5 Study Design Considerations in Evaluating Environmental Impacts

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5.1 INTRODUCTION

Concerns about the safety and environmental impact of preservatives used to protect wood from biodegradation have increased in recent years, as has research to quantify preservative leaching and environmental accumulation. Early studies of preservative leaching tended to focus on the ability of a preservative to provide long-term protection. Preservative permanence in the wood is critical to efficacy, and leaching studies remain an integral part of research to evaluate potential new preservative systems. These types of leaching trials emphasize comparative evaluations of preservative formulations, and they typically use methods that accelerate leaching. More recently, emphasis has shifted to evaluating the environmental impact of wood preservatives. These latter studies place greater emphasis on quantifying in-service leaching rates and measurement of environmental concentrations of leached preservative. Researchers who are relatively unfamiliar with preservative formulations, treatment practices and wood properties often conduct these environmental impact evaluations. Not surprisingly, studies conducted by researchers with varying fields of expertise and a range of research objectives have produced results that are often conflicting and may be difficult to compare and interpret. The purpose of this chapter is to make the reader aware of how choices in study parameters may influence the outcome of treated-wood environmental impact evaluations.

5.1.1 Wood as a Substrate

One of the greatest contributors to variability in leaching trials is the complexity of wood as a substrate. The structure, anatomy and chemistry of wood affect the way that preservative components and leaching medium move through and react with the wood substrate. On the most basic level, wood can be thought of as a collection of elongated, hollow cells arranged in a series of parallel circles along the length of the tree (Figure 5.1). As a tree develops, new cells grow around the outer circumference of the stem, forming the conductive tissues, which comprise the sapwood. Tree growth is fastest in the spring, producing relatively thin-walled cells (early wood), wherereas

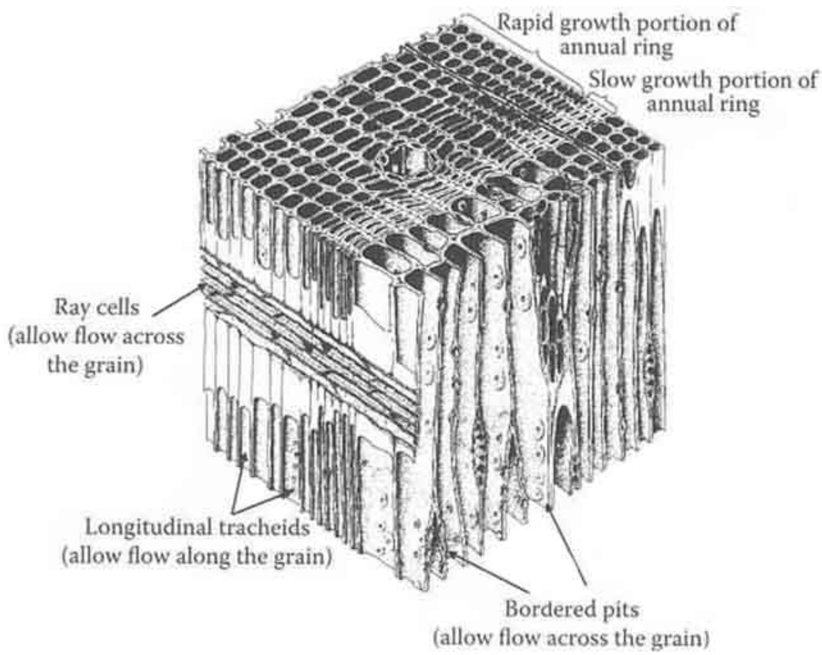

FIGURE 5.1 Typical structure of softwood species.

thick-walled cells are formed late in the season (late wood). These alternating bands of thick- and thin-walled cells form growth rings, or annual rings. The older, inner sapwood cells eventually stop functioning and form a darker core of nonconductive tissues called heartwood. The thickness of the sapwood band varies greatly by species. Heartwood differs from sapwood most notably in its much higher extractive content and much lower permeability. Although the majority of wood cells are aligned to maximize flow parallel to the grain, the wood structure does allow some flow across the grain. This transverse flow is accomplished through ray cells and through openings between longitudinal cells called bordered pits (Figure 5.1). The composition and chemical nature of wood also plays a key role in preservative fixation and leachability.

Wood cell walls are composed of an interlocking network of polysaccharides (cellulose and hemicelluloses) and lignin. Cellulose constitutes approximately 50% of dry wood weight. The majority of cellulose units in wood are bound to other cellulose chains by a regular, orderly system of hydrogen bonds to form "crystalline" cellulose, but there are regions in which the arrangement of cellulose chains is more random. The hemicelluloses represent 20 to 30% of the wood weight and are composed of shorter molecular chains containing pentose and hexose sugar monomers. Hydroxyl groups in both cellulose and hemicellulose are often proposed as reactive sites for wood preservative components, as are the carboxylic acid groups within hemicellulose. Lignin constitutes approximately 20 to 35% of the wood substance in softwoods and 15 to 25% in hardwoods. Lignin can be thought of as the cement that binds cell wall components together and to adjacent cells. It is an amorphous polymer of phenylpropanol units, which are often substituted with either one methoxy group (softwood lignin) or two methoxy groups (hardwood lignin). The hydroxyl and methoxy groups on lignin are often proposed as reactive sites for wood-preservative components.

