and copper also suggests that water repellent has a more complicated effect on leaching than simply restricting water movement into the wood.

Interestingly, a more direct comparison of the effect of water repellents on leaching also produced conflicting results (Cui and Walcheski 2000). In that study, end-matched specimens were treated without water repellent or with one of three types of commercially available water repellents at two different loadings. At the lower water repellent loading, two of the water repellents reduced arsenic leaching, while the third appeared to slightly increase arsenic leaching. At higher loadings, all three water repellents decreased arsenic leaching over the course of the test, but conflicting results were obtained for specific rain events. The effects on copper and chromium leaching also varied depending on water repellent formulation and concentration. The authors suggest that the different types and amounts of surfactants used in the water repellents may be interacting with CCA fixation products within the wood (Cui and Walcheski 2000).

Changes in rate of release over time

Regardless of treatment or rainfall rate, the quantity of each CCA component released, as a function of amount of rainfall, was greatest during the initial stages of exposure **(Fig. 1).** This pattern of release is typical for preservative-treated wood and is even more evident when wood is leached through submersion (Lebow 1996, Kartal and Lebow 2002). The initial leaching reflects the loss of poorly fixed or readily available preservative components. In the study reported here, leaching rates tended to stabilize after approximately 254 mm of rainfall, although a very slight continued decline was evident in many cases. One would expect that over years of exposure the rate of leaching would slowly decline as the more leachable components become depleted. Eventually, the reservoir of CCA within the wood would also be depleted. However, at the highest rates detected in this study (less than 1% per year), the half-life of CCA in the wood would be greater than 50 years. This slow release rate is substantiated by the long-term ability of CCA to protect wood from biodegradation.

Estimated contribution to soil arsenic levels

To estimate the annual rate of arsenic release, we averaged the release rates for the last four collection intervals, where the rate of arsenic release had stabilized **(Fig. 1a).** Release rates from specimens with and without water repellent were combined. The average arsenic release rates based on this calculation were 0.0143, 0.0079, and 0.0062 µg/cm2/mm rainfall for 2.5, 8.0, and 25.4 mm/hr. rainfall, respectively. Using these release rates, we estimated the annual arsenic contribution to the soil based on the following assumptions:

- Soil density of 1.5 g/cc;
- All leached arsenic is adsorbed within upper 15 cm of soil (based on findings of Stilwell and Gorny 1997, Lebow et al. 2000);
- Annual rainfall of 762 mm
- Rainwater from deck is evenly distributed in soil beneath deck.

This resulted in estimated soil concentrations of approximately 1.2, 0.7, and 0.5 ppm for the 2.5, 8.0, and 25.4 mm/hr. rainfall rates, respectively.

The last assumption is especially troublesome because rainwater from a deck falls into drip lines with smaller volume than that of all the soil beneath a deck. Because arsenic tends to be adsorbed to some soil components, its mobility is limited and it is not uniformly distributed. This is one reason why soil Samples removed from beneath decks tend to contain a wide range of arsenic levels. In addition, a deck includes more treated wood components than just the deck boards. For example, for samples removed from beneath an elevated walkway (Lebow et al. 2000), the area Sampled was also directly below the handrail and side rails of the boardwalk, which also contributed to the arsenic levels detected.

The significance of the addition of 0.5 to 1.2 mg/kg arsenic per year to the soil beneath a deck depends to some extent on the location of the deck. There are currently no national standards for acceptable arsenic levels in soil, and levels set by the states vary widely. This is at least in part because naturally occurring arsenic levels in soils across the United States vary between 1 and 40 mg/kg (O'Neill 1990), with a national average of 7.4 mg/kg (Eisler 1988). In California, the acceptable level of arsenic is set at 22 mg/kg in residential areas and 480 mg/kg in industrial areas. In Florida, which has very low levels of naturally occurring arsenic, the maximum acceptable arsenic level is 0.8 mg/kg in residential areas and 3.7 mg/kg in industrial areas.

The levels of accumulation of arsenic in the soil over a period of years depend on the mobility of arsenic in the individual soil. If the arsenic is well fixed in the soil, levels may steadily accumulate as long as leaching continues. Soils high in iron, aluminum, calcium, and clay are particularly effective in limiting arsenic mobility (Woolson et al. 1971, Fordham and Norrish 1974, Frost and Griffin 1977). However, arsenic does have some mobility in soil, and the rate of arsenic release from treated wood must eventually decline over the very long term. The combination of these two factors limits the levels of arsenic that accumulate in soil.