Although they represent a small fraction (3 to 10%) of wood substance and are not a structural component, extractives may play a relatively large role in preservative leaching. Extractive is a general term for a wide range of extraneous organic and inorganic wood components that can be removed with water or organic solvents. Nutrients such as sugars, starch and fats are common extractives in sapwood, whereas phenolic compounds are common in the heartwood. Because extractives are often in readily accessible locations within the wood cells and because they can be mobile, they have been thought to play a role in both preservative fixation and subsequent leaching.

All the wood characteristics discussed above can play a role in preservative fixation and leaching. Differences in these characteristics may occur within a single tree and between trees of the same species. However, these differences are greatest between species or groups of species. The greatest general differences are found between the two broad classes called hardwoods and softwoods. Most people are familiar with hardwoods as broad-leaved deciduous trees. Although these characteristics are usually typical for hardwoods, hardwoods are more precisely defined as angiosperms; the seeds are enclosed in the ovary of the flower. The wood structure of hardwoods is more complex than that of softwoods and is most readily characterized by the presence of large vessel elements. The chemical makeup of hardwood cells also differs from softwood cells, with the greatest differences occurring in the amount and structure of lignin and in the types of extractives.

In contrast, softwoods are gymnosperms (seeds are naked) and are conifers (possessing needles or scale-like leaves). More detail on the structure and chemical composition of hardwoods and softwoods can be found in Chapter 2 of Reference 1. Softwoods represent the vast majority of treated wood produced in the U.S. Even within softwoods and hardwoods, there are major anatomical differences between species. These differences have been recognized from the perspective of wood treatment, and species groups or classifications have been developed and incorporated into the treatment standards of the American Wood Preservers' Association.[2] The species group that is most often treated with preservatives in the U.S. is the southern pine species group. This species group, which includes loblolly, shortleaf, slash, and longleaf pines, grows primarily in southern and southeastern U.S. Southern pine trees are characterized by a large sapwood zone that is readily penetrated by most types of preservatives. Treated southern pine is used for nearly all types of treated-wood applications. In the western U.S. and Canada, species most often treated are Douglas fir, ponderosa pine, and the hem-fir species group (predominately western hemlock with a lower proportion of true firs). With the possible exception of ponderosa pine, these species tend to be more difficult to treat with preservatives or are more variable in their treatability. Often they must be incised (small slits cut into the wood) to obtain adequate penetration. There is also a tendency to separate these species according to end use. Douglas fir is the predominant western species used for transmission poles and piles, whereas hem-fir and ponderosa pine are more often treated for use as lumber. Another major species group is the spruce-pine-fir (SPF) group. This group contains a large number of species that grow in the northern U.S. and Canada. Like the hem-fir species, these species tend to be difficult to treat or to vary widely in their treatability. SPF species are widely used for construction framing, and there is now increasing interest in treating these species when they are used in construction in areas of the U.S. with high termite hazard. The use of treated hardwoods is largely confined to railroad ties and bridge timbers. Of the hardwood species, red oak, which grows throughout the eastern U.S., is the single most often utilized species. More detail on treatability of major U.S. wood species, and on treating processes in general, can be found in Chapter 14 of Reference 1.

5.1.2 Sources of Variability

Wood is an inherently variable material, and this factor alone can make assessments of environmental impact more challenging. However, there are other factors as well, including the treatment process, type of treated-wood application and exposure environment. The role of these various factors and of wood itself is dependent on the type of evaluation as well as its goal. This chapter discusses some approaches used to evaluate preservative leaching and/or environmental accumulation and the influence of various aspects of these methods on research results. Evaluations of preservative leaching and environmental accumulation can be grouped into two general types: those in which study conditions are controlled and those that are more observational in nature. Controlled studies are often laboratory studies, and observational studies typically use existing in-service structures, although these groups overlap.

5.2 CONSIDERATIONS IN LABORATORY STUDIES

In controlled studies, researchers must consider methods to select test specimens and treat with preservative, expose samples to a source of leaching and determine preservative loss.

5.2.1 SELECTION OF TEST SPECIMENS

The size and dimensions of test specimens have a great effect on the percentage of preservative leached from the wood. Smaller specimens have a larger portion of their surface area exposed for leaching and allow more rapid water penetration. The effect of grain orientation is also exaggerated in smaller samples. The rate of movement of liquids along the grain of the wood is several orders of magnitude greater than that across the grain, and samples with a high proportion of exposed end-grain will exhibit exaggerated rates of preservative leaching.[3,4] The standard leaching method used by the AWPA purposefully employs small blocks with a high proportion of exposed end-grain to accelerate leaching.[2] Although a valuable comparative method, this method and others using small specimens should not he used to predict the amount of leaching that will occur from product-sized material in service. It may not be practical, however, to conduct a laboratory leaching study using full-length lumber, poles or piles. To avoid the problem of end-grain effect. specimens may be cut from product-sized material and end-sealed with a waterproof sealer prior to leaching.

Wood species can also greatly affect the rate of preservative loss from treated specimens. Permeability varies greatly among wood species, and those species that are more permeable tend to leach at a higher rate because of more rapid movement of water through the wood.[5,6] One study of the leaching characteristics of small specimens cut from the surfaces of commercially treated poles found that rates of preservative leaching from red pine were approximately double those from lodgepole pine, Douglas fir and western red cedar.[7] A subsequent study found that hardwoods such as maple, red oak and beech have a greater percentage of extractable arsenic than does red pine (Figure 5.2).[8,9] Other studies also indicate that preservative components may he more leachable from hardwoods than from softwoods.[10,11] Wood species may also affect the distribution of preservative within the wood and. as discussed below, the chemical reactions that occur to fix water-based preservatives within the wood. Because of these species effects, it is important to use a species that is typical for the application under evaluation or to at least identify and report the wood species.

Leaching of preservatives may also be affected by the presence and amount of heartwood in a sample. In most wood species, the inner heartwood portion of a tree is much less permeable than the outer sapwood portion. Accordingly, heartwood portions of test specimens may contain much less preservative than does the sapwood and may also be more resistant to penetration of the leaching medium. These effects might be expected to result in lower leaching rates from heartwood. but this generalization may be confounded by differences in preservative fixation in heartwood or by the presence of a higher concentration of preservative at the heartwood surface. Because the presence of heartwood in specimens complicates interpretation of leaching results, heartwood should either be avoided or quantified and reported. Heartwood represents a major

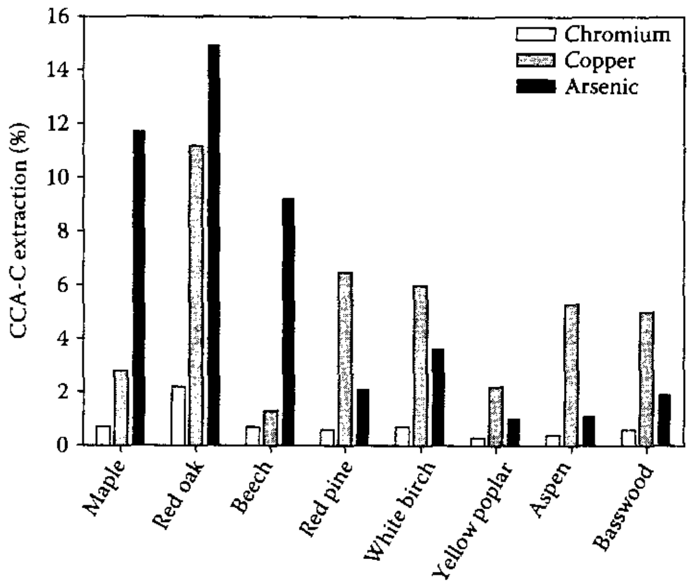

FIGURE 5.2 Relative leaching of CCA components from different species (AWPA E11 leaching tests). (Reprinted with permission from Cooper, P.A., Minimizing preservateive emissions by post treatment conditioning and fixation, in *Proceedings of Enhancing the Durability in Lumber and Engineered Wood Products, February 11-13, Kissimmee, FL,* Forest Products Society, Madison, WI, 2002.

proportion of the wood produced from some species, such as Douglas fir, but a much smaller proportion of wood produced from southern pine species.

In some studies, a researcher may have the objective characterizing rates of leaching from a particular species-preservative combination. In the design of such studies, the researcher must be aware that even within the sapwood or heartwood of a single tree species, there can be variability in wood properties, including rate of preservative leaching. Not suprisingly, wood properties typically vary much more between trees and boards than within a single board. Consequently, it is desirable to obtain specimens from as many different boards as possible. For example, if 10 replicates are to be used in a leaching evaluation, it is usually more appropriate to cut a sigle specimen from each of the 10 boards than to cut 10 relicate specimens from a single board. Obtaining boards from a range of geographic locations can achieve an even greater sense of variability as well as broaden the inference space. As mentioned previously, specimens, cut from longer boards may be end-sealed to prevent exaggerated leaching rates attributable to exposed end-grain.

5.2.2 Preservative Treatment and Fixation of Test Specimens

Obtaining preservative-treated specimens is a problematic step for many reserchers. Many laboratories do not have ready access to stock solutions of commerical wood preservatives or the equipment needed to conduct pressure treatments. In these cases, researchers typically purchase commerically treated products for leaching trials.

Unfortunately, the researcher has no knowledge of the treatment process, treating solution concentration, and fixation conditions. Ideally, the treated products will be purchased from several retailers over time to make the sample more representative. In some cases, researchers have purchased commercially produced lumber and then cut specimens to a smaller width or thickness than that of the original board. Because penetration of a preservative is often not uniform throughout the thickness of a board, specimens cut in this manner may have one or more faces that have a different (usually lower) preservative concentration than that of the original board face.

When the researcher treats specimens, a preservative solution that is nearly identical to the commercial formulation should be prepared or obtained. Proportions and types of solvents used can affect leaching. For example, leaching of copper from copper amine preservatives can be increased if an excess of amine is used in preparing the treatment solution. In addition, some types of preservatives may be or may have been produced in multiple formulations. Before chromated copper arsenate Type C (CCA-C) became the industry standard, wood was also treated with CCA-A and CCA-B. Past studies indicate that arsenic release from wood treated with CCA-B was greater than that from wood treated with CCA-A or CCA-C.[13] The treatment process should ensure adequate penetration of the specimens without development of surface deposits. With some preservative systems, extended soaking periods that allow evaporation of solvents may produce a precipitated surface residue on the wood.