Effect of finishes on leaching

Application of paint or stain to the specimens had a dramatic effect on leaching. All the finishes were effective, reducing the leaching of arsenic, chromium, and copper by over 99 percent in comparison to leaching from uncoated specimens **(Table 4).** None of the water collected from specimens coated with latex or oil-based paint contained detectable levels of CCA elements. In some cases, water collected from specimens coated with the water-repellent deck stain contained detectable levels of copper and arsenic. A previous report indicated that a clear water-repellent finish greatly reduced arsenic release from fencing, although arsenic was still detectable in the run-off (Cooper et al. 1997b). In the study reported here, the greatest individual sample concentration of arsenic detected in any individual specimen finished with the deck stain was 14 µg/L, which is comparable to the

Table 4 – Leaching from finished and unfinished decking specimens.[a]

Type of finish	Average total amount leached			Average leaching rate[b]		
	Arsenic	Chromium	Copper	Arsenic	Chromium	Copper
	(mg)			($\times 10^{-4}$ µg/cm^2/mm rainfall)		
Uncoated	13.77	6.88	12.57	188.3	94.6	173.0
	1.94	*1.63*	*1.36*	*22.5*	*23.5*	*21.5*
Latex primer and paint	BD	BD	BD	BD	BD	BD
Oil-based primer and paint	BD	BD	BD	BD	BD	BD
Water-repellent deck stain	0.05	BD	0.40	0.53	BD	4.48
	0.06		*0.32*	*0.70*		*3.95*

[a] Numbers in italics represent one standard deviation about the mean. BD indicates element was below detection limits for all water samples collected. Detection limits of method were 5 µg/L for arsenic and 2 µg/L for chromium and copper. Seven replicates per treatment group.

[b] Because of the high proportion of exposed end grain in uncoated specimens, the rate of release was higher than would be expected from treated lumber used in typical residential applications.

allowable level (10 µg/L) set by the Environmental Protection Agency for arsenic in drinking water. Further evaluation is needed to determine the effect of weathering on the ability of finishes to prevent leaching and to determine the duration of their efficacy.

The coatings evaluated in this study were probably effective because they limited the movement of water into and out of the treated wood. Other types of coatings that prevent wetting of wood are likely to have the same effect. However, coatings that are likely to blister and peel and subsequently require sanding or scraping, such as varnish, may not be desirable for this type of application.

Conclusions

The amount of arsenic, chromium, and copper leached from decking commercially treated with CCA was significantly affected by the rate of rainfall. This suggests that leaching will be of greatest concern in climates typified by steady, drizzly rainfall, and of least concern where rainfall tends to occur in short, heavy showers. As is typical for other leaching exposures, the rate of leaching was greatest initially and then declined to the more stable average release rate of 0.0143, 0.0079, and 0.0062 µg/cm^2/mm rainfall for 2.5, 8.0, and 25.4 mm/hr. rainfall, respectively. These leaching rates correspond to less than 1 percent annual loss of CCA from the wood.

The presence of an incorporated water repellent did not consistently reduce leaching, and it appeared to increase leaching in some cases. Although water repellent formulations vary, it is apparent that purchase of material with an incorporated water repellent does not necessarily ensure that the decking will be more leach resistant. Based on the rates of leaching determined in this study, it appears that leaching from CCA-treated decking would annually contribute between 0.5 and 1.2 mg/kg of arsenic to soil beneath a deck. While this amount is relatively small compared to naturally occurring soil arsenic levels (1 to 40 mg/kg in the United States), the low mobility of arsenic in some types of soils could lead to higher accumulations in areas of soil directly below drip lines. It is likely that this low soil mobility, in combination with contributions from other non-leached sources of arsenic such as construction residue and refinishing, has resulted in the wide range of arsenic levels reported in soil below CCA-treated decks.

Where concern does occur about CCA leaching from decking, the application of a finish may be warranted. Although only a preliminary study was conducted on this aspect of leaching, the results clearly demonstrate that several types of common exterior finishes are effective in reducing the amount of copper, chromium, and arsenic leached from CCA-treated wood,

Literature cited

American Wood-Preservers' Association (AWPA). 2001. Book of Standards. Standard A12-01, Wood densities for preservative retention calculations. Standard A2 1-00, Analysis of wood and treating solutions by inductively coupled plasma emission spectrometry. AWPA, Granbury, TX.