The fixation conditions that specimens are exposed to after treatment can also affect the outcome of a leaching study. In general terms, fixation refers to the series of chemical reactions that render water-based preservatives difficult to leach during service. Although the fixation reactions of preservatives differ. they all depend on solution concentration, time, temperature and rate of drying. Complete fixation of CCA depends on the wood species; it requires 10 to 20 days at room temperature for pine species.[8] Test specimens exposed to leaching within a few days after treatment may exhibit abnormally high leaching rates of chromium, copper and arsenic. The fixation reactions also require moisture, and rapidly drying specimens after treatment may lead to inadequate fixation even after a lengthy fixation period (Figure 5.3).[8,14] This is particularly a concern for small specimens such as the 19-mm cubes specified by the AWPA leaching standard.[2] For CCA, the rate of fixation and subsequent leaching of CCA components are dependent on wood species. In general, species in which fixation occurs very rapidly also tend to have higher rates of arsenic leaching.[8,9] Differences in the chemical composition of the wood, and especially the amount and type of lignin, can affect the rate of fixation and subsequent preservative leachability.[15] Again, it is important to identify wood species when reporting leaching results. The solution strength or retention of preservative in the wood can also affect the rate of fixation. For CCA, arsenic fixation is more rapid at higher solution concentrations. whereas fixation of chromium and copper is slowed. Higher retentions have also been reported to slow fixation of copper in amine copper-based preservative systems.[16]

5.2.3 Controlled Leaching Exposures

Most controlled leaching trials of preservative-treated wood expose samples to leaching via immersion. Immersion is perhaps the simplest type of leaching mechanism to

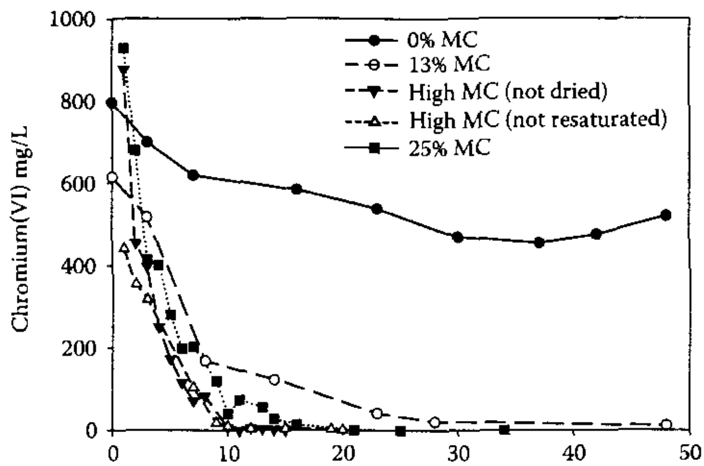

FIGURE 5.3 Effect of wood moisture content on chromium reduction. (Reprinted with permission from Cooper, P.A., Minimizing preservative emissions by post treatment conditioning and fixation, in *Proceedings of Enhancing the Durability of Lumber and Engineered Wood Products, February 11–13, Kissimmee, FL,* Forest Products Society, Madison, WI, 2002.)

control and replicate, and it provides a severe leaching environment. However, the immersion conditions can affect the results obtained. In some situations, the leached preservative in the water may reach concentrations that inhibit further 1eaching.[17] This problem can be addressed either by frequently changing the leaching water, as specified in AWPA Standard E11, or by constructing a flow-through leaching apparatus that circulates fresh leaching water.[2,17] In the latter case, care must be taken to accurately control or measure the flow rate so that the dilution factor can be calculated.

The characteristics of the leaching water can also influence leaching of preservatives. Standardized methods, such as AWA Standard E11, generally specify the use of deionized or distilled water to minimize these effects.[2] The presence of some types of inorganic ions in water has been reported to increase leaching from CCA-treated wood, whereas they have been reported to decrease leaching with at least one type of preservative.[18-22] Water pH can also affect leaching of preservatives. Leaching of CCA is greatly increased when the pH of the leaching water is lowered to below 3, and the wood itself also begins to degrade.[3,23] Water pH ranges more typical of those found in the natural world are less likely to have a great effect on leaching, although the presence of organic acids may influence leaching at more moderate pH levels.[24] Warner and Solomon reported that adding citric acid to leaching water greatly increased leaching in laboratory tests.[25] Although it is doubtful that high levels of citric acid will be a problem in service, surface waters containing high levels of humic or fulvic acid from peaty organic soils can have the potential for increasing CCA leaching.[7,10] Cooper and Ung compared CCA-C losses from jack pine blocks exposed in garden soil and organic-rich compost and found that leaching was more than doubled by compost exposure.[26]

Water temperature has also been reported to significantly affect leaching from wood treated with a CCA formulation.[27] In that study, copper, chromium and arsenic leaching were approximately 1.4, 1.6 and 1.5 times greater, respectively, from wood leached at 20°C than from wood leached at 8°C. Brooks also concluded that leaching of copper from CCA-treated wood could be substantially increased as water temperatures increased from 8 to 20°C.[17] A similar temperature effect was noted in a study of release of creosote components from treated wood.[28]

The rate of water movement around the test specimens can also influence leaching, although this effect has not been well quantified. Xiao et al. reported that the release of creosote was greatest at the highest flow rate tested, and that turbulent flow may have greatly increased leaching.[28] Van Eetvelde et al. also reported that leaching of CCA was greater when using stirred leaching water than with static leaching trials?' The AWPA standard leaching test specifies the use of a slow stirring speed (for example, a tip speed of 25 to 50 cm/s).[2] However, care must be taken that the method of stirring or agitation used does not mechanically abrade the surface of the wood.

Although an immersion leaching exposure may be relatively simple to simulate, most treated wood in service is not placed directly in water. Terrestrial applications are more common, and in such cases, the treated structure is in soil contact or above the ground or water. Because studies have illustrated that soil composition may affect both leaching and subsequent mobility of CCA components, efforts have been made within the AWPA to develop a standard method of evaluating preservative loss in soil exposures.[2,29-31] One challenge in this type of exposure is choosing a representative soil type: Crawford et al.[30] recommend using at least three different soil types as well as characterizing and reporting soil properties.

Both immersion and soil-contact leaching tests are likely to greatly overestimate the amount of leaching that will occur from treated wood exposed aboveground. However, laboratory evaluations of aboveground leaching are rare, in part because it is difficult to simulate natural rainfall. It appears that rate of rainfall, not just volume, can affect the amount of leaching from wood exposed above ground. Studies in outdoor exposures have indicated this effect, and recent laboratory evaluations have attempted to quantify the effect of rate of rainfall on leaching (Figure 5.4).[5,32,33] Laboratory evaluations also indicate that exposure to UV light may increase leaching from CCA-treated wood exposed above ground.[34]

The orientation of the wood product (vertical vs. horizontal) can also affect the amount of water that enters the wood to facilitate leaching.[3] Although complex, further research is needed to determine principal factors affecting leaching from wood exposed aboveground and to develop laboratory methods to predict leaching in service.

5.2.4 Determining Preservative Leaching in Laboratory Exposures

Regardless of the leaching exposure, one must somehow quantify the amount of preservative that has been lost from the wood. This is usually accomplished by either assaying the wood before and after leaching or by analyzing the leaching water and calculating the rate of leaching and cumulative amount leached. Although analysis

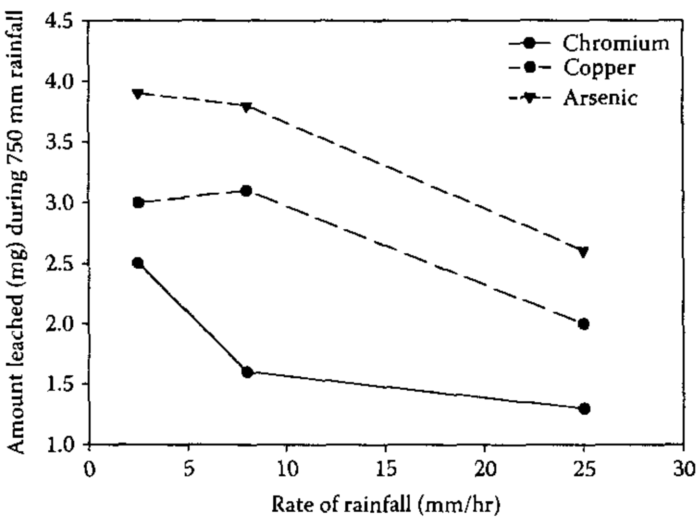

FIGURE 5.4 Effect of tate of rainfall on leaching of chromium, copper, and arsenic from CCA-treated decking. (Reprinted with permission from Lebow, S.T., Foster, D.O. and Lebow, P.K. Rate of CCA leaching from commerically treated decking For. Prod. J., 54, 81, 2004..)

of the treated wood before and after leaching is a convenient way to assess leaching, this approach may not provide a meaningful data unless substantial leaching has occured. With well-fixed preservative systems, only a small percentage of preservative may be lost during a laboratory leaching test, and error in measurement of preservative content in the wood can easily obscure over- or underestmate leaching. Lower levels of leaching can be detected by analysis of leaching water, although care must be taken in calculating the dilution factor, and complex error structures may arise if repeated measurements are made over time. Analysis of leaching water also allows a researcher to evaluate changes in the rate of leaching during the course of the exposure period.

5.3 FIELD STUDIES OF IN-SERVICE STRUCTURES

There has been a recent increase in evaluations of preservative release from in-service structures. These are generally observational (not controlled) studies. Evaluations of in-service structures provide valuable information on leaching and environmental accumulation in actual applications. The disadvantages of these types of studies is that they are specific to the conditions at that specific site and are difficult to relate to other exposures. The original treatment may be unknown, and there maybe little historical data to indicate whether the site was previously exposed to contamination from construction debris or other sources. In-service leaching results are affected by a range of site-specific conditions in addition to the treatment, fixation and species effects discussed in the previous text. These include the age of structure, type of exposure, climate and construction and maintenance practices.

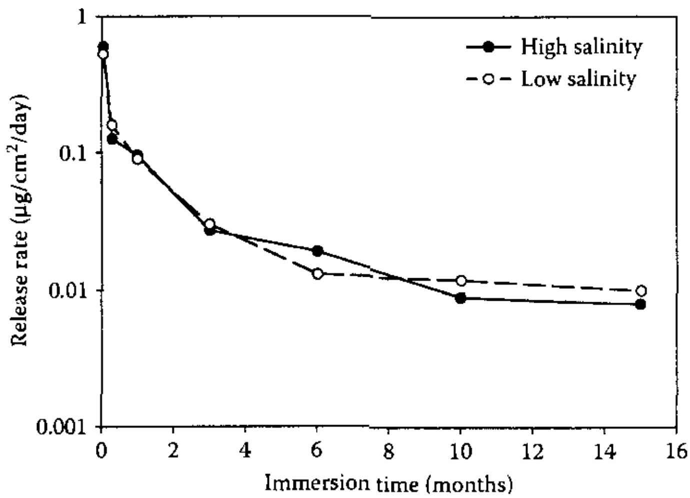

FIGURE 5.5 Change in rate of arsenic release from CCA-treated (3.8- by 8.9-cm lumber) specimens immersed in seawater. (Reprinted with permission from Lebow. S.T., Foster, D.O. and Lebow, P.K., Release of copper, chromium and arsenic from treated southern pine exposed in seawater and freshwater, *For Prod. J.,* 49, 89, 1999.)