Brooks, K.M. 2000. Assessment of the environmental effects associated with wooden bridges preserved with creosote, pentachlorophenol, or chromated copper arsenate. Res. Paper FPL-RP-587. USDA Forest Serv., Forest Prod. Lab., Madison, WI. 100 pp.

Cockroft, R. and R.A. Laidlaw. 1978. Factors affecting leaching of preservatives in practice. IRG/WP 3113. Inter. Research Group on Wood Preservation, Stockholm, Sweden.

Comfort, M. 1993. Environmental and occupational health aspects of using CCA treated timber for walking track construction in the Tasmanian Wilderness Heritage Area. Scientific Rept. 93/1. Tasmanian Parks and Wildlife Service, Hobart, Tasmania.

Cooper, P.A. and R. MacVicar. 1995. Effect of water repellents on leaching from CCA-treated wood. IRG/WP 95–50044. Inter. Research Group on Wood Preservation, Stockholm, Sweden.

__________, Y.T. Ung, and J.P. Aucoin. 1997a. Environmental impact of CCA-C treated poles. IRG/WP97-50087. Inter. Research Group on Wood Preservation, Stockholm, Sweden.

____________________, and R. MacVicar. 1997b. Effect of water repellents on leaching of CCA from treated fence and deck units. An update. IRG/WP 97–50086. Inter. Research Group on Wood Preservation, Stockholm, Sweden.

Cui, F. and P. Walcheski. 2000. The effect of water-repellent additives on the leaching of CCA from simulated southern yellow pine decks. IRG/WP 00–50158. Inter. Research Group on Wood Preservation, Stockholm, Sweden.

Eisler, R. 1988. Arsenic hazards to fish, wildlife and invertebrates: A synoptic review. Biological Rept. 85(1.20), Contaminant Hazards Review Rept. 12. U.S. Dept. of Interior, Fish and Wildlife Serv., Washington, DC.

Evans, F.G. 1987. Leaching from CCA-impregnated wood to food, drinking water and silage. IRG/WP/3433. Inter. Research Group on Wood Preservation, Stockholm, Sweden.

Fordham, A.W. and K. Norrish. 1974. Direct measurement of the contamination of soil components which retain added arsenate. Australian J. Soil Research 12: 165-172.

Frost, R.R. and R.A. Griffin. 1977. Effects of pH on adsorption of arsenic and selenium from landfill leachate by clay minerals. Soil Sci. Soc. of America 41:53-57.

Kartal, S.N. and S.T. Lebow. 2002. Effects of incising on treatability and leachability of CCA-C treated eastern hemlock. Forest Prod. J. 52(2):44-48.

Lebow, S.T. 1996. Leaching of wood preservative components and their mobility in the environment: Summary of pertinent literature. Gen. Tech. Rept. FPL–GTR–93USDA Forest Serv., Forest Prod. Lab., Madison, WI.

__________, D.O. Foster, and P.K. Lebow. 1999. Release of copper, chromium and arsenic from treated southern pine exposed in seawater and freshwater. Forest Prod. J. 49(7/8):80-89.

__________, P.K. Lebow, and D.O. Foster. 2000. Part I. Leaching and environmental accumulation of preservative elements. In: Environmental Impact of Preservative Treated Wood in a Wetland Boardwalk. Res. Paper FPL–RP–582. USDA Forest Serv., Forest Prod. Lab., Madison, WI. 126 pp.

Morrell, J.J. and R. Rhatigan. 2000. Preservative movement from Douglas-fir decking and members treated with ammoniacal copper zinc arenate using Best Management Practices. Forest Prod. J. 49(2):54-58.

National Oceanic and Atmospheric Administration (NOAA). 2001. Climate of 2001: Annual review. U.S. Summary. National Climatic Data Center. http://lwf.ncdc.noaa.gov/oa/climate/research/2001/preann2001/us-summary.html.

O'Neill, P. 1990. Arsenic. In: Heavy Metals in Soils. B.J. Alloway, ed. John Wiley and Sons, New York. pp. 83-99.

SAS Institute, Inc. 1999. SAS/STAT User's Guide. Version 8.1. SAS Institute, Inc., Cary, NC. 3,884 pp.

Stilwell, D.E. and K.D. Gorny. 1997. Contamination of soil with copper, chromium and arsenic under decks built from pressure treated wood. Bull. Environ. Contam. Toxicol. 58: 22-29.

Woolson, E.A., J.H. Axley, and P.C. Kearney. 1971. The chemistry and phytotoxicity of arsenic in soils. I. Contaminated field soils. In: Proc. Soil Science Society of America 35: 938-943.