5.3.1 Age of Structure

In general, the greatest rate of leaching from treated wood occurs upon initial exposure to the leaching medium. An initial wave of readily available and unfixed or poorly fixed components moves out of the wood, it is followed by a rapid decline to a more stable leaching rate (Figure 5.5)[3,19,29,35,36] This time-dependent leaching pattern is a function of the size of the treated product, the amount and type of surface area exposed, and the extent to which the preservative components are fixed. It also appears to depend on the severity of leaching exposure, with a steeper gradient occurring under more severe leaching conditions such as water immersion and a flatter gradient occurring for wood exposed aboveground. However, regardless of specific conditions, it is likely that rate of leaching occurring during the first year of exposure will be greater than that during subsequent years. Extrapolating early rates of leaching to longer time periods may overestimate long-term leaching. An exception to this pattern was suggested by Khan et al., who found that arsenic release from older CCA-treated material was sometimes greater than that of newly treated lumber.[37] However, because the same material was not tested over time, it is difficult to determine if this effect was related to the age of the treated wood or resulted from differences in the initial treatment or wood properties.

5.3.2 Type of Exposure

The type of exposure or application also greatly influences in-service leaching. Regardless of whether the treated wood is exposed to precipitation, freshwater, seawater, sediments or soil, the movement and composition of water is the key to the leaching of preservative components from the wood. Structures that are only intermittently exposed to precipitation will have much lower leaching rates than those continually

TABLE 5.1
Hierarchy of Severity of Leaching Exposures in Order of Increasing Severity

Exposure Condition	Typical or Example Application
Partially protected from rainfall	Covered patios, gazebos, siding, substructure of decks and bridges
Occasional or partial exposure to rainfall	Fence boards
Complete exposure to rainfall	Shakes and shingles, decking, railings, stairs, steps
Exposure to soil	Fence posts, poles, land piles, retaining walls, treated wood foundations
Exposure to fresh surface water	Cribs, lock gates, freshwater piles
Exposure to seawater, acidified water or warm water	Marine piles, piers, cribs, cooling towers, acid lakes
Exposure to metal complexing compounds	Silos, bog water (hypothesized), wood stave pipes and tanks, citric acid

Source: Cooper P.A., Leaching of wood preservatives from treated wood in-service, Report prepared for Public Works Canada, 1991, 79.

immersed in water, especially in water containing solubilizing organic or inorganic components. Cooper proposed a hierarchy of leaching exposures based on application and site conditions (Table 5.1).[3] Within each of these types of exposures is a range of conditions that may potentially affect leaching. These include temperature and composition of soil and water. Because most treated wood is exposed aboveground. climate plays an important role in leaching. Amount and rate of rainfall affect leaching, and it is likely that temperature and the presence or absence of freezing temperatures do as well.[38] Although these conditions cannot he controlled, they should be noted and factored into the interpretation of leaching results.

5.3.3 Construction and Maintenance Practices

Construction and maintenance practices for a structure can also affect the rate of preservative leaching or the amount of preservative detected in the environment. If treated-wood sawdust or shavings generated during construction are allowed to enter soil or water below a treated structure. they make a disproportionately large contribution to environmental contamination. As shown in Figure 5.6, leaching of CCA from construction sawdust and shavings immersed in water is vastly greater than that from solid wood. Environmental samples removed from areas where construction shavings were deposited are likely to have much higher elevations of preservative components than might be expected from leaching alone. This effect may be responsible for some of the higher soil arsenic levels reponed in recent studies of soil adjacent to CCA-treated decks, whereas other studies reported much lower concentrations.[35-39-41] Although associated with the treated structure, environmental contamination caused by construction shavings is attributable to construction practices and is not an inherent characteristic of the treated wood.[42] Cleaning and maintenance practices such as

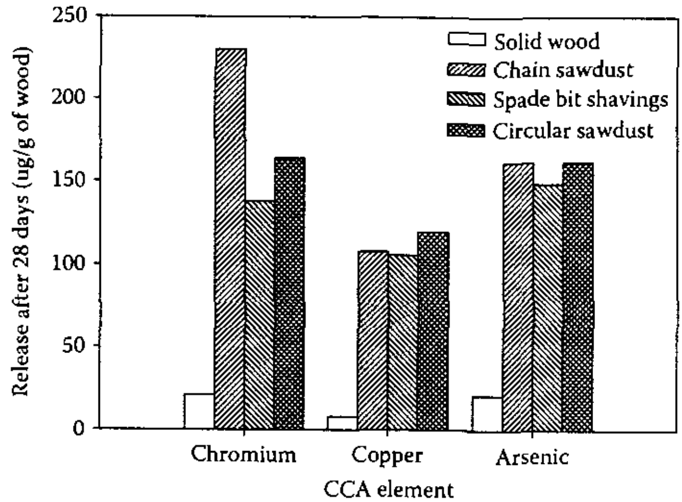

FIGURE 5.6 Comparison of amount of preservative released from solid wood or construction debris. (Reprinted with permission from Lebow, S.T. and Tippie, M., Guide for minimizing the effect of preservative treated wood on sensitive environments, Gen. Tech. Rep., FPL-GTR–122, US. Department of Agriculture. Forest Service, Forest Products Laboratory, Madison. WI, 2001.)

aggressive scrubbing, power-washing or sanding can also remove particles of treated wood and deposit them in soil or water beneath a treated structure. In addition, some ingredients used in deck cleaners have been shown to react with and potentially increase the solubility of preservative components.[43]

5.3.4 Application of Finishes

Whereas construction debris and cleaning activities may increase environmental releases from a treated structure, application of finishes appears to have the opposite effect. One report indicated that a clear water-repellent finish greatly decreased CCA release from fencing.[44] Even after 2 years, arsenic concentration in rainwater collected off the finished specimens was approximately five times lower than that from the unfinished specimens. An observational study of the concentrations of arsenic, copper and chromium in soil under residential decks found that levels appeared to be lower under a deck that had been painted, although the design of that study did not allow a controlled comparison.[40] A laboratory study has also indicated that latex paint, oil-based paint and semitransparent penetrating stains are all effective in decreasing leaching from horizontal surfaces.[38] Again, although construction and maintenance activities generally cannot be controlled in an in-service leaching evaluation, they should be considered in the interpretation of leaching results.

5.3.5 Quantifying Leaching for In-Service Exposures

For in-service evaluations, leaching is generally evaluated either by assaying the treated wood or by collecting and analyzing environmental samples adjacent to the treated wood. Determining preservative loss by assaying wood after exposure requires knowledge of

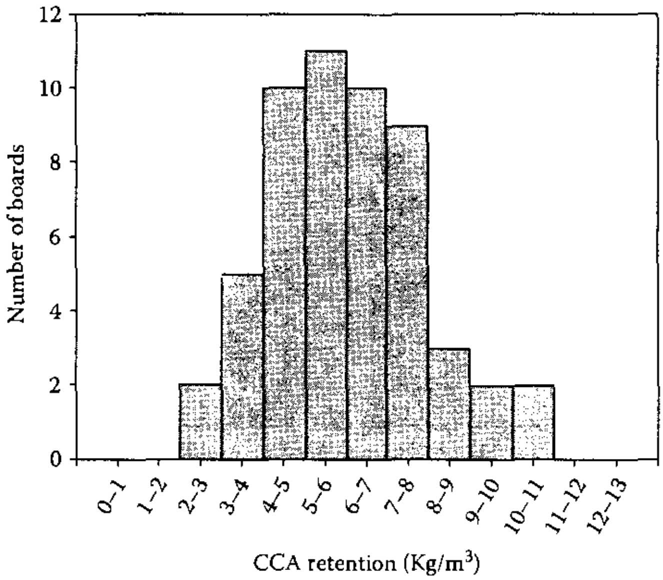

FIGURE 5.7 Range of CCA retentions measured in 3.8- by 14-cm southern pine lumber treated to target retention of 6.4 kg/m^3. (Reprinted with permission from Lebow, S.T., Foster, D.O. and Lebow, P.K., Rate of CCA leaching from commerically treated decking, *For. Prod. J.,* 54, 81, 2004..)

original preservative retention in the wood. Often original retention is assumed based on the specified target or standard retention for treated wood used in that application. This assumption can be a problematic, as preservative retention in a treated product can be substantially higher or lower than the target retention. This particularly true for some oil-type treatments where retention is controlled by adjusting the treatment process and not by adjusting the treatment solution concentration. Even with water-based perservatives, retention can vary greatly between material in a single charge and even more greatly between plants.[45] Figure 5.7 shows the distribution of CCA retention in CCA-treated 3.5 × 14-cm southern pine lumber purchased from several retailers over the course of 1 year. All the boards were treated to a target retention of 6.4 kg/m^3. It is evident that retention varies greatly between boards, and that leaching would be either overestimated or underestimated for most boards based on an assumed original retention of 6.4 kg/m^3. Variability in retention can be even greater in more difficult-to-treat wood species.

Another technique used to quantify leaching in service is comparison of the aboveground or above-water retention to the below-ground or below-water retention, with the assumption that leaching is minimal for samples exposed above ground.[10,46,47] This method can provide an idication of significant losses in the lower portions of treated wood. However, it is vulnerable to underestimation of leaching because some leaching does occur from above ground and preservative may redistribute within the wood during serivice.[47-49]

Becuase of challenges associated with assaying treated wood to quantify leaching from in-service structures, researchers may instead collect environmental samples adjacent to treated structure. This approach has the advantage of providing information on environmental accumulation of leached preservatives, but it gives limited information on the amount of preservative released from the wood. Environmental sampling also introduces a range of sources of variability into a leaching study. In addition to leaching rate, environmental concentrations of preservative components will he a function of background concentrations, sampling location and soil or water characteristics.

Determining background or preconstruction environmental concentrations of preservative components is a key, but sometimes difficult, step in evaluating environmental accumulation. Many wood-preservative components, including copper, chromium and arsenic, have been widely used for other applications in the past, and soil and sediments may contain unpredictable concentrations of these components. This problem has generally been addressed by removing environmental samples at varying distances from the treated structure and considering those at an extended distance from the structure as representing the background concentration.[39-41] Although generally a valid approach, there is the concern that human activities probably are or have been greater in close proximity to the treated structure, and thus the risk of other sources of contamination is greater in that area than in other nearby but less-used areas.

5.3.6 SURFACE AREA

The surface area of a structure contributing to soil levels in a particular area is an important consideration in environmental sampling. In complicated structures such as decks, it may be difficult to determine the surface area of the structure that is contributing to soil accumulations in any specific sampling location. Other structures, such as utility poles, have a large aboveground surface that drains into a small volume of soil at the base of the pole, and it is not surprising that relatively high levels of preservative components have been detected in soil adjacent to poles.[50]

5.3.7 NUMBER AND LOCATION OF SAMPLES

For a field study, the specific parameters and/or hypotheses of interest relevant to the inference population(s), such as a 95% confidence interval for the median amount of copper within 152 mm of a structure, need to be identified before the study starts. Then, the best sampling strategy and analysis methodologies to address these information needs can be selected. Selection and number of sampling locations for removal of environmental samples can also influence levels of preservative components detected. Common preservative components such as copper, chromium and arsenic are reactive with soil constituents and are not freely mobile in soil.[13] Thus, environmental concentrations tend to be concentrated in areas immediately adjacent to treated wood or where water drips off treated wood into soil. Even when soil samples are removed from directly under the drip line of a deck, environmental concentrations of leached preservative components can vary greatly.[35] Because of this wide variation, a statistically designed sampling plan is needed to characterize preservative concentration in the environment adjacent to treated wood. Practical general advice on environmental studies can be found in van Belle[51], whereas more specific statistical methodology is given in Gilbert, Gibbons and Coleman, and Manly.[52-54]

Environmental sampling typically yields many samples with relatively low levels of preservative components and a few samples with much higher level.[35,39,40] Because of this skewness, traditional normality-based statistical methods directly applied to samples from an underlying skewed distribution may be overly sensitive to the "outlying" observations and lack power in comparing parts of the distribution where there is less information. Lognormal distributions are commonly assumed in environmental sampling: Ott discusses in detail the physical and stochastic reasons why lognormal populations naturally arise in environmental settings.[55] Gibbons and Coleman provide statistical methods for testing distributional assumptions as well as for testing for outliers.[53] If the lognormal distribution can be assumed, the normality-based methods can be applied to log transformed data, and the results reverse transformed to the original scale, to estimate various population parameters as well as confidence limits. For example, the sample geometric mean provides a simple estimate of the median, which can be a better estimator than the sample median of the median preservative concentration within that area. However, for small sample sizes with high skewness, this estimator has higher levels of associated positive bias.[52] Parametric approaches can offer more sophisticated modeling approaches than do nonparametric procedures, but depending on the particular questions that are to be answered in a particular study, nonparametric methods may also be appropriate.[51]

Besides potential sampling and temporal and spatial variability, analytical uncertainty is another consideration, as discussed by Gibbons and Coleman.[53] Care needs to be taken that analytical uncertainty is not used to characterize other types of variability. Also common to field studies are values that are censored below the quantifiable limit(s) of a measurement device, necessitating appropriate statistical analysis methods to accommodate the censored data. Although there is agreement about using an appropriate statistical procedure, the particular choice depends on several things, including the objectives, degree of censoring and ease of use.[53]

5.3.8 Site Characteristics

Independent of leaching rates, site characteristics strongly influence environmental accumulation of leached preservative components. Leached preservative components are reactive with naturally occurring ligands in soil, sediments and water, which limits their mobility. Movement in soil is generally limited but is greater in soils with high permeability and low organic content.[24,56-61] Mass flow with a water front is probably most responsible for moving metals appreciable distances in soil, especially in permeable, porous soils.[61] Preservatives leached into water have the potential for greater migration compared with that of preservatives leached into soil, with much of the mobility occurring in the form of suspended sediment.[35,62] These environmental factors interact with leaching rates to create a pattern of environmental accumulation specific to a particular site.

5.4 SUMMARY

Evaluation of the leaching and environmental accumulation of preservatives from treated wood is a complex process. and many factors can influence the results of such studies (Table 5.2). In laboratory studies, the effects of specimen dimensions, wood

TABLE 5.2
Summary of Major Study Parameters That Play an Important Role in the Outcome of Environmental Impact Evaluations

Design Parameter	Role in Leaching or Environmental Accumulation
	Laboratory Studies
Specimen dimensions	Is the proportion of end-grain appropriate? Leaching is much greater from end-grain.
Wood species	Wood structure, chemistry, and extractive content vary by species.
Sapwood or heartwood	Heartwood is less permeable, contains less preservative, and has more phenolic compounds.
	Preservative Treatment
Is the formulation correct?	Small changes can greatly affect fixation.
Sludging and precipitates	These are not normal and will affect leaching.
Fixation	Leach resistance may depend on chemical reactions after treatment. They may need time and moisture.
	Leaching Conditions
Water characteristics	Factors such as water pH, inorganic ions. and organic ligands can affect solubility of preservatives.
Temperature	Higher temperatures have been reponed to increase leaching.
Water movement	More movement causes more leaching but can be difficult to quantify.
Exposure	Rates of leaching differ for water immersion. precipitation, and soil contact.
	Field or In-Service Studies
Age of structure	Rate of release may change with time. Soil may trap and accumulate leached components.
Type of exposure	Rates of leaching differ for freshwater immersion, seawater immersion. precipitation. and soil contact.
Construction and maintenance	Sawdust from construction or maintenance may increase soil concentrations near a structure. Finishes may reduce the amount of leaching.
Surface area/wood volume	It can be difficult to determine the surface area or wood volume that is contributing to environmental concentrations.
Number and location of environmental samples	Environmental concentrations tend to be skewed. with a lognormal distribution sometimes assumed.
Site characteristics	These influence mobility and accumulation in the environment.

species, treatment practices, fixation and leaching exposure must be considered. Evaluation of in-service structures introduces additional variability, with factors such as age of the structure, type of exposure, construction and maintenance practices and site characteristics. There is no perfect study design to account for all of these factors. and in many cases, they cannot be controlled. However, researchers should be aware of these factors, and the relative importance of these sources of variability to a particular study should be considered when interpreting and reporting study results.

